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Assessment of climate change vulnerability of farm households in Pyapon District, a delta region in Myanmar

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ABSTRACT

Sea level rise causes saltwater intrusion and flooding of agricultural land and ultimately threatens the livelihoods of farm households in the delta region of Myanmar. Empirical research on the effects of climate change on the delta's agriculture and an assessment of the vulnerability are becoming necessary. This study explores the vulnerability of farm households to sea level rise using two methods: the Livelihood Vulnerability Index (LVI), which is comprised of 37 indicators, and the Socioeconomic Vulnerability Index (SeVI), which contains 35 indicators. Interviews with 178 farmers were conducted in Bogale, Pyapon and Dedaye Townships in Pyapon District. In addition, 7 focus group discussions were performed, with at least 2 discussions in each Township. Both methods identify Bogale to be the most vulnerable Township, followed by Dedaye and Pyapon Townships. Following the LVI approach, Bogale Township has the highest sensitivity to climate effects and the highest exposure to natural hazards, but also a higher adaptive capacity than the other townships. In contrast using the SeVI approach, Bogale was found to have the highest sensitivity and exposure to natural hazards but the lowest adaptive capacity score. The study found that the climate change adaptation measures taken by the farmers are important to limit vulnerable to the adverse effects of climate change and thus promotion of the adaptive capacity of farmers is important for the delta region of Myanmar.

1. Background

Climate change poses risks to human and natural systems on a global scale. Sea level rise caused by the melting of ice caps and the increasing occurrence of droughts and floods are the most important risks associated with global warming. For every degree of global warming, the sea level is expected to rise more than 2.3 m [2,23]. Throughout the 21st century, coastal ecosystems and low-lying areas will increasingly experience adverse impacts, such as coastal flooding and intensified submergence, causing saltwater intrusion on agricultural land and coastal erosion [23,24,50].

Delta areas are also affected by storm surges that drive saltwater upstream [32]. Nguyen [36] highlighted that saltwater intrusion can reach a considerable distance from the coastline and affect water use in estuaries. In coastal areas, climate change induced sea level rise causes severe salinization, a situation which is likely to worsen rapidly [30]. This results in reduced wetland areas, coastal erosion, and increased salinization of cultivated land and groundwater [12,33,42], thereby threatening the livelihoods of people living around the delta and coastal areas.

Over the coming years the average sea level rise in Asia is estimated to be between 1 and 3 mm per year [39]. As a consequence, the coastal zones of Myanmar will be increasingly affected, threatening the livelihoods of the local population [28]. Accordingly, Myanmar is considered one of the most vulnerable countries to climate change and sea level rise [28]. Furthermore, agriculture is highly sensitive to different hydro-climatic conditions and an agriculture-based country such as Myanmar is seriously affected by changing climate and natural hazards. The most productive rain-fed farming areas in Myanmar are already threatened by the rising sea level and salt intrusion [1,19,3]. Especially in the Ayeyarwaddy delta areas, where agriculture is dominated by rice cultivation, saltwater intrusion and flooding have considerable negative impacts on the livelihoods and socioeconomic conditions of farm households.

Moreover, the rice-growing areas in the delta region are not well protected against periodic saltwater intrusion during the monsoon periods. Therefore, flooding and saltwater intrusion, along with the rise in sea level, are becoming the main challenge for the farming communities in this zone. However, in depth knowledge on the climate change vulnerability of farm households and their adaptive capacity in the delta region in Myanmar is still lacking. In addition, it is particularly relevant to understand the tendency of farming communities

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towards climate change vulnerability alongside the frequency and occurrence of natural hazard events. Therefore, empirical research on the effects of natural hazards and saltwater intrusion and an assessment of climate change vulnerability of farm households is necessary.

1.1. Theoretical conceptualization

Although climate change is a global process, vulnerability is very site-specific. Many scholars have therefore recommended localized assessment of climate change vulnerability [5,6,13,31]. Hahn et al. [18] and Deressa [13] recommended testing climate change vulnerability at community level, so that vulnerability of communities within a district or region can be compared. Indicator methods are widely used to assess climate change vulnerability. Because of the simplicity of aggregating indicators to form an index, different vulnerability indexes have been developed [13,48]. Several authors, however, argue that the vulnerability concept remains vague and is still inconsistently defined [4,20,49] leading to different indexes. Others even state that vulnerability, in principal, cannot be measured [35,38]. Nevertheless, Hinkel [21] only criticized the development of the indicators and presented four types of argument for developing vulnerability indicators: (i) deductive (ii) inductive (iii) normative and (iv) non-substantial arguments.

Most previous vulnerability studies use one single measurement for the vulnerability of a specific community using normative judgment, while a few studies make a comparison. In this study, we use and compare two methods - the livelihood and socioeconomic vulnerability index. Moreover, Pandey and Jha [37] highlighted that respondents' perceptions about climate change could be compared with historical weather data to ensure the validity of perception indicators in a vulnerability index. In this study, respondents' perceptions with respect to the adverse effects of climate change were used alongside other indicators to scrutinize past experiences of climate change. This gives a more complete picture of climate-induced vulnerability of farm households.

Ahsan and Warner [5] suggested that by using an indicator approach, a type of sensitivity analysis is also possible to calibrate the vulnerability assessment within and between vulnerable areas by manipulating some of the contributing factor scores. Additionally, the standard deviations also convey important messages to policy makers and development planners in terms of estimating the potential degree of climate exposure in the future. Moreover, the advantage of vulnerability assessment through an indicator approach includes the possibility of seeing intervention effects. For example, Ahsan and Warner (05) mentioned that the intervention of certain natural hazard management workshops held in the area concerned over a time period could be incorporated and, thus, the newly developed index can be compared with the baseline index. In addition, Vincent [47] and Hinkel [21] addressed the need to choose an appropriate indicator; they criticize the lack of deductive arguments for aggregating indicating variables and the lack of inductive arguments at larger scales. Moreover, the contributing indicators could vary with different spatial and time aspects. Therefore, care should be taken in formulating specific indicators to assess climate change and natural hazard vulnerability.

No single indicator approach to assess climate change vulnerability has been put forward, because each method has its own strengths and limitations. For example, the Livelihood Vulnerability Index (LVI) method assigns equal-weight importance to the indexes, whereas the effects on climate change vulnerability of farm households may not be the same [13,18]. In some cases, a number of economic and social indicators did not fit with the LVI components and could therefore not be used. These indicators did, however, fit the Socioeconomic Vulnerability Index (SeVI) domain and were used to separately calculate the socioeconomic vulnerability of farm households. In this study, indicators were selected and assigned to indicate vulnerability separately and, thus, the indices were formed explicitly. Therefore, it is agreed that assessment of household livelihood profiles would be an adequate assessment if it is considered from the social and economic perspective of the region concerned [5,16].

Considering the above-mentioned facets, we applied two index-based climate change vulnerability assessments to obtain a complete picture of the vulnerability of farm household communities to saltwater intrusion and flooding. A weighted quantitative assessment of observed events was explored in this study. For example, we applied some secondary data conducive to identifying the regional level household sensitivity to natural hazards. However, we used the most recent published survey data as importance weights for contributing factor scores. Moreover, the primary survey data were used in both assessments and we therefore assumed that measurement errors, missing data problems and self-reported data errors are minimized. To capture this, local knowledge and expertise were used to select the contributing indicators for both vulnerability index assessments. Moreover, this study considered the LVI method as an additional tool and used it as an offset against the SeVI approach for assessing vulnerability.

As stated above, the climate change vulnerability assessment using an indicator approach has many advantages and some shortcomings. In this study, the indicators were formulated based on rigorous literature reviews. In addition, the indicators were tested with local experts. The difference in the methodological approaches between the livelihood vulnerability index and socioeconomic vulnerability index could depict the different dimensions and ranges of household vulnerability. Nevertheless, the study acknowledges the strengths and weaknesses of both indicator approaches and we therefore suggest that climate change vulnerability of farm households is assessed using a combination of LVI and SeVI.

Overall, the objectives of this study are twofold: Firstly, to look at performance in terms of each vulnerability indicator, considering the importance of the components and sub-components in different Townships in Pyapon district. Secondly, to compare the vulnerability of farm households in Pyapon district based on the livelihood and socioeconomic vulnerability index. In our study, the indicators used are based on the conceptual similarities between livelihood and socioeconomic vulnerability of the farm households affected by saltwater intrusion and seasonal flooding in Pyapon district, in the delta region of Myanmar. In the following section, we provide the data collection methods and processes in relation to our study region.

2. Method

2.1. Profile of the study region

The Ayeyarwady delta basin is the largest river basin in Myanmar, covering 404,200 km^2. It is known as the rice pot of Myanmar. Rice production in the region accounts for 30% of total production in Myanmar [11]. The Pyapon district comprises 4 Townships (Bogale, Pyapon, Kyaiklat, Dedaye), which include 298 village-tracts and 1450 villages. The Pyapon district is situated between 16°15′N and 95°30′E (see Fig. 1) and is located 131 Km from Yangon, the capital city. The total area of Pyapon district is about 5500 km^2, and its cultivable land area is roughly 3400 km^2. The total area of Pyapon and Bogale Township is approximately 1410 km^2 and 2023 km^2 respectively and that of Dedaye 1038 km^2. The total population is around 1.03 million, 13.11% of whom are urban dwellers and 86.89% live in rural areas [34]. The 30-year rainfall data show that the area received an average rainfall of 111.65 in. (2835.85 mm).[1] Rice is a major food crop in the region and it is estimated that nearly 98% of farmers cultivate rice [25]. However the region, which is densely populated, lies just 3 m above sea level and is therefore vulnerable to flooding, saltwater intrusion and other adverse effects of climate change [14]. Sea level rise and the seasonal river

[1] Department of Agricultural Service, Pyapon District (2014).

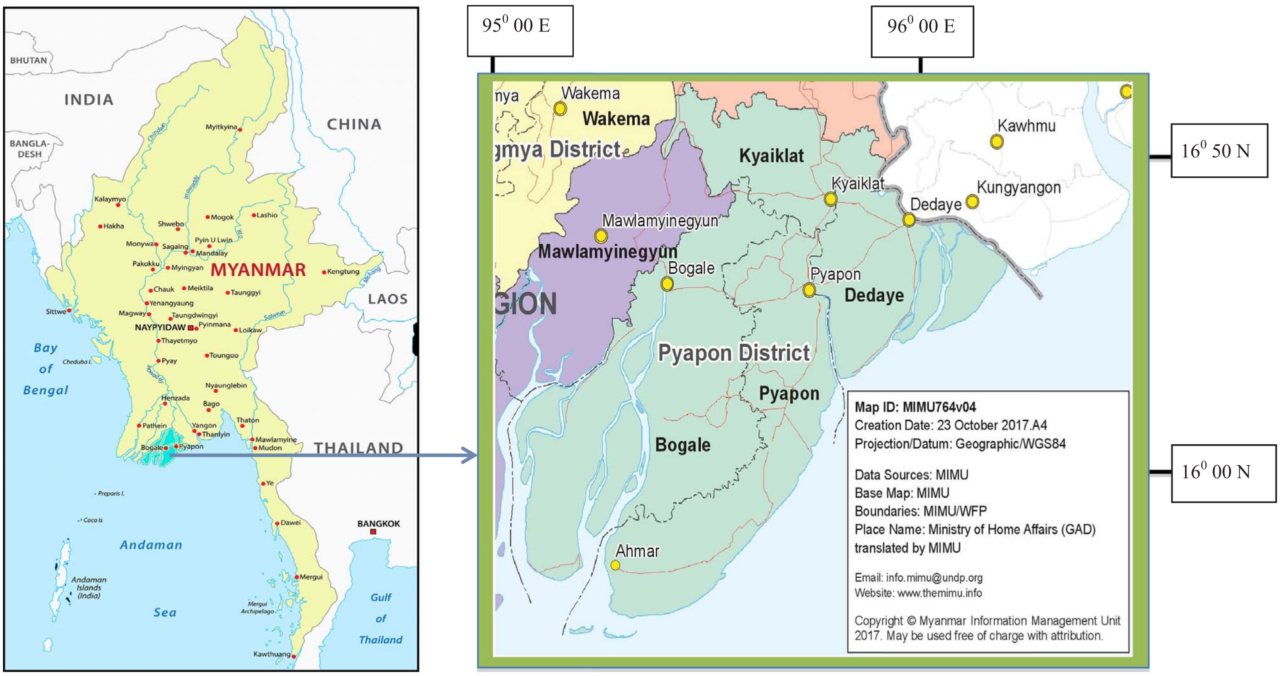

Fig. 1. Maps showing the location of Pyapon District.
(source: Acknowledge the MIMU)

Table 1
Rice production area under salt Intrusion and flooding conditions (2014).
Source: Department of Agricultural Service, Pyapon District, Ayeyarwaddy region, Myanmar (2014)

Rice production area (hectare)	Pyapon	Bogale	KyikeLatt	Dedaye	District Total
Fresh Water Area (ha)	19,963	33,497	55,721	22,318	131,500
Mixed Area (ha)	11,429	19,606	n.a	17,073	48,109
Salt Affected Area (ha)	52,828	72,682	n.a	32,842	158,353
Total (ha)	84,222	125,786	55,721	72,234	337,964
Monsoon rice production areas (ha)	Pyapon	Bogale	KyikeLatt	Dedaye	District Total
Monsoon rice under Flooding (ha)	73,623	113,625	50,258	69,466	306,973
Severely flooded rice area (ha)	38,526	560	1946	27,295	68,328
Mildly affected rice area (ha)	8722	169	n.a	3388	12,281

runoff seem to be the major causes of salinity in the delta region. As reported by the Department of Meteorology and Hydrology, Pyapon and Labutta district are adversely affected by the inflow of saline water. Increased flooding occurred for example after the devastating cyclone Nargis hit these areas in 2008 [40]. The severity of the salt intrusion can be seen in Table 1, which shows the rice production area affected by salt and flood water in the different townships.

2.2. Data collection

A farmer level survey was conducted in Bogale, Pyapon and Dedaye Townships – the areas in Pyapon district most affected by climate-induced saltwater intrusion and flooding (see Table 1). To acquire an understanding of the overall local vulnerability conditions in the sampled areas, interviews were first conducted with six agricultural extension officers and three specialists. In each Township, the flood-affected and saltwater intruded villages were purposively chosen. As vulnerability is assumed to be site-specific, we focused on micro-level analyses and on the village areas to understand the latent vulnerability of farmers. At the village level, the respondents were also randomly selected. By selecting 10 farmers in each village, understanding is gained about the impact of saltwater intrusion and flooding at individual farm level. Six villages from each Township were randomly chosen as the sample villages. A total of 18 villages from Pyapon district were selected. Structured questionnaires were used to interview farmers. Each survey took about an hour and 30 min. The questionnaires included questions about demographic characteristics, livelihoods, occupation and water management practices, food security, social networks and economic characteristics. The questionnaires were designed to capture the farmers' vulnerability to natural hazards, and to formulate the indices for the assessment. This was completed with a broad range of literature findings, and information. Moreover, information about the farmers' adaptation practices to flooding and saltwater intrusion was collected. When conducting the survey, an agricultural extension officer from the Township Department of Agriculture Service (TDAS) formally introduced the author to the farmers. Being introduced by somebody familiar to the farmers increased their active participation in the survey. The author conducted the interviews with 60 farmers from Dedaye, 66 farmers from Pyapon and 60 farmers from Bogale Township and thus a total of 186 respondents were interviewed in 2015–2016. Due to missing information, 8 samples were removed from consideration and a total of 178 samples were included in the data. In addition to this, focus group discussions were performed to formulate the relative weights, which were used to validate the indicators concerned. Before conducting a focus group discussion, semi-structured questionnaires were prepared. Several stakeholders from different administrative departments, key farmers or leaders, project leaders from private organizations (NGOs, and INGOs) were invited. These discussions looked at the preparedness against disasters, and were used to identify locally applicable and reliable indicators to assess vulnerability. Seven focus group discussions were held, at least two in each township.

2.3. Empirical model and index specification

Vulnerability indexes are based on major components as an aggregate of different sub-components. In the case of equally weighted indicators, or equal importance, a standardization approach needs to be

Table 2
Indicator index scores and overall SeVI scores in Pyapon district, Myanmar.

Domain	Indicator	Dedaye (n = 60)	Pyapon (n = 65)	Bogale (n = 53)	Max.	Min
Demographic	Dependency ratio (Child dependency ratio: Age < 18 years)	55.429	54.799	72.693	100	0
	Population Density (people per km^2)	0.817	1	0		
	Female and male ratio (Rounded[a])	1.092:1	1.181:1	1.076:1	1.22:1	10:1
	Average year of farming experiences	26.5	26.276	22.538	50	4
	Percentage of households with family members unemployed (age between 16 and 60)	0.216	0.154	0.679	4	0
Social	Percentage of households not receiving assistance from relatives/friends	8.3%	13.8%	3.8%	100	0
	Percentage of households not receiving public extension services	15%	9.2%	15.1%	100	0
	Percentage of households not in contact with neighbor farmers	1.7%	10.8%	1.9%	100	0
	Percentage of households reporting a social relationship with money lenders	91.7%	95.4%	93.3%	100	0
Economic	Percentage of households not receiving any off-farm income	45%	46.2%	17%	100	0
	Percentage of households not receiving any non-farm Income	51.7%	29.2%	43.4%	100	0
	Percentage of households borrowing money from private money- lenders	11.7%	9.2%	13.2%	100	0
	Percentage of households reporting that they could not solve financial problems by themselves	21.7%	7.7%	20.8%	100	0
Physical	Percentage of households not changing crop varieties	18.3%	9.2%	7.5%	100	0
	Percentage of households not undertaking banding practices	15%	1.5%	11.3%	100	0
	Percentage of households not undertaking irrigation management	6.7%	4.6%	96.2%	100	0
	Percentage of households not undertaking brine seed treatment[b]	53.3%	18.5%	39.6%	100	0
	Percentage of households not adjusting planting dates	5%	1.5%	75.5%	100	0
	Percentage of households not introducing salt-tolerant varieties	61.7%	44.6%	58.5%	100	0
	Percentage of households not applying chemical insecticides	23.3%	7.7%	18.9%	100	0
	Percentage of households not applying sufficient fertilizer[c]	66.7%	63.1%	96.2%	100	0
	Percentage of households not applying manure as fertilizer	85%	84.6%	96.2%	100	0
	Percentage of households with no crop diversification	60%	46.2%	86.8%	100	0
	Percentage of households reporting that crop yield was affected by climatic shocks	91.7%	96.9%	90.6%	100	0
Exposure to natural hazard	Percentage of households reporting problems with agricultural production due to climate shocks	96.6%	93.8%	98.1%	100	0
	Percentage of households *reporting loss of land due to climatic hazards*	5%	1.5%	5.7%	100	0
	Percentage of households *reporting receipt of warning information via the radio*	100%	100%	100%	100	0
	Percentage of households *reporting receipt of warning information from the government*	5%	9.2%	1.9%	100	0
	Percentage of households reporting increased saltwater intrusion (last 5 years)	65	72.3	75.47	100	0
	Percentage of households reporting loss of draught animals due to recent disaster	73	17	270	32	2
	Percentage of households reporting loss of ducks (livestock) due to recent disaster	10	0	79	60	10
	Percentage of households reporting loss of pigs (livestock) due to recent disaster	6	5	5	3	1
	Average rainfall perception index (%)	51.66	76.92	98.11	100	0
	Average perception index for future possible climate events	91.67	81.53	94.33	100	0
	Average perception index for future potential flooding and saltwater intrusion	90	69.23	98.11	100	0

[a] All the expected frequencies have been rounded to integers for the convenience of discussion.
[b] Brining seed is an effective seed treatment that can prevent infection by micro flora and fauna.
[c] Adequate fertilizer application means using 50 kg of Urea (or compound) per acre in their rice fields.

followed to minimize the erroneous estimation of different sub-components and to avoid selection biases and missing data problems. However, in the case of unequally weighted indicators, many methodological approaches can be used to avoid the uncertainty of equal weighting of the different indicators used [13]. Methodological approaches in a number of studies include the use of expert judgment [26], principal component analysis [10] or correlation with past disaster events [7]. In this study, the method of conceptualization and standardization of indicators and aggregation of the selected indicators is used (*see* Tables 2 and 3). In addition, this study explores the vulnerability of farm households using two indexes: the Livelihood Vulnerability Index, which is comprised of 37 indicators, and the Socioeconomic Vulnerability Index, which contains 35 indicators. As mentioned above, the indicators were formulated to capture the vulnerability of farm households in the community and were specifically selected on the basis of a broad range of literature findings, and information suited to a locally based vulnerability assessment. Furthermore, climate exposure, sensitivity and adaptive capacity were calculated and depicted with spider and triangular diagrams and were discussed separately. In the following section, the two indexes used to assess farm households' vulnerability are presented.

2.3.1. The socioeconomic vulnerability index

In the vulnerability index assessment applied by, for example Cherni et al. [9], Urothody and Larsen [45], Vincent and Cull [46], Ahsan and Warner [5], five capital assets, namely – human, natural, financial, social and physical capital are used to examine the vulnerability of farm households. The vulnerability consists of three main dimensions: adaptive capacity, sensitivity and exposure [5,22,45,46]. The individual indicators are measured at different scales and, thus, it is necessary to standardize each of them. In order to estimate the vulnerability indexes for each dimension, it is relevant to use different indicators [5,18,37]. The following approach see [44] is used to obtain the indicator index value for Township *'t'*.

$$\boldsymbol{Indicator\,Index\,Score\,(IIS)_t} = \frac{\boldsymbol{X_d} \; - \; \boldsymbol{X_{min}}}{\boldsymbol{X_{max}} \; - \; \boldsymbol{X_{min}}} \tag{1}$$

Where, $\boldsymbol{X_d}$ is the original value of the indicator for Township*'t'*; $\boldsymbol{X_{max}}$ is the highest value of this indicator and $\boldsymbol{X_{min}}$ is the lowest value of the indicator. Once the indicator index score was obtained; the relative

Table 3
Indicator index scores and overall LVI scores in the district of Pyapon, Myanmar.

Major Components	Sub-components	Dedaye (n = 60)	Pyapon (n = 65)	Bogale (n = 53)	Max	Min
Socio-demographic Profile	Dependency ratio in the sample	23.42%	16.28%	41.16%	200	0
	Percentage of household heads not achieving secondary education	81.7%	81.6%	83.1%	100	0
	Percentage of Female headed households in the sample	13.3%	30.8%	5.7%	100	0
	Percentage of household heads without secondary occupation	33.3%	58.5%	71.7%	100	0
	Percentage of households with basic (normal) housing condition	81.7%	78.5%	84.9%	100	0
Livelihood strategies	Percentage of households with family members migrated outside communities	8.30	12.3	11.3	100	0
	Percentage of households reliant on agriculture as the main source of livelihood income and food	93.3	90.8	100	100	0
	Percentage of households not in receipt of government loan	5	1.5	16.9	100	0
	Percentage of households not in receipt of loan from private organizations	55	49.2	35.8	100	0
	Percentage of households with no solar plates for power supply	16.7	15.4	15.1	100	0
	Percentage of households with no battery/engine power supply	83.3	63.1	83.1	100	0
Social network	Average Receive: Give ratio (cash and kind)	2.65	2.477	2.563	100	0
	Percentage of household heads who have not been head of community in the last 12 months	41.7%	30.8%	41.5%	100	0
	Percentage of households unaware of ballot system (2015 general election)	10%	1.5%	11.3%	100	0
	Average distance to nearest market (miles)	6.55	8.815	17,717	23	3
Health	Average Distance to health facilities (miles)	6.083	8.431	17.492	20	2
	Percentage of households with chronically ill family members	21.7%	21.5%	18.9%	100	0
	Percentage of households with family members missing work or school due to illness (within previous month)	33.3%	46.2%	28.3%	100	0
	Percentage of households with family members with malaria infection	15%	10.8%	17%	100	0
	Percentage of households reporting insufficient mosquito nets	98.3%	100%	98.1%	100	0
	Percentage of households without sanitary latrine/toilet	11.7%	10.8%	20.8%	100	0
Food	Percentage of households reliant on family farm for food	96.67	95.38	100	100	0
	Percentage of households reporting that they have not saved food in last 12 months	6.7%	7.7%	7.8%	100	0
	Percentage of households reporting that they have not saved seeds in last 12 months	3.4%	4.7%	5.7%	100	0
	Percentage of households reporting reliance on non-cash food items	20%	13.8%	22.4%	100	0
	Average household Food Expenditures (US$)	110.246	132.894	90.857	1556.4	31.12
	Average number of months households struggle to find food	2.72	2.57	2.90	6	0
Water	Percentage of households reporting that their farms have flooding problems	46.7%	58.5%	45.3%	100	0
	Percentage of households without their own water source/pipes	86.7%	87.7%	96.3%	100	0
	Percentage of households reporting water drainage difficulties on their farms	45%	52.3%	43.4%	100	0
	Average travelling time to obtain water from water source (min)	29.53	21.8	72.339	180	3
Natural hazard	Percentage of households reporting not received early warning Information	3.4%	7.7%	13.3%	100	0
	Percentage of households with family members injured in recent disaster	90%	90.8%	92.5%	100	0
	Percentage of households reporting death of family members in recent disaster	16.7%	20%	26.4%	100	0
	Percentage of households reporting loss of livestock due to disaster	38.3%	16.9%	79.2%	100	0
	Percentage of households reporting loss of assets due to disaster	88.3%	89.2%	98.1%	100	0
	Mean standard deviation in monthly precipitation (last 10 years)	14.957	12.079	17.442		

weight was obtained through a follow-up focus group and this was multiplied with the concerned indicator. In this way, a weighted score for an indicator, as shown by Eq. (2), was determined. The next step is then to combine the different indicators for a specific domain in a domain vulnerability score by aggregating the weighted scores for all indicators within the same domain in (Eq. (3) [5,18,45,46].

$$\mathbf{WeightedIndicatorScore(WIS)_t = \quad (IIS)_{jt}{*}(AverageWeight_{jt})} \tag{2}$$

$$\mathbf{DomainVulnerabilityScore(DVS)_t = \frac{\sum_{j=1}^{n}(WIS)_{jt}}{\sum_{j=1}^{n}(Averageweight)_{jt}}} \tag{3}$$

Here, "$(DVS)_t$" denotes the domain scores for the vulnerability index for Township *'t'; 'j'* is the number of indicators within the domain concerned. When the domain values of vulnerability indexes are obtained, the different dimension values of vulnerability can be deducted as the ratio between the sum of domains under adaptive capacity, sensitivity, and exposure and by the number of different domains involved in the analysis. This is denoted as follows:

$$\boldsymbol{DM_{kt} = \frac{\sum_{j=1}^{n} DVS_{jt}}{n}} \tag{4}$$

Here, *'k'* denotes the number of domains under adaptive capacity, sensitivity, and exposure to saltwater intrusion and flood occurrence, respectively. By following the method adopted by Ashan and Warner [5], the socioeconomic vulnerability index *(SeVI)* for Township 't' can be derived from the following equation.

$$Socioeconomic\,Vulnerability\,Index \quad (SVI) \quad t = \boldsymbol{\frac{DM_{act} + DM_{st} + DM_{et}}{3}} \tag{5}$$

The vulnerability is directly related to a system's sensitivity and exposure, and inversely related to its adaptive capacity [5,17]. The average effects of these specific dimensions (adaptive capacity, sensitivity, and exposure) contribute in the same way to the overall vulnerability index for Township 't' *(5)*. Therefore, we applied the inverse value for adaptive capacity. In our study, 35 indicators were selected for assessment of the socioeconomic vulnerability of farm households.

2.3.2. Livelihood Vulnerability Index (LVI)

The LVI includes seven major components: Socio-Demographic Profile, Livelihood Strategies, Social Networks, Health, Food, Water, and Natural hazards and Climate Variability. Each component is comprised of several indicators or sub-components. The indicators are standardized in the same way as those of the SeVI. However, the LVI uses a balanced weighted average approach [41] where each sub-component contributes equally to the overall index [18]. The LVI was calculated based on the sub-components of each of the major components. The average sub-component can be calculated after each index has been standardized following Eq. (1).

$$M_t = \frac{\sum_{i=1}^{n} indexS_t i}{n} \tag{6}$$

Where, M_t denotes one of the seven major components for Township*'t', $indexS_t$* represents the subcomponent, index by *'i' and 'n'* is the number of sub-components in each major component. After the sub-components of the Township 't' for each of the seven major components were deduced, the average LVI can be calculated as follows:

$$LVI_t = \frac{\sum_{i=1}^{7} - W_{it} M_{it}}{\sum_{i=1}^{7} - W_{it}} \tag{7}$$

Where, LVI_t is the livelihood vulnerability index for the Township *'t', 'i'* is the index of different farm households in Township *'t',* W_{it} denotes the number of sub-components that make up each major component. In addition, the contribution factors (exposure, sensitivity, or adaptive capacity) defined by IPCC can be built as the following equation.

$$CF_t = \frac{\sum_{i=1}^{n} W_{it} M_{it}}{\sum_{i=1}^{n} W_{it}} \tag{8}$$

Where, CF_t is an IPCC-defined contributing factor for Township *'t',* M_{it} are the major components for Township *'t'* indexed by *'i';* W_{it} is the weight of each major component in each contributing factor. Accordingly, we objectively selected the required indicators and otherwise trimmed the unnecessary indicators, whereas we followed the common method of standardization of the indicators (*see* Tables 3 and 4). Again, the LVI vulnerability index was scaled from 0 (least vulnerable) and 1 (most vulnerable). Overall, 37 indicators were selected for the calculation of livelihood vulnerability. For both vulnerability indicator methods, the $\boldsymbol{VulnearbilityIndex\,(IPCC_t)}$ can be calculated as the following equation, once we have calculated exposure, sensitivity and adaptive capacity.

$$\boldsymbol{LVI \quad (IPCC_{t)} = (e_t - a_t)^* \quad S_t} \tag{9}$$

Where, $Vulnerability\,Index\,(IPCC_t)$ is the LVI and SeVI for Township*'t'* expressed using the IPCC vulnerability framework. Decomposed, *"e, a, and s"* are the calculated exposure, adaptive capacity and sensitivity for Township 't'. In our study, the $Vulnerability\,Index\,(IPCC_t)$ was scaled from -1 (least vulnerable) to 1 (most vulnerable).

3. Results and discussions

Table 1 gave an overview of the effect of salt-water intrusion on rice production acreage in different parts of Pyapon district and on the different rice production systems. Secondary data shows that the area affected by saltwater intrusion in Pyapon district is increasing. In total, about 158,000 ha of rice production area is affected by saltwater intrusion and Bogale Township is mainly affected (72,000 ha).

3.1. Domain wise vulnerability: SeVI

Table 4 presents the scores for the individual indicators composing the SeVI, distributed over the 5 domains. Each of the components and sub-components is briefly discussed and the vulnerability of farm households, based on the SeVI approach, is presented in the following sections.

3.1.1. Demographic vulnerability

Pyapon is the most populated Township with 215 people per km^2, which is double the population of Bogale Township (111 people per km^2). Duriyapong and Nakhapakorn [15] indicated that land use, and population density are significant parameters leading to high vulnerability. However, the households in Bogale Township reported a higher child dependency ratio (< 18 years). Khan [29] mentioned that populations with more children and elderly people have a higher vulnerability to natural hazards because they have limited capacity to protect themselves and household members have to take care of them. We furthermore observed the highest unemployment rate in Bogale Township (score: 0.169) and the lowest in Pyapon Township (score: 0.038). Overall, for this domain, Pyapon was found to be the most vulnerable Township with a weighted average score of 0.607 (±0.395), whereas Dedaye and Bogale had a score of 0.56 (±0.329) and 0.434 (±0.366) respectively.

3.1.2. Social vulnerability

Four indicators were selected for this domain. Again Pyapon came out as the most vulnerable Township with a weighted average score of 0.527 (±0.467), followed by Dedaye Township (score: 0.466 (±0.483) and Bogale Township (score: 0.459(±0.499)). More farmers in Pyapon Township had no contact with public extension workers. Farmer-to-farmer extension contact can be used as a proxy for social capital and relationships between farmers, where farmers basically share agricultural technologies and information [43]. In this study, about 10.8% of Pyapon Township's households reported they no social relationship with neighboring farmers; this is higher than in Dedaye (1.7%) and Bogale Township (1.9%). In the study, the majority of farm households reported that they had a good social relationship with their moneylenders. Social relationship with moneylenders is another proxy of social capital in the region and is necessary for farmers to obtain money or loans for investing in agriculture when access to government subsidized loans is insufficient to compensate for their agricultural investment.

3.1.3. Economic vulnerability

Economically, Pyapon was found to be the least vulnerable Township, with an average score of 0.449 (± 0.262). Dedaye was identified as the most vulnerable township (score of 0.658(± 0.207) in this domain. About 46.2% of the sample in Pyapon Township had no off-farm income. This was approximately 45% for households in Dedaye Township, whereas the lowest percentage (17%) was found in Bogale Township. The lack of off-farm and non-farm income opportunities is the main reason for farm households receiving additional incomes from relatives. This is related to higher migration in the sampled areas. Farmers reported that they do not have full access to credit. The Myanmar Agriculture Development Bank (MADB) only allocates agricultural loans in mid-season for crop cultivation. Farmers report that they need agricultural loans before the start of cultivation periods. Thus, farmers often borrow money from moneylenders with higher interest rates during the cultivation seasons. Farmers also report that reasons for increasing debt are low yield returns and higher prices for farm inputs, and lack of yield stability due to the changing climate.

3.1.4. Physical vulnerability

A number of climate change adaptation strategies applied by farm households were used as the indicators for this domain. These indicators revealed that a high percentage of households (61.7) in Dedaye Township did not use salt-tolerant rice varieties, whereas this was 58.5% in Bogale Township and 44.6% in Pyapon Township. The majority of farm households explained that it is very difficult to gain timely access to improved and salt-tolerant varieties due to the lack of access to credit and the higher cost compared to traditional varieties. Farmers also report that they have little knowledge about such varieties because public extension services do not provide guidelines and recommendations with respect to these crops. On the other hand, when we conducted the focus group discussions, agricultural service providers reported that farmers are very reluctant to adopt new crop varieties and many socioeconomic factors influence their choice of varieties. From the perspective of crop diversification, the percentage of

Table 4
Major components, sub-components indexes of SeVI in the district of Pyapon district, Myanmar.

Domain	Indicator	Dedaye (n = 60)	Pyapon (n = 65)	Bogale (n = 53)
Demographic (5)	Dependency ratio (Child dependency ratio: Age < 18 years)	0.554	0.548	0.727
	Population Density (people per km^2)	0.817	1.00	0.00
	Female and male ratio (Rounded[a])	0.886	0.965	0.872
	Average year of farming experiences	0.489	0.484	0.403
	Percentage of households with unemployed family members (age between 16 and 60)	0.054	0.038	0.169
	Weighted Average Score (St. dev.)	0.56 (0.329)	0.607 (0.395)	0.434 (0.366)
Social (4)	Percentage of households not receiving assistance from relatives/friends	0.083	0.138	0.038
	Percentage of households not receiving public extension services	0.85	0.908	0.849
	Percentage of households having no contact with neighboring farmers	0.017	0.108	0.019
	Percentage of households reporting a social relationship with money lenders	0.917	0.954	0.933
	Weighted Average Score (St. dev.)	0.466 (0.483)	0.527 (0.467)	0.459 (0.499)
Economic (4)	Percentage of households not receiving any off-farm income	0.45	0.462	0.17
	Percentage of households not receiving any non-farm Income	0.517	0.292	0.434
	Percentage of households borrowing money from private money- lenders	0.883	0.815	0.868
	Percentage of households reporting inability to solve financial problems by themselves	0.783	0.23	0.792
	Weighted Average Score (St. dev.)	0.658 (0.207)	0.449 (0.262)	0.566 (0.325)
Physical (11)	Percentage of households not changing crop varieties	0.183	0.092	0.075
	Percentage of households not undertaking banding practices	0.15	0.015	0.113
	Percentage of households not undertaking irrigation management	0.067	0.046	0.433
	Percentage of households not undertaking brine seed treatment[b]	0.533	0.185	0.396
	Percentage of households not adjusting planting dates	0.05	0.015	0.755
	Percentage of households not introducing salt-tolerant varieties	0.617	0.446	0.585
	Percentage of households not applying chemical insecticides	0.233	0.077	0.189
	Percentage of households not applying sufficient fertilizer[c]	0.667	0.631	0.962
	Percentage of households not applying manure as fertilizer	0.85	0.846	0.962
	Percentage of households with no crop diversification	0.60	0.462	0.868
	Percentage of households reporting that crop yield was affected by climatic shocks	0.917	0.969	0.906
	Weighted Average Score (St. dev.)	0.442 (0.315)	0.344 (0.348)	0.567 (0.345)
Exposure to natural hazard (11)	Percentage of households reporting problems with agricultural production due to climate shocks	0.966	0.938	0.981
	Percentage of households reporting *loss of land due to climatic hazards*	0.05	0.015	0.057
	Percentage of households reporting *receipt of warning information from radio*	1	1	1
	Percentage of households reporting *receipt of warning information from the government*	0.05	0.092	0.019
	Percentage of households reporting increased saltwater intrusion (last 5 years)	0.65	0.723	0.755
	Percentage of households reporting loss of draught animals due to recent natural hazards	0.202	0.0472	0.75
	Percentage of households reporting loss of ducks (livestock) due to recent natural hazards	0.112	0	0.887
	Percentage of households reporting loss of pigs (livestock) due to recent natural hazards	0.375	0.312	0.312
	Average rainfall perception index	0.516	0.76.9	0.981
	Average perception index on future possible climate events (rainfall/temperature)	0.916	0.815	0.943
	Average perception index on future potential flooding and Saltwater intrusion	0.9	0.692	0.981
	Weighted Average Score (St. dev.)	0.522 (0.384)	0.463 (0.409)	0.697 (0.381)

[a] All the expected frequencies have been rounded to integers for the convenience of discussion.
[b] Brining seed is an effective seed treatment that can prevent infection by micro flora and fauna.
[c] Adequate fertilizer application means using 50 kg of Urea (or compound) per acre in rice fields.

households not diversifying crops was highest in Bogale Township (86.8%), followed by Dedaye Township (60%) and Pyapon Township (46.2). Moreover, farmers reported that lack of proper land areas, lack of access to credit and climate change impacts are fundamental constraints to diversifying crops. Based on the weighted average scores, in physical terms, Bogale was found to be the most vulnerable Township with a score of 0.567 (±0.345); followed by Dedaye 0.442 (±0.315) and Pyapon (score: 0.344 (±0.348)). In Bogale Township, fewer farm households have taken climate change adaptation measures. Farm households who have taken climate change adaptation measures are more likely to be resilient and less vulnerable to the adverse effects of a changing climate.

3.1.5. Exposure to natural hazards

Results identify Bogale as the most vulnerable Township in terms of exposure to natural hazards, with a score of 0.697 (±0.381), whereas Pyapon was the least vulnerable with a score of 0.463 (±0.409). In this domain, farmers' perceptions about different exposures to natural hazards and climate change were included as indicators. Considering the perception over different climate parameters, 98.1% of households in Bogale Township reported increased rainfall variability, while this was 76.9% for Pyapon Township (and 51.6% in Dedaye Township. All of the households indicated that they received climate information and warnings via the radio. On the contrary, many households reported that climate information and warnings from government organizations are very scarce. Farmers explained that after the devastation of cyclone Nargis, the destruction of farmlands, deterioration of natural ecosystems and silt depositions triggered the saltwater intrusion onto their agricultural lands. Furthermore, farmers reported that the application of climate change adaptation measures limits the adverse effects of climate impact on farming and reduces their climate change vulnerability.

3.2. Components based vulnerability: LVI

Table 5 presents the scores for the individual indicators comprising the LVI distributed over the 7 components. Each of the components is briefly discussed and the vulnerability of farm households based on the LVI approach is presented in the following sections.

3.2.1. Socio-demographic profile

As shown in Table 5, Bogale was the most vulnerable in terms of the

Table 5
Major components, sub-components indexes of LVI in the district of Pyapon, Myanmar.

Major Components	Sub-components	Dedaye (n = 60)	Pyapon (n = 65)	Bogale (n = 53)
Socio-demographic Profile (5)	Dependency ratio in the sample	0.117	0.082	0.206
	Percentage of household heads who did not achieve secondary education	0.817	0.816	0.831
	Percentage of Female headed households in the sample	0.133	0.308	0.057
	Percentage of household heads without secondary occupation	0.333	0.585	0.717
	Percentage of households with basic (normal) housing condition	0.817	0.785	0.849
	Weighted Average Score (St. dev.)	0.443 (0.351)	0.515 (0.316)	0.532 (0.373)
Livelihood strategies (6)	Percentage of households with family members migrated outside communities	0.083	0.123	0.113
	Percentage of households reliant on agriculture as the main source of livelihood income and food	0.933	0.908	1
	Percentage of households not in receipt of loan from government	0.05	0.015	0.169
	Percentage of households not in receipt of loan from private organizations	0.55	0.492	0.358
	Percentage of households with no solar plates for power supply	0.167	0.154	0.151
	Percentage of households with no battery/engine power supply	0.833	0.631	0.831
	Weighted Average Score (St. dev.)	0.436 (0.391)	0.387 (0.347)	0.437 (0.384)
Social network (4)	Average Receive: Give ratio (cash and kind)	0.0265	0.0247	0.0256
	Percentage of household heads who have not been head of community in the last 12 months	0.417	0.308	0.415
	Percentage of households unaware of ballot system (2015 general election)	0.1	0.015	0.113
	Average distance to nearest market (miles)	0.1775	0.29075	0.7355
	Weighted Average Score (St. dev.)	0.180 (0.169)	0.159 (0.162)	0.323 (0.322)
Health (6)	Average Distance to health facilities (miles)	0.227	0.357	0.861
	Percentage of households with chronically ill family members	0.217	0.215	0.189
	Percentage of households with family members having to miss work or school due to illness (within previous month)	0.333	0.462	0.283
	Percentage of households with family members with malaria infection	0.15	0.108	0.17
	Percentage of households reporting insufficient mosquito nets	0.017	0	0.019
	Percentage of households without sanitary latrine/toilet	0.117	0.108	0.208
	Weighted Average Score (St. dev.)	0.338 (0.324)	0.375 (0.336)	0.448 (0.369)
Food (6)	Percentage of households reliant on family farm for food	0.967	0.954	1
	Percentage of households reporting they have not saved food in last 12 months	0.067	0.077	0.078
	Percentage of households reporting they have not saved seeds in last 12 months	0.034	0.047	0.057
	Percentage of households reporting reliance on non-cash food items	0.20	0.138	0.224
	Average households Food Expenditure (US$)	0.635	0.817	0.479
	Average number of months households struggle to find food	0.453	0.428	0.483
	Weighted Average Score (St. dev.)	0.393 (0.364)	0.410 (0.394)	0.386 (0.353)
Water (4)	Percentage of households reporting flooding problems on their farm	0.467	0.585	0.453
	Percentage of households without their own water source/pipes	0.867	0.877	0.963
	Percentage of households reporting difficulties with drainage of water	0.45	0.523	0.434
	Average travelling time to obtain fresh water from water sources (minutes)	0.149	0.106	0.238
	Weighted Average Score (St. dev.)	0.483 (0.294)	0.523 (0.317)	0.522 (0.309)
Natural hazard (in previous 10 years) (6)	Percentage of households reporting non-receipt of early warning Information	0.034	0.077	0.133
	Percentage of households with family members injured as a result of recent natural hazard	0.9	0.908	0.925
	Percentage of households reporting death of family members as a result of recent natural hazards	0.167	0.20	0.264
	Percentage of households reporting livestock loss due to natural hazards	0.383	0.169	0.792
	Percentage of households reporting loss of assets due to natural hazards	0.883	0.892	0.981
	Mean standard deviation in monthly precipitation (last 10 years)	0.825	0.373	0.464
	Weighted Average Score (St. dev.)	0.532 (0.387)	0.436 (0.372)	0.593 (0.356)

socio-demographic profile, with a weighted average score of 0.532 (±0.373), followed by Pyapon Township .515 (±0.316). Dedayehas had the lowest vulnerability for this component, with an average score of 0.443 (±0.351). Zooming in on the indicators for this component, Bogale Township has the highest percentage (71.7%) of household heads without a secondary occupation, whereas in Pyapon and Dedaye Townships this is 58.5% and 33.3%, respectively. This means that farmers in Pyapon and Dedaye Townships have more income diversification options than farmers in Bogale Township. Furthermore, approximately 83.1% of household heads in Bogale Township did not achieve secondary education. Bogale also has a higher dependency ratio index (0.206) than Dedaye (0.117) and Pyapon (0.082). Most farm households own basic types of housing such as a thatch roof and a bamboo wall, or the *Dani*[2] roof and a Dani wall. In the study area, it was found that farmers with secondary occupations mostly owned the medium and standard types of housing. This study agrees with Burns and Suji [8] that there is a positive relationship between household incomes and investment in house improvements. Overall, it seems that Bogale and Dedaye are demographically more vulnerable than Pyapon.

3.2.2. Livelihood strategies

Based on the weighted average score for the Livelihood Strategies component, Pyapon was found to be the least vulnerable Township with a score of 0.387 (±0.347). All farm households in Bogale Township reported that agriculture is their main livelihood activity, whereas this is 93.3% and 90.8% in Dedaye and Pyapon respectively. Farmers reported that a lack of alternative income opportunities, especially off-season, is a fundamental constraint on their livelihoods. As a consequence, household members migrate to cities or other communities for jobs. None of the interviewed farmers has access to electricity. Farmers generally use solar energy and/or battery or engines as energy sources. 16.9% of the respondents in Bogale report insufficient provisioning of loans by government organizations. This is much more than in the other townships. The main problem is that the amounts foreseen by, for example, the Myanmar Agriculture Development Bank are too small (max 780 US$ for a large landholding farmer). Apparently, the

[2] Nipa palm (stitch nipa leaves into thatch).

private credit sector is even less adequate; as a result 55% of the households in Dedaye Township 49.2% in Pyapon Township, and 35.8% in Bogale Township do not have access to credit.

3.2.3. Social networks

Bogale Township has the highest vulnerability score (0.323 (±0.322)), whereas Dedaye was found to be the second most vulnerable Township (score: 0.180 (±0.169)) and Pyapon was the least vulnerable Township (score: 0.159 (±0.162)) with respect to the social networks component. Within this component, four indicators were considered. Farmers in Bogale Township reported an average travelling distance of 28.5 km to the nearest market, whereas for Pyapon and Dedaye this is only 14.2 km and 10.7 km. Farm households indicate that accessible markets are necessary not only for the agricultural inputs and selling of agricultural commodities but also for sharing of climate and market information among the farmers and brokers. Better access to information, and credit can be ensured by enhanced social capital [27,43]. Again, 41.5% of the households in Bogale and 41.7% of those in Dedaye report they have not taken the position of community or village head or head of commune groups within their villages, while 30% of households in Pyapon Township said they had never taken those positions. There is not much difference in assistance received. Thus, enhancing social capital and social involvement is important to reduce the risks of climate change for the poor communities in the light of a changing climate. However, lack of infrastructure and accessible markets are the main stumbling blocks for the development of farm households' livelihoods in the study areas.

3.2.4. Health

In terms of the health component, Bogale is the most vulnerable Township with a weighted average score of 0.448 (±0.369), whereas Pyapon Township has a greater vulnerability for the health component (score: 0.375(± 0.336)) than Dedaye Township (score: 0.338(±0.324)). Farmers said that local public health services are not working properly and that they use private health services in the nearest cities or towns. Distance to health services was found to be the greatest for Bogale Township (28.147 km) while distance for farmers from Pyapon Township is, on average, 13.568 km.

For farmers in Dedaye Township the distance to health services was, on average, only 9.789 km. The occurrence of malaria infections was found to be the lowest in Pyapon Township (10.8%) compared to 11.7% in Dedaye Township and 20.8% in Bogale Township (20.8%). Access to sanitation was 89.2% in Pyapon Township, 88.3 in Dedaye and 79.2 in Bogale.

3.2.5. Food

Pyapon was shown to be the most vulnerable Township for the food component (score: 0.410 (±0.394)), whereas Dedaye has a greater vulnerability (score: 0.393 (±0.364)) than Bogale Township (score: 0.386 (±0.353)). Indicators for this component show that farming is the primary profession for the farm households in the region. On average, 22.4% of households in Bogale Township had to rely on non-cash food sources such as fishing, eel collecting, etc. while this was 20% for Dedaye and 13.8% for Pyapon Township. Households in Bogale reported that, on average, 2.9 months per year they had struggled to provide adequate food for their families, while for households in Dedaye Township and Pyapon Township this was 2.72 months and 2.57 months per year. Farmers reported that the difficult periods for obtaining food occurred during the off-seasons and during inter-cultivation periods. At that time, farm households who do not keep food or save seeds are the most vulnerable. Therefore, the farm households reported that saving seed for remedial conditions or the next growing season and prior saving of food (rice) at home are the best risk-avoidance options.

3.2.6. Water

The water indicators identified Bogale as the most vulnerable Township with a weighted average score of 0.561 (±0.269), followed by Pyapon Township (score: 0.523 (±0.317)), whereas Dedaye was found to be the least vulnerable Township, with a score of 0.483 (±0.294). The majority of the households in all three Townships do not own water pipes or wells. In Bogale Township none of the farmers owned a water source. Moreover, households in Bogale Township reported travelling for up to 45.2 min, on average, to obtain fresh water, compared to 21.8 min in Pyapon and 29.5 min in Dedaye Township. Therefore, farmers reported that land leveling and land development processes are necessary and crucial for improving water management in the region.

3.2.7. Natural hazard

In this component, the assessment of the indicators was undertaken based on the past 10 years. Bogale Township had the highest vulnerability in terms of the natural hazard component (score: 0.593 (±0.356)), whereas the second most vulnerable Township was Dedaye (score: 0.532 (±0.387)) and Pyapon was least vulnerable. Farmers reported that loss of livestock such as draught cattle affected their livelihoods the most, even more than the loss of houses, or assets. In the focus group discussions, several stakeholders reported that the problems of hardship, loss of human lives and livestock due to cyclones and storms were caused by the lack of climate awareness by the local people and lack of government preparedness before the natural hazard events, and weak rehabilitation and resettlement processes afterwards. Therefore, it is necessary to implement climate change awareness programs, preventive measures, and climate change mitigation and adaptation measurements in the region.

4. IPCC defined vulnerability assessment based on the LVI and SeVI

The calculated results of the major components or domains of the LVI and SeVI are presented in spider diagrams and the contributing factor scores are depicted in a triangular diagram in Fig. 2. In this section, the vulnerability of farm households, based on both LVI and SeVI approaches, are compared and briefly discussed. Based on the final weighted average scores in Fig. 3, we identified that the economic and physical indicator, health and water indicators and natural hazard occurrence are found to be more influential indicators of sensitivity in Bogale Township than in the other Townships: Pyapon and Dedaye, which may result in greater livelihood and socioeconomic vulnerability in Bogale Township. In our study, Bogale Township has lower health and water indicator scores than Dedaye and Pyapon Township, because Bogale Township was weaker in provisioning health services, physical infrastructure and sanitation equipment, and has been struggling with water availability and drainage problems. In addition, Bogale Township has the highest exposure to the impact of natural hazards and climate variability in terms of both vulnerability indexes. In the aftermath of extreme climatic events, such as cyclone Nargis, the agricultural lands were destroyed and not cultivated for some time. Moreover, the mangrove forests were destroyed and the livelihoods dependent on them were severely impacted. Some of their cultivable lands were lost and some cannot be rehabilitated. In addition, households in these areas were subject to loss of draught cattle, and household properties.

However, the government and government associated local organizations, as well as the private sector, have worked hard for the reestablishment and rehabilitation of the region. But, the region has still far from recovered. The overall IPCC- vulnerability index scores indicate that farm households in Bogale Township are more vulnerable than households in Dedaye and Pyapon Township, because Bogale's households may be more exposed to climate extremes such as seasonal flooding and saltwater intrusion. The overall IPCC-vulnerability index scores demonstrate that Pyapon was the least vulnerable Township. In

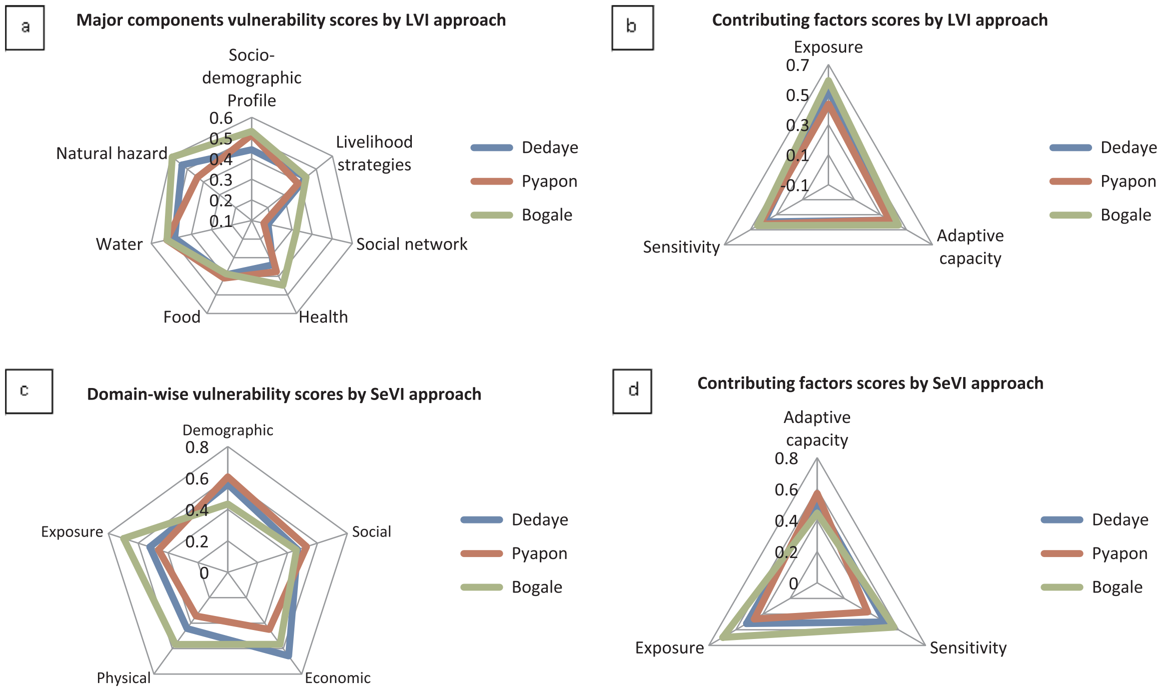

Fig. 2. Major components (spider diagram) and contributing factors (triangular diagram) of LVI (***a*** and ***b***) and SeVI (***c*** and ***d***) in Pyapon District, Myanmar.

both assessments, Pyapon was neither the area most affected by natural hazards nor the most climate sensitive area in the study region. We identified that Pyapon Township may have better and more robust economic conditions and practice climate adaptation measures compared to the other Townships. On the other hand, the overall vulnerability scores pointed to the vulnerability of Dedaye Township, which is illustrated in Figs. 2 and 3. Altogether, Pyapon district (Bogale, Dedaye and Pyapon Townships) is one of the most hazard-prone areas in delta regions of Myanmar, and suffers from the impact of climate change (Table 6). Among the three Townships in Pyapon district, Bogale is found to be the most vulnerable Township with very high exposure to natural hazards and only a medium adaptive capacity, making it more vulnerable than Dedaye and Pyapon Townships. On the contrary, Pyapon appears to be the least vulnerable Township in terms of the LVI index, with medium exposure to natural hazards and a very high adaptive capacity score.

Table 6
Comparison of the degree of LVI and SeVI vulnerability in Pyapon district, Myanmar.

LVI	Sensitivity[a]	Adaptive Capacity[b]	Exposure[θ]
Dedaye (n = 60)	Medium	High	High
Pyapon (n = 65)	Low	Very High	Medium
Bogale (n = 53)	High	Medium	Very High
Overall LVI score[c]	High	Medium	High
SeVI			
Dedaye (n = 60)	Low	Low	High
Pyapon (n = 65)	Medium	Low	Medium
Bogale (n = 53)	Medium	Medium	High
Overall SeVI score	High	Medium	Very High

[a,θ] Very high (> 0.6), High (> 0.5 and < 0.6), Medium (> 0.50) and (< 0.4), and Low (< 0.4).
[b] Very high (> 0.55), High (> 0.5 and < 0.55), Medium (> 0.4) and (< 0.5), and Low (< 0.4).
[c] Very high (> 0.6), High (> 0.5 and < 0.6), Medium (> 0.4) and (< 0.5), and Low (< 0.4).

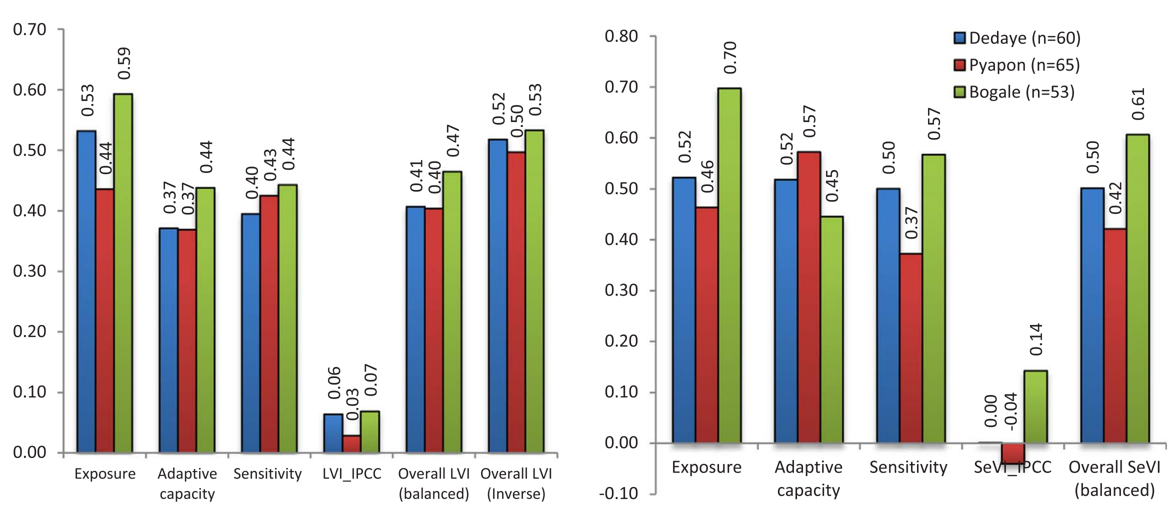

Fig. 3. Overall vulnerability score and major component scores for LVI and SeVI (Pyapon District).

5. Conclusion and recommendations

In this study, we have examined the vulnerability of farm households in the Pyapon district in the delta region of Myanmar by calculating and comparing two vulnerability assessment methods: LVI and SeVI. Although the individual indicators of different components show different trends for different Townships, the overall indexes indicate that farm households in Bogale Township are the most vulnerable. This study confirms that farm households who fail to adopt any strategies for adaptation to the impacts of climate change are more vulnerable than adapted households. Both assessments come to the same conclusion that lack of farm households' access to basic infrastructure, opportunities for additional income from farm or non-farm sources, and sole reliance on agriculture make households highly sensitive to the adverse effects of climate change. Therefore, this study calls for policy makers and/or development planners to prepare disaster risk management to reduce exposure, and climate change vulnerability of the communities and to promote climate change adaptation strategies, and strengthen the adaptive capacity of farm households.

This study also points out that the lack of adaptive capacity of farmers (socio-demographic, livelihood strategies and social networks) is a major cause of high vulnerability to the impacts of climate change. Therefore, this study encourages increasing investment in education and rural income diversification. Moreover, the following policy interventions could have a significant impact on vulnerability: development of rural credit markets, provision of basic infrastructure, sanitation equipment, accessible market places, safe drinking water, and distribution of mosquito nets. In addition, policy makers, stakeholders and development managers need to carry out a rigorous assessment of farming and the effects of past disasters and natural hazard events, so that they can intervene with the necessary preventive measures and policies aimed at promoting adaptive capacity and reducing the climate change vulnerability of farm households.

Furthermore, the study suggests that provision of seeds and fertilizers, creating non-farm income-earning opportunities, provision of more extension services and climate, as well as market, information could increase the adaptive capacity of farm households and would thus lessen farm households' vulnerability to saltwater intrusion and flooding in Pyapon. Moreover, farm households with other income-earning opportunities are less vulnerable to natural hazards in the study area. Thus, creation of rural income diversification opportunities by the government should be undertaken.

This study found that exposure to natural hazards is the highest indicator for climate change vulnerability of farm households in the study area. In addition, lack of early warning systems and climate information are also major indicators for climate change vulnerability of farm households to saltwater intrusion and natural hazards. Therefore, an early warning climate information system should be established in the study area and delta area of Myanmar to reduce the potential for losses of farm household property through natural hazard events.

This study only assessed the livelihoods and socioeconomic vulnerability of farm communities in Pyapon district, in the delta region of Myanmar, and could therefore only provide location specific information for policy makers and development planners. Additional measurement in different districts or other parts of the delta region of Myanmar should be carried out to gain a deeper understanding of climate change vulnerability and regional climate adaptation measurements for the entire delta region of Myanmar.

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References

[1] Asian Development Bank (ADB), Myanmar: Unlocking the Potential, Country Diagnostic Study, Economics and Research Department, Asian Development Bank, Mandaluyong City, Philippines, 2014.

[2] Asian Development Bank (ADB), A Region at Risk, The Human Dimensions of Climate Change in Asia and the Pacific, Asian Development Bank, Mandaluyong City, Philippines, 2017, http://dx.doi.org/10.22617/TCS178839-2.

[3] Asian Disaster Preparedness Center (ADPC), Risk Assessment Roadmap, Myanmar, In technical collaboration with ADPC funded by UNICEF.

[4] W.N. Adger, Vulnerability, Glob. Environ. Change 16 (2006) 268–281, http://dx.doi.org/10.1016/j.gloenvcha.2006.02.006.

[5] M.N. Ahsan, J. Warner, The socioeconomic vulnerability index: a pragmatic approach for assessing climate change led risks—a case study in the south-western coastal Bangladesh, Intern. J. Disaster Risk Reduc. 8 (2014) 32–49, http://dx.doi.org/10.1016/j.ijdrr.2013.12.009.

[6] T.B. Below, K.D. Mutabazi, D. Kirschke, C. Franke, S. Sieber, R. Siebert, et al., Can farmers' adaptation to climate change be explained by socio-economic household-level variables? Glob. Environ. Change 22 (2012) 223–235, http://dx.doi.org/10.1016/j.gloenvcha.2011.11.012.

[7] N. Brooks, W.N. Adger, P.M. Kelly, The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation, Glob. Environ. Change 15 (2005) 151–163, http://dx.doi.org/10.1016/j.gloenvcha.2004.12.006.

[8] J.C. Burns, O.W. Suji, Impact Assessment of the Zimbabwe Dams and Gardens Project. The Feinstein International Center in partnership with the Bill and Melinda Gates Foundation and CARE international, Friedman School of Nutrition Science and Policy, 2007.

[9] J.A. Cherni, I. Dyner, F. Henao, P. Jaramillo, R. Smith, R.O. Font, Energy supply for sustainable rural livelihoods. A multi-criteria decision-support system, Energy Policy 35 (3) (2007) 1493–1504, http://dx.doi.org/10.1016/j.enpol.2006.03.026.

[10] S.L. Cutter, B.J. Boruff, W.L. Shirley, Social vulnerability to environmental hazards, Social. Sci. Q. 84 (2) (2003) 242–261, http://dx.doi.org/10.1111/1540-6237.8402002.

[11] Department of Agricultural Planning (DAP), Myanmar Agriculture at a Glance, Ministry of Agriculture and Irrigation (MOAI), Nay Pyi Taw, Myanmar, 2014.

[12] J.W. Day, C. Ibáñez, F. Scarton, D. Pont, P. Hensel, J. Day, R. Lane, Sustainability of Mediterranean deltaic and lagoon wetlands with sea-level rise: the importance of river input, Estuaries Coasts 34 (2011) 483–493, http://dx.doi.org/10.1007/s12237-011-9390-x.

[13] T.T. Deressa, Assessment of the Vulnerability of Ethiopian Agriculture to Climate Change and Farmers' Adaptation Strategies (Ph.D. Thesis), University of Pretoria, 2010, 〈http://hdl.handle.net/2263/28969〉.

[14] W.F.V. Driel, T.A. Nauta, Vulnerability and Resilience Assessment of the Ayeyarwaddy Delta in Myanmar, Scoping phase. Bay of Bengal Large Marine Ecosystem (BOBLME) Project, Global Water Partnership (GWP) and Delta Alliance, Delft-Wageningen, The Netherlands, 2014.

[15] F. Duriyapong, K. Nakhapakorn, Coastal vulnerability assessment: a case study of SamutSakhon coastal zone, Sonklanakarin J. Sci. 33 (4) (2011) 469–476.

[16] H. Eakin, L.A. Bojorquez-Tapia, Insights into the composition of household vulnerability from multicriteria decision analysis, Glob. Environ. Change 18 (2008) 112–127, http://dx.doi.org/10.1016/j.gloenvcha.2007.09.001.

[17] J.D. Ford, B. Smit, A framework for assessing the vulnerability of communities in the Canadian Arctic to risks associated with climate change, Arctic (2004) 389–400 〈http://www.jstor.org/stable/40512642〉.

[18] M.B. Hahn, A.M. Riederer, S.O. Foster, The livelihood vulnerability index: a pragmatic approach to assessing risks from climate variability and change-a case study in Mozambique, Glob. Environ. Change 19 (2009) 74–88, http://dx.doi.org/10.1016/j.gloenvcha.2008.11.002.

[19] Hazard Profile of Myanmar (HPM), Institutional Arrangements for disaster management in Myanmar, MES, MGS, MIMU, ADPC, DMH, and Union of Myanmar, Ministry of Social Welfare, Relief and Resettlements, the Republic of the Union of Myanmar, 2009.

[20] J. Hinkel, Trans-Disciplinary Knowledge Integration. Cases from Integrated Assessment and Vulnerability Assessment (Ph.D. Thesis), Wageningen University, Wageningen, The Netherlands, 2008.

[21] J. Hinkel, Indicators of vulnerability and adaptive capacity: towards a clarification of the science-policy interface, Glob. Environ. Change 21 (2011) 198–208, http://dx.doi.org/10.1016/j.gloenvcha.2010.08.002.

[22] Intergovernmental Panel on Climate Change (IPCC), Contribution of Working Group II to the Fourth Assessment Report of IPCC on Climate Change, Impacts, adaptations and vulnerability, Cambridge University Press, 2007.

[23] Intergovernmental Panel on Climate Change (IPCC), C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.K. Plattner, S.K. Allen, M. Tignor,, P.M. Midgley (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA, 2012, p. 594.

[24] Intergovernmental Panel on Climate Change (IPCC), Climate Change: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on

Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, IPCC. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastra, 2014.
[25] Japan International Cooperation Agency (JICA), Data Collection Survey on Agricultural Sector in the Repulic of the Union of Myanmar, SANYU consultants INC, 2013.
[26] U. Kaly, C. Pratt, Environmental vulnerability index: development and provisional indices and profiles for Fiji, Samoa, Tuvalu and Vanuatu. Phase II report for NZODA. SOPAC Technical Report 306, 89p, 2000.
[27] E.M. Katungi, Social Capital and Technology Adoption on Small Farms: The Case of Banana Production Technology in Uganda (PhD Dissertation), Department of Agricultural Economics, Extension and Rural Development, University of Pretoria, 2007.
[28] S. Kerft, D. Eckstein, L. Junghans, C. Kerestan, U. Hagen, Global Climate Risk Index 2015, Who suffers most from Extreme Weather Events? Weather-related loss events in 2013 and 1994 to 2013. Think Tank @ Research, Bonn and Berlin, Germanwatch, 2014.
[29] S. Khan, Vulnerability assessments and their planning implications: a case study of the Hutt Valley, New Zealand (http://hdl.handle.net/), Nat. Hazards 64 (2012) 1587–1607, http://dx.doi.org/10.1007/s11069-012-0327-x.
[30] B. Mabrouk, H.F. Abd-Elhamid, M. Badr, R. Ludwig, Adaptation to the impact of sea level rise in the Northeastern Nile Delta, Egypt, Geophys. Res. Abstr. 15 (2013) (4042).
[31] R. Mano, C. Nhemachena, Assessment of the Economic Impacts of Climate Change on Agriculture in Zimbabwe: A Ricardian Approach, The World Bank, Washington, DC, 2007〈http://hdl.handle.net/10986/7485〉.
[32] J.P. Masterson, S.P. Garabedian, Effects of sea-level rise on ground water flow in a coastal aquifer system, Ground Water 45 (2) (2007) 209–217, http://dx.doi.org/10.1111/j.1745-6584.2006.00279.x.
[33] E. McLeod, B. Poulter, J. Hinkel, E. Reyes, R. Salm, Sea level rise impact models and environmental conservation: a review of models and their applications, Ocean Coast. Manag. 53 (9) (2010) 507–517, http://dx.doi.org/10.1016/j.ocecoaman.2010.06.009.
[34] Ministry of Immigration and Population (MIP), The Myanmar Population and Housing Census, the union report, Census Report Vol.2, The Republic of the Union of Myanmar, 2015, 2014.
[35] R.H. Moss, A.L. Brenkert, E.L. Malone, Vulnerability to Climate Change: A Quantitative Approach. Pacific Northwest National Laboratory PNNL-SA-33642, US Department of Energy, 2001.
[36] A.D. Nguyen, Salt Intrusion, Tides and Mixing in Multi-Channel Estuaries (Dissertation), Delft University of Technology, The Netherlands, 2008.
[37] R. Pandey, S. Jha, Climate vulnerability index - measure ofclimate change vulnerability to communities: a case of rural Lower Himalaya India, Mitig. Adapt. Strateg. Glob. Change 17 (5) (2012) 487–506, http://dx.doi.org/10.1007/s11027-011-9338-2.
[38] A.G. Patt, D. Schro, A.C. ter, R.J.T. de la Vega-Leinert, R.J.T. Klein, Vulnerability research and assessment to support adaptation and mitigation: common themes from the diversity of approaches, in: A.G. Patt, D. Schrö ter, A.C. de la Vega-Leinert, R.J.T. Klein (Eds.), Environmental Vulnerability Assessment, Earthscan, London, UK, 2008.
[39] Regional Integrated Multi-Hazard Early Warning System (RIMES), Managing Climate Change risks for Food Security in Myanmar, Technical Reports, RIMES, Bangkok Thailand. (access from: 〈http://www.rimes.int/〉).
[40] S.M.U. Seinn, M.M. Ahmad, G.B. Thapa, R.P. Shrestha, Farmers' adaptation to rainfall variability and salinity through agronomic practices in Lower Ayeyarwady Delta, Myanmar, J. Earth Sci. Clim. Change 6 (2015) 258, http://dx.doi.org/10.4172/2157-7617.1000258.
[41] C. Sullivan, J.R. Meigh, T.S. Fediw, Derivation and Testing of the Water Poverty Index Phase 1, Final Report, Department for International Development, United Kingdom, UK, 2002.
[42] J.P.M. Syvitski, A.J. Kettner, I. Overeem, E.W.H. Hutton, M.T. Hannon, G.R. Brakenridge, et al., Sinking deltas due to human activities, Nat. Geosci. 2 (10) (2009) 681–686, http://dx.doi.org/10.1038/ngeo629.
[43] Y.A. Tessema, C.S. Aweke, G.S. Endris, Understanding the process of adaptation to climate change by smallholder farmers: the case of east Hararghe Zone, Ethiopia, J. Agric. Food Econ. (2013) 1–13, http://dx.doi.org/10.1186/2193-7532-1-13.
[44] United Nations Development Program (UNDP), Human development reports 2007/8. Fighting climate change: human solidarity in a divided world. New York, USA, 2007.
[45] A.A. Urothody, H. Larsen, Measuringclimate change vulnerability: a comparison of two indexes, Bank. Janakari 20 (1) (2010) 9–16, http://dx.doi.org/10.3126/banko.v20i1.3503.
[46] K. Vincent, T. Cull, A household social vulnerability index (HSVI) for evaluating adaptation projects in developing countries. in: Proceedings of PEG-Net Conference: Policies to Foster and Sustain Equitable Development in Times of Crises. Midrand; 2-3 Sept, 2010.
[47] K. Vincent, Uncertainty in adaptive capacity and the importance of scale, Glob. Environ. Change 17 (1) (2007) 12–24, http://dx.doi.org/10.1016/j.gloenvcha.2006.11.009.
[48] K. Vincent, Creating an index of social vulnerability to climate changes for Africa. Working Paper 56, Tyndall Centre for Climate Change Research and School of Environmental Sciences, University of East Anglia, 2004.
[49] S. Wolf, J. Hinkel, M. Hallier, A. Bisaro, D. Lincke, C. Lonescu, R.J.T. Klein, Clarifying vulnerability definitions and assessments using formalization, Int. J. Clim. Change Strateg. Manag. 5–1 (2013) 54–70, http://dx.doi.org/10.1108/17568691311299363.
[50] World Bank. Turn Down the Heat: Confronting the New Climate Normal. Washington DC, 2014.