รายงานวิจัยฉบับสมบูรณ์ (ภาคผนวก)

Appendices of Main Final Report

โครงการ “การเพิ่มสมรรถภาพการฟื้นตัวจากภัยพิบัติทางอุตุอุทกวิทยาในลุ่มน้ำมูล ภาคตะวันออกเฉียงเหนือของประเทศไทย”

Project: ENRICH - Enhancing resilience to future hydro-meteorological extremes in the Mun River Basin in Northeast of Thailand

โดย ศ.ดร.ธวัชชัย ติงสัญชลี และคณะ

15 มีนาคม 2565

สัญญาเลขที่ RDG6130025

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Project: ENRICH - Enhancing resilience to future hydro-meteorological extremes in the Mun River Basin in Northeast of Thailand

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15 March 2022

APPENDIX A

Appendix A-1 - Details on Scenarios used

Table A1- 1 Details on the Scenarios

Scenario	Methodologies				Driving factors
1. Business as usual (BAU)	Use of a Markov Chain - following past trends determined by the LDD maps				DEM, Drainage, Fertility, Population Density, River Distance, Road Distance, Slope, Soil Type, Soil Suitability
	Optimisation tool – Excel Solver				
	Objective	Variables	Constraints	Additional Info	Driving Factors
2. Conservation - 25% Forest cover by 2050	All land use types (Variables total) to equal Mun catchment area	Land use classes (Paddy Field, Field Crop, Perennial and Orchard, Other Agriculture, Forest, Water, Marsh and Swamp, Urban and Miscellaneous)	Paddy field <= BAU Field crop <= BAU P and O <= BAU Other Agr <= BAU Forest = set % Water = set amount M and S <= BAU Urban = set amount Mic <= BAU	Total forest cover 2030 – 15% 2040 – 20% 2050 – 25% 2060 – 25%	Same as BAU.
3. Productivity – Crop and Perennials to 45%	Field Crop and P & O total had to equal the % coverage set	Same as above	Paddy field <= BAU Field crop >= BAU P and O >= BAU Other Agr <= BAU Forest = set amount Water = set amount M and S <= BAU Urban = set amount Mic <= BAU Total area covered by variables = Mun Catchment size	Total catchment covered by P and O and Field crops 2030 – 30% 2040 – 35% 2050 – 40% 2060 – 45%	Same as BAU.
4. Urban – Linear Forecast	All land use types (Variables total) to equal Mun catchment area	Same as above	Paddy field <= BAU Field crop <= BAU P and O <= BAU Other Agr <= BAU Forest = set amount	Total urban cover 2030 – 8% 2040 – 9% 2050 – 10% 2060 – 11%	Same as BAU.

			Water = set amount M and S <= BAU Urban = set changing % Mic <= BAU		
5.Combination-scenarios 2 and 4	All land use types (Variables total) to equal Mun catchment area	Same as above	Paddy field <= BAU Field crop >= BAU P and O >= BAU Other Agr <= BAU Forest = set to changing % Water = set amount M and S <= BAU Urban >= set to changing % Mic <= BAU	Total urban 2030 – 8% 2040 – 9% 2050 – 10% 2060 – 11% Total forest 2030 – 15% 2040 – 20% 2050 – 25% 2060 – 25%	Same as BAU.
6. Dynamic Policy – Random Number Generator	Objective dependant on policy/scenario chosen.	Same as above	Constraints dependant on policy/scenario chosen (see above constraints). However, future LU coverage are dependent on previous year's outputs rather than BAU. Thus updated over time.	Policy to follow 2025 – S4 2030 – S2 2035 – S2 2040 – S4 2045 – S3 2050 – S2 2055 – S5 2060 – S4	Same as BAU.
7. Water stress – Additional climatic drivers	All land use types (Variables total) to equal Mun catchment area	Same as above	Based on Outputs from Logistic Regression. Paddy field = BAU Field crop <= BAU P and O >= BAU Other Agr >= BAU Forest <= BAU Water >= BAU M and S = set to changing % Urban = BAU Mic <= BAU	Total Catchment covered by Marsh and Swamp 2025 – 1% 2030 – 1.25% 2035 – 1.5% 2040 – 1.75% 2045 – 1.8% 2050 – 1.90% 2055 – 2% 2060 – 2.2%	Same as BAU, but also including maps of Rainfall, T max, T min and Crop water defect.

Appendix A-2 - **Equations used for urban growth scenario**

Forecast Syntax

$$Fu = FORECAST\left(x, known'_y s, known'_x s\right)$$

$$Fu = Future\ Urban\ Extent$$

$$Where\ x = year\ you\ want\ to\ predict\ urban\ value$$

$$known\_y's = The\ dependent\ array\ of\ data$$

$$known\_x's = The\ indeoendat\ array\ of\ data$$

Forecast Equation

$$Forecast = a + bx$$

$$a = \bar{y} - b\bar{x}$$

$$b = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sum(x - \bar{x})^2}$$

$$Where\ x\ and\ y\ are\ the\ sample\ means\ Average(known\_x's)\ and\ Average\ (known\_y's)$$

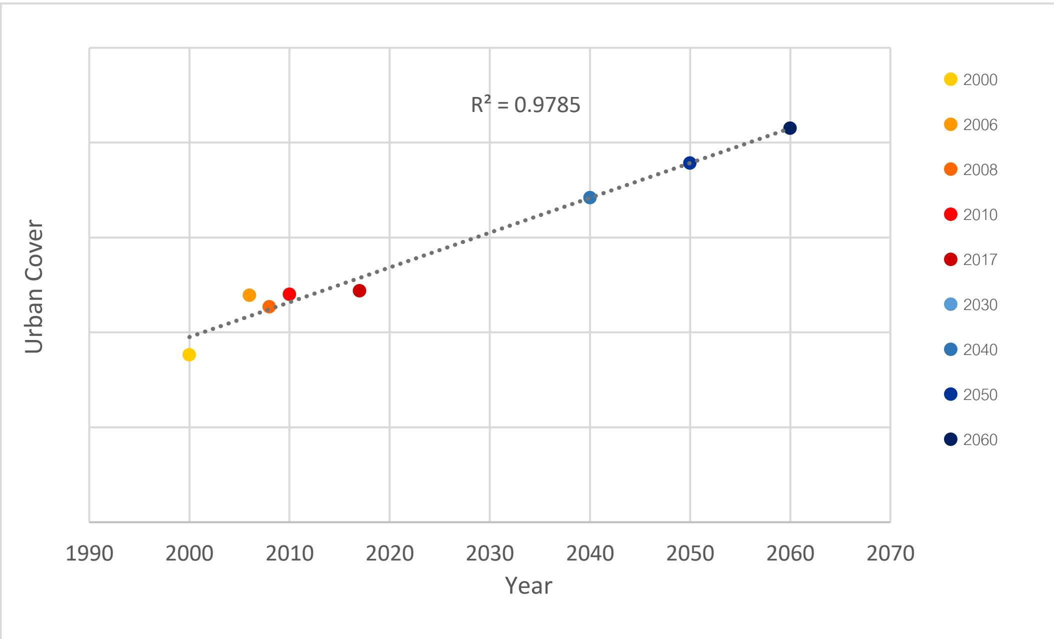

Figure A2- 1 Known Urban Cover (yellow-red) and forecasted Urban cover (blues).

Appendix A-3 - Scenario 7 calculations

$$By\ 2037\ to\ restore\ 5{,}632Km^2\ of\ degraded\ watersheds/wetlands$$

$$Thailand\ Total\ Area = 513{,}120Km^2$$

$$\frac{5{,}632Km^2}{513{,}120Km^2} = around\ 1\%\ of\ Thailands\ Total\ Area$$

$$Mun\ River\ Basin = 119{,}180Km^2$$

$$\frac{119{,}180Km^2}{513{,}120Km^2} \times 100 = 23\%$$

$$\therefore The\ Mun\ covers\ 23\%\ of\ the\ Total\ Area\ of\ Thailand$$

$$\therefore 23\%\ of\ 5632Km^2\ is\ 1295.36Km^2$$

$$\therefore \frac{1295.36Km^2}{119{,}180Km^2} \times 100 = 1.09\%$$

$$\therefore Marsh\ and\ Swamp\ area\ to\ increase\ by\ \ 1\%\ by\ 2037$$

$$Linear\ Forcast\ was\ then\ used\ to\ predic\ future\ coverage\ from\ 2040 - 2060$$

Table A3- 1 Details of the Meteorological stations used in the study

New Coverage			
2025	1.00%	**2045**	1.80%
2030	1.25%	**2050**	1.90%
2035	1.50%	**2055**	2.00%
2040	1.75%	**2060**	2.20%

APPENDIX B

Appendix B-1 - Details of the observational, re-analyzed and climate models simulations used in the study.

Table B1- 1 Details of the Meteorological stations used in the study.

S.N.	Station ID	Province	Data period	Location	
				Lat	Lon
1	431201	Nakhon Ratchasima	1971 - 2017	14°58.26'	102°6'
2	431301	Nakhon Ratchasima	1971 - 2017	14°42.89'	101°25.08'
3	431401	Nakhon Ratchasima	1971 - 2017	14°43.93'	102°9.78'
4	381002	Khon Kaen	1975 - 2017	15°48.96'	102°36'
5	387004	Maha Sarakham	1975 - 2017	15°47.83'	103°1.86'
6	387008	Maha Sarakham	1975 - 2017	15°30.93'	103°11.7'
7	403008	Nakhon Ratchasima	1975 - 2017	14°55.93'	102°16.8'
8	431002	Nakhon Ratchasima	1975 - 2017	15°34.67'	102°25.32'
9	431003	Nakhon Ratchasima	1975 - 2017	15°12.56'	101°42.96'
10	431004	Nakhon Ratchasima	1975 - 2017	14°53.93'	101°49.32'
11	431005	Nakhon Ratchasima	1975 - 2017	14°43.19'	102°1.32'
12	431006	Nakhon Ratchasima	1975 - 2017	14°31.3'	102°14.4'
13	431011	Nakhon Ratchasima	1975 - 2017	15°31.86'	102°43.32'
14	431012	Nakhon Ratchasima	1975 - 2017	15°19.76'	102°10.32'
15	431015	Nakhon Ratchasima	1975 - 2017	14°52.56'	101°45.96'
16	431018	Nakhon Ratchasima	1975 - 2017	14°53.09'	101°40.8'
17	431019	Nakhon Ratchasima	1975 - 2017	15°15.1'	102°29.76'
18	431023	Nakhon Ratchasima	1975 - 2017	15°9.1'	102°30.78'
19	431025	Nakhon Ratchasima	1975 - 2017	14°23.1'	101°52.8'
20	431016	Nakhon Ratchasima	1975 - 2017	14°42.1'	101°24.78'
21	405002	Roi Et	1975 - 2017	15°36.56'	103°48'
22	432201	Surin	1971 - 2017	14°52.95'	103°29.7'
23	432301	Surin	1971 - 2017	14°53'	103°27'
24	432401	Surin	1971 - 2017	15°19.16'	103°40.5'
25	409001	Si Sa Ket	1975 - 2017	15°7.15'	104°19.32'
26	409002	Si Sa Ket	1975 - 2017	14°38.81'	104°38.76'
27	409004	Si Sa Ket	1975 - 2017	15°20.41'	104°9.18'
28	409005	Si Sa Ket	1975 - 2017	14°42.8'	104°11.88'
29	409009	Si Sa Ket	1975 - 2017	14°37.57'	104°13.98'
30	409010	Si Sa Ket	1975 - 2014	15°1.3'	104°14.88'
31	432003	Surin	1975 - 2017	14°56.8'	103°47.46'
32	432004	Surin	1975 - 2017	15°21.01'	103°23.46'
33	432005	Surin	1975 - 2017	15°1.33'	103°56.22'
34	432006	Surin	1975 - 2017	15°7.03'	103°36.72'
35	432009	Surin	1974 - 2017	14°36.1'	103°19.8'
36	436401	Buri Ram	1971 - 2017	14°37.75'	102°47.58'
37	436001	Buri Ram	1975 - 2017	14°59.63'	103°6.24'
38	436002	Buri Ram	1971 - 2017	14°24.77'	102°51.42'
39	436003	Buri Ram	1975 - 2017	15°1.53'	102°50.34'
40	436005	Buri Ram	1975 - 2017	14°55.28'	103°18.06'
41	436004	Buri Ram	1975 - 2017	15°17.76'	103°17.52'
42	436006	Buri Ram	1975 - 2017	14°36.55'	103°6.9'
43	436014	Buri Ram	1975 - 2015	14°25.43'	103°5.7'

Table B1- 2 Detail of the 28 selected climate models from the fifth phase of the Coupled Model Intercomparison Project (CMIP5).

ID	Model Designation	Modeling Group	Atmospheric. Resolution (lat × lon) in degrees	Number of vertical levels	Ensemble-member
1.	ACCESS1-0	Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology, Australia (CSIRO-BOM)	1.25 × 1.875	38	r1i1p1
2.	ACCESS1-3	Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology, Australia (CSIRO-BOM)	1.25 × 1.875	38	r1i1p1
3.	BCC-ESM1-1	Beijing Climate Center, China Meteorological Administration (BCC)	2.8 × 2.8	26	r1i1p1
4.	BNU-ESM	Beijing Normal University (BNU)	2.8 × 2.8	26	r1i1p1
5.	CanESM2	Canadian Centre for Climate Modelling and Analysis (CCCaa)	2.8 × 2.8	35	r1i1p1
6.	CCSM4	US National Center for Atmospheric Research (NCAR)	0.9 × 1.25	27	r1i1p1
7.	CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici (CMCC)	0.75 × 0.75	31	r1i1p1
8.	CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique (CNRM-CERFACS)	1.4 × 1.4	31	r1i1p1
9.	CSIRO-Mk3-6-0	Queensland Climate Change Centre of Excellence and Commonwealth Scientific and Industrial Research Organisation (CSIRO)	1.875 × 1.875	18	r1i1p1
10.	EC-EARTH	EC-EARTH consortium	1.12 × 1.125	62	r1i1p1
11.	FGOALS-g2	State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics–Center for Earth System Science (LASG-CESS)	2.8 × 2.8	26	r1i1p1
12.	FGOALS-s2	The State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, The Institute of Atmospheric Physics (LASG-IAP)	1.7 × 2.8	26	r1i1p1
13.	GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory (NOAA-GFDL)	2 × 2.5	24	r1i1p1
14.	GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory (NOAA-GFDL)	2 × 2.5	24	r1i1p1
15.	GISS-E2-H	National Aeronautics and Space Administration-Goddard Institute for Space Studies, United States (NASA-GISS)	2 × 2.5	40	r1i1p1
16.	GISS-E2-R	National Aeronautics and Space Administration-Goddard Institute for Space Studies, United States (NASA-GISS)	2 × 2.5	40	r1i1p1
17.	HadGEM2-AO	National Institute of Meteorological Research/ Korea Meteorological Administration (NIMR-KMA)	1.25 × 1.875	60	r1i1p1
18.	HadGEM2-ES	UK Met Office Hadley Centre (MOHC)	1.25 × 1.875	38	r1i1p1
19.	HadGEM2-CC	UK Met Office Hadley Centre (MOHC)	1.25 × 1.875	60	r1i1p1
20.	INMCM4	Russian Institute for Numerical Mathematics (INM)	1.5 × 2	21	r1i1p1
21.	IPSL-CM5B-LR	Institut Pierre-Simon Laplace, France (IPSL)	1.9 × 3.75	39	r1i1p1
22.	IPSLCM5A-MR	Institut Pierre-Simon Laplace, France (IPSL)	1.25 × 2.5	39	r1i1p1
23.	MIROC4h	The University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC)	0.56 × 0.56	56	r1i1p1

ID	Model Designation	Modeling Group	Atmospheric. Resolution (lat × lon) in degrees	Number of vertical levels	Ensemble-member
24.	MIROC5	The University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC)	1.4 × 1.4	40	r1i1p1
25.	MRI-CGCM3	Meteorological Research Institute, Japan (MRI)	1.1 × 1.125	48	r1i1p1
26.	MRI-ESM1	Meteorological Research Institute, Japan (MRI)	1.1 × 1.125	48	r1i1p1
27.	MPI-ESM-MR	Max Planck Institute for Meteorology (MPI-M)	1.875 × 1.875	95	r1i1p1
28.	Nor-ESM1-M	Norwegian Climate Center (NCC)	1.9 × 2.5	26	r1i1p1

Table B1- 3 Details of the 32 selected climate models from the sixth phase of the Coupled Model Intercomparison Project (CMIP6- Historical experiments).

ID	Model Designation	Modeling Group	Atmospheric Resolution (km)	Number of vertical levels	Ensemble -member
1.	ACCESS-CM2	Commonwealth Scientific and Industrial Research Organization and Australian Research Council Centre of Excellence for Climate System Science (CSIRO-ARCCSS)	250	85	r1i1p1f1
2.	ACCESS-ESM1-5	Commonwealth Scientific and Industrial Research Organization (CSIRO)	250	38	r1i1p1f1
3.	AWI-ESM-1-1-LR	Alfred Wegener Institut (AWI)	250	47	r1i1p1f1
4.	BCC-CSM2-MR	Beijing Climate Center (BCC)	100	46	r1i1p1f1
5.	BCC-ESM1	Beijing Climate Center (BCC)	250	26	r1i1p1f1
6.	CAMS-CSM1-0	Chinese Academy of Meteorological Sciences (CAMS)	100	31	r2i1p1f1
7.	CanESM5	Canadian Centre for Climate Modelling and Analysis (CCCaa)	500	49	r1i1p1f1
8.	CESM2	National Center for Atmospheric Research (NCAR)	100	70	r1i1p1f1
9.	CESM2-FV2	National Center for Atmospheric Research (NCAR)	250	32	r1i1p1f1
10.	CMCC-CM2-HR4	Centro Euro-Mediterraneo per I Cambiamenti Climatici (CMCC)	100	30	r1i1p1f1
11.	CMCC-ESM2	Centro Euro-Mediterraneo per I Cambiamenti Climatici (CMCC)	100	30	r1i1p1f1
12.	CNRM-CM6-1	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique (CNRM-CERFACS)	250	91	r1i1p1f2
13.	CNRM-CM6-1-HR	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique (CNRM-CERFACS)	50	91	r1i1p1f2
14.	EC-Earth3	EC-EARTH consortium	50	91	r1i1p1f1
15.	EC-Earth3-CC	EC-EARTH consortium	100	91	r1i1p1f1
16.	FGOALS-f3-L	Chinese Academy of Sciences (CAS)	100	32	r1i1p1f1
17.	FGOALS-g3	Chinese Academy of Sciences (CAS)	250	26	r1i1p1f1
18.	GFDL-ESM4	NOAA Geophysical Fluid Dynamics Laboratory (NOAA-GFDL)	100	49	r1i1p1f1
19.	HadGEM3-GC31-LL	UK Met Office Hadley Centre (MOHC)	250	85	r1i1p1f3
20.	HadGEM3-GC31-MM	UK Met Office Hadley Centre (MOHC)	100	85	r1i1p1f3
21.	IITM-ESM	Center for Climate Change Research-Indian Institute of Tropical Meteorology (CCCR-IITM)	250	64	r1i1p1f1
22.	INM-CM5-0	Russian Institute for Numerical Mathematics (INM)	100	73	r1i1p1f1
23.	IPSL-CM6A-LR	Institut Pierre-Simon Laplace, France (IPSL)	250	79	r1i1p1f1
24.	MIROC6	The University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC)	250	81	r1i1p1f1
25.	MPI-ESM1-2-HR	Max Planck Institute for Meteorology (MPI-M)	100	47	r1i1p1f1

ID	Model Designation	Modeling Group	Atmospheric Resolution (km)	Number of vertical levels	Ensemble -member
26.	MPI-ESM1-2-LR	Max Planck Institute for Meteorology (MPI-M)	250	95	r1i1p1f1
27.	MRI-ESM2-0	Meteorological Research Institute, Japan (MRI)	100	80	r1i1p1f1
28.	NorCPM1	Norwegian Climate Center (NCC)	250	26	r1i1p1f1
29.	NorESM2-LM	Norwegian Climate Center (NCC)	250	32	r1i1p1f1
30.	NorESM2-MM	Norwegian Climate Center (NCC)	100	32	r1i1p1f1
31.	TaiESM1	Research Center for Environmental Changes, Academia Sinica, Taiwan (AS-RCEC)	100	30	r1i1p1f1
32.	UKESM1-0-LL	UK Met Office Hadley Centre (MOHC)	250	85	r1i1p1f2

Table B1- 4 Details of the 12 selected climate models from the sixth phase of the Coupled Model Intercomparison Project (CMIP6- HighResMIPs).

ID	Model Designation	Modeling Group	Atmospheric resolution (km)	Number of vertical levels	Ensemble-member
1.	CNRM-CM6-1	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique (CNRM-CERFACS)	250	91	r1i1p1f2
2.	CNRM-CM6-1-HR	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique (CNRM-CERFACS)	50	91	r1i1p1f2
3.	EC-Earth3P	EC-EARTH consortium	100	91	r1i1p2f1
4.	EC-Earth3P-HR	EC-EARTH consortium	50	91	r1i1p2f1
5.	ECMWF-IFS-HR	European Centre for Medium-Range Weather Forecasts (ECMWF)	25	91	r1i1p1f1
6.	GFDL-CM4C192	NOAA Geophysical Fluid Dynamics Laboratory (NOAA-GFDL)	100	33	r1i1p1f1
7.	HadGEM3-GC31-HH	UK Met Office Hadley Centre (UK-MOHC)	50	85	r1i1p1f1
8.	HadGEM3-GC31-HM	UK Met Office Hadley Centre (UK-MOHC)	50	85	r1i1p1f1
9.	HadGEM3-GC31-MM	UK Met Office Hadley Centre (UK-MOHC)	100	85	r1i1p1f1
10.	HadGEM3-GC31-LL	UK Met Office Hadley Centre (UK-MOHC)	250	85	r1i1p1f1
11.	INMCM5-H	Russian Institute for Numerical Mathematics (INM)	100	73	r1i1p1f1
12.	MPI-ESM1-2-HR	Max Planck Institute for Meteorology (MPI-M)	100	95	r1i1p1f1

Table B1- 5 Details of the 19 selected climate models from the sixth phase of the Coupled Model Intercomparison Project (CMIP6- Historical experiments).

Model id	Institution id	Source id	Model Resolution (Lat x Lon)
A	CSIRO-ARCCSS	ACCESS-CM2	1.25º x 1.87º
B	CSIRO	ACCESS-ESM1-5	1.25º x 1.87º
C	AWI	AWI-ESM1-1-LR	1.86º x 1.87º
D	CCCma	CanESM5	2.80º x 2.80º
E	NCAR	CESM2	0.94º x 1.25º
F	NCAR	CESM2-FV2	1.89º x 2.50º
G	CMCC	CMCC-CM2-HR4	0.94º x 1.25º
H	CMCC	CMCC-CM2-SR5	0.94º x 1.25º
I	CMCC	CMCC-ESM2	0.94º x 1.25º
J	CNRM-CERFACS	CNRM-CM6-1	1.40º x 1.40º
K	CNRM-CERFACS	CNRM-CM6-1-HR	0.50º x 0.50º
L	CNRM-CERFACS	CNRM-ESM2-1	1.40º x 1.40º
M	EC-Earth-Consortium	EC-Earth3	0.70º x 0.70º
N	NOAA-GFDL	GFDL-CM4	2.00º x 2.50º
O	IPSL	IPSL-CM6A-LR	1.27º x 2.50º
P	MIROC	MIROC6	1.40º x 1.40º
Q	MPI-M	MPI-ESM1-2-LR	1.85º x 1.87º
R	MPI-M	MPI-ESM1-2-HR	0.93º x 0.93º
S	HAMMOZ- Consortium	MPI-ESM-1-2-HAM	1.87º x 1.87º

Appendix B2 - Comparison of station-based interpolated rainfall with global rainfall datasets.

The rainfall gauging stations, although are fairly distributed within the basin, to verify the robustness of the interpolated rainfall data, it is compared with four gridded rainfall products namely 'Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation' (APHRODITE) (Yatagai et al., 2012), 'Climate Prediction Center' (CPC) (CPC, 2020), 'Global Precipitation Climatology Center (GPCC) (Becker et al., 2013), and he Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) (Funk et al., 2015). APHRODITE is developed by the Research Institute for Humanity and Nature (RIHM) and the Meteorological Research Institute of Japan Meteorological Agency (MRI/JMA) and is available for all land areas in Asia from 1951 to 2015 at a spatial resolution of 0.25°. CPC rainfall, provided by the NOAA/OAR/ESRL PSL, Boulder, Colorado, USA, has data from 1979 onwards and is based on a combination of two large datasets, namely the Global Historical Climatology Network version 2 (GHCN) and the Climate Anomaly Monitoring System (CAMS) (Fan & Van den Dool, 2008). GPCC is a global gridded rainfall prepared from assembling and analyzing rain-gauges data from over 85,000 stations worldwide. The data is available at a spatial resolution from 0.25° to 2.5° since 1901. Similarly, CHIRPS data is a combination of satellite estimates of precipitation with the station observation (Funk et al., 2015) available at 0.05° spatial resolution since 1981. Figure B1-1 compares the monthly and annual time-series of average rainfall in the Mun River basin for the 1979-2015 period. The rainfall by the gridded observed data is very close to the mean of the global rainfall product, whereas the APHRODITE data has dry bias while CPC, GPCC, and CHIRPS have wet biases, particularly during the rainy season (May-Oct). Table B1-1. presents the correlation between the datasets using monthly rainfall time-series which shows the data are highly correlated. Similarly, the spatial pattern of the annual rainfall is presented in Figure B1-2. The rainfall increases from the western part of the basin (900mm) towards the eastern part (1,550mm) (also shown in Fig. 1c). APHRODITE rainfall better captured the spatial pattern of the rainfall as it has a spatial correlation of 0.84 with the observed gridded data, while CPC, CHIRPS, and GPCC have the correlation of 0.75, 0.72, and 0.79, respectively. These results show that the observed interpolated rainfall data is consistent with the global datasets.

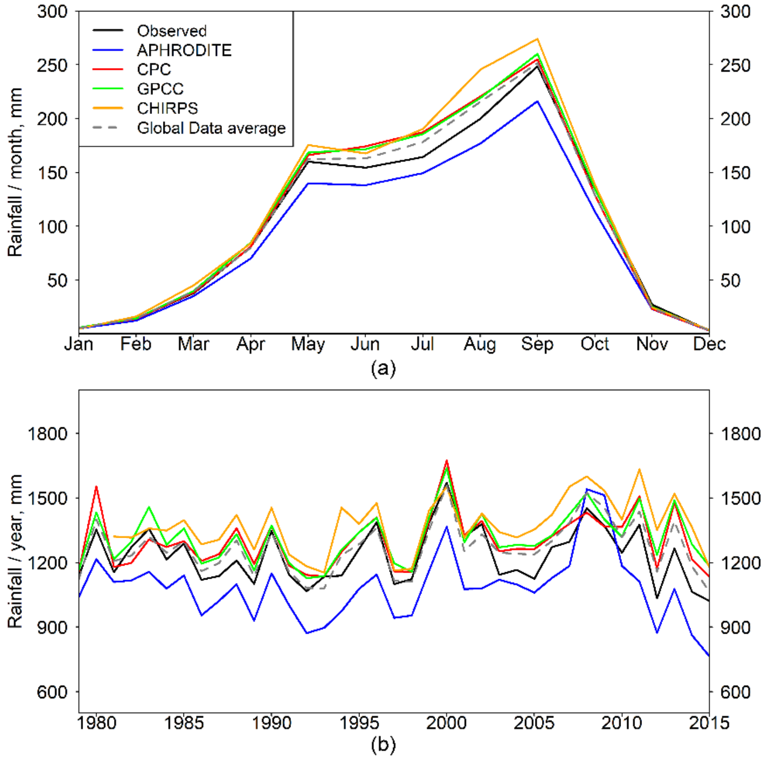

Figure B2- 1 Comparison of (a) monthly average and (b) annual time-series of the rainfall in the Mun river basin for 1979-2015 period represented by observed station averaged data, four global datasets (APHRODITE, CPC, CHIRPS, and GPCC), and the average of the four global datasets. The average of the global datasets is shown by the 'dashed' line.

Table B2- 1 Correlation matrix of five rainfall datasets (Observed, APHRODITE, CPC, CHIRPS, and GPCC) using the monthly time-series data for the 1979-2015 period for the Mun River basin.

	Observed	APHRODITE	CPC	CHIRPS	GPCC	Global data average
Observed	1	0.99	0.98	0.97	0.99	0.98
APHRODITE	0.99	1	0.98	0.97	0.98	0.99
CPC	0.98	0.98	1	0.98	0.99	1
CHIRPS	0.97	0.97	0.98	1	0.98	0.99
GPCC	0.99	0.98	0.99	0.98	1	1
Global data average	0.98	0.99	1	0.99	1	1

** CHIRPS data period is 1981-2015*

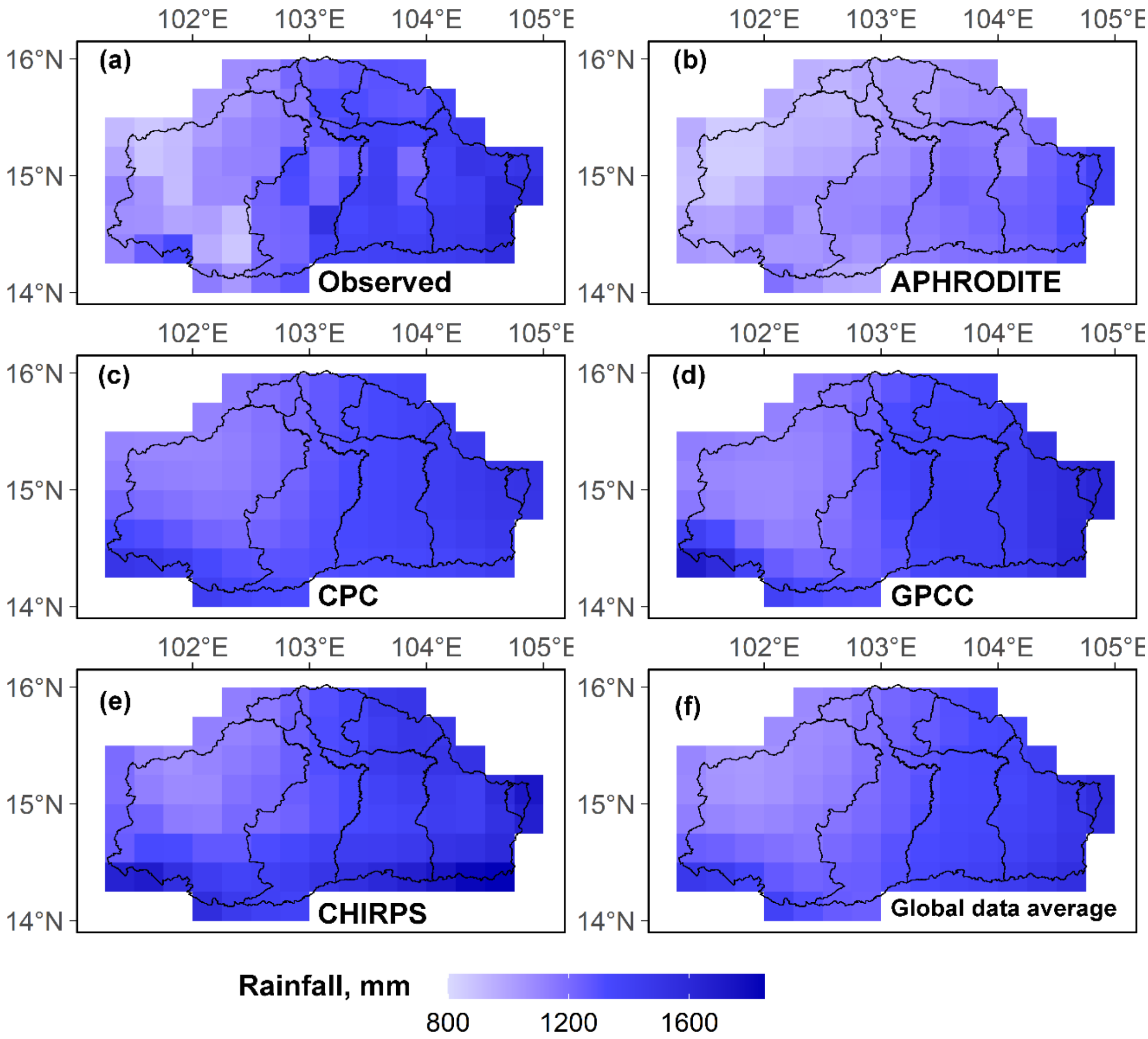

Figure B2- 2 The spatial pattern of the annual average rainfall during 1979-2015 period in the Mun river basin by (a) Interpolated rainfall measured at 43 stations, (b) APHRODITE, (c) CPC, (d) GPCC, (e) CHIRPS, and (f) Average of the four global data products.

Appendix B3 - Comparison of station-based maximum and minimum temperature with global rainfall datasets.

Daily temperature (maximum and minimum) data are available for 10 stations only in the basin, so global gridded temperature products are considered in the study. Available global temperature products generally are more consistent among each other than precipitation products and have a high degree of agreement among them in several regions including Asia (Rao et al., 2018). In this study, three gridded temperature products: ECMWF Re-Analysis land surface temperature (ERA5 - 0.25° grids) (Copernicus Climate Change Service (C3S), 2017), Climate Prediction Center (CPC - 0.5° grids) Global Land Surface Air Temperature Analysis (Fan & van del Dool, 2008), and The Berkley Earth Surface Temperature land surface air temperature data (BEST – 1.0° grids) (Rohde et al., 2013) are considered. Figure B2-1 shows the comparison of monthly and annual time-series of maximum and minimum temperature using three datasets with an average of the station data. BEST and CPC temperature data are very close to the observed data while the temperatures are under-estimated by ERA5. The minimum temperature by all datasets is in close agreement with each other than the maximum temperature. Table B2-1 shows the correlation among the datasets which are close to 1 indicating data are highly consistent among each other. CPC is available at higher spatial resolution and is also better able to capture variations in temperature with elevation; hence, it is preferred for the study. CPC data from 1979-2017 is resampled at 0.25-degree grid resolution using bilinear interpolation.

Table B3- 1 Correlation matrix of four temperature datasets (Observed average, BEST, CPC, and ERA5) (a) maximum temperature, and (b) minimum temperature using the monthly time-series data for 1979-2015 period for the Mun River basin.

(a) Max. Temperature

	Observed	BEST	CPC	ERA5	Global data average
Observed	1	1	1	0.98	1
BEST	1	1	1	0.98	1
CPC	1	1	1	0.98	1
ERA5	0.98	0.98	0.98	1	0.99
Global data average	1	1	1	0.99	1

(b) Min Temperature

	Observed	BEST	CPC	ERA5	Global data average
Observed	1	1	1	0.98	1
BEST	1	1	1	0.99	1
CPC	1	1	1	0.99	1
ERA5	0.98	0.99	0.99	1	0.99
Global data average	1	1	1	0.99	1

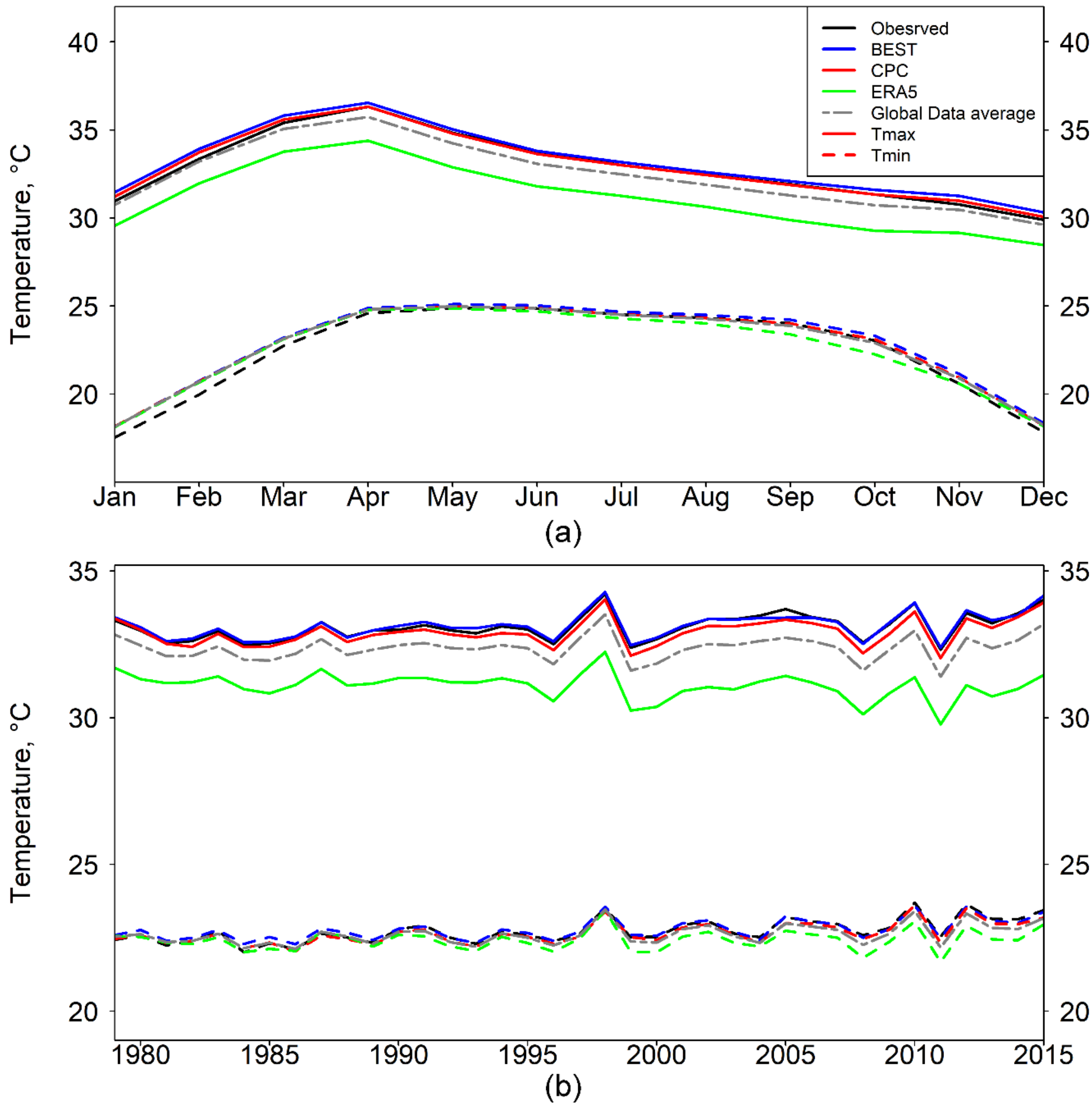

Figure B3- 1 Comparison of (a) monthly average and (b) annual time-series of the maximum and the minimum temperature in the Mun river basin for the 1979-2015 period represented by observed station averaged data, three global datasets (BEST, CPC, and ERA5), and the average of the three global datasets. The maximum temperature is shown by the 'solid' line while the minimum temperature is shown by the 'dashed' line. The average of the global datasets is shown by the 'double dashed line.

APPENDIX C

Appendix C-1 - Details of the Hydrological stations used in the study

Table C1- 1 Details of the Hydrological stations used in the study

S.N.	Station ID	Province	Data period	Location	
				Lat	Lon
1	M104	Buri Ram	2001 - 2017	15°26.13'	103°0.73'
2	M159	Buri Ram	1998 - 2017	15°8.5'	103°25.71'
3	M185	Buri Ram	2008 - 2017	15°0.05'	102°48.82'
4	M2A	Nakhon Ratchasima	2000 - 2017	14°58.08'	102°14.28'
5	M176	Si Sa Ket	2001 - 2017	15°0.5'	104°37.79'
6	M182	Si Sa Ket	2007 - 2017	15°7.95'	104°29.29'
7	M5	Si Sa Ket	1996 - 2017	15°20.39'	104°9.18'
8	M9	Si Sa Ket	1954 - 2017	15°7.1'	104°19.11'
9	M6A	Surin	1964 - 2017	15°17.94'	103°17.52'

Appendix C-2 - Spatial patterns of droughts in the Mun River basin during the observed period.

This appendix provides the visualization of the spatial patterns of average duration, intensity, severity, and the number of drought events in the Mun River basin using SPEI, SRI, and SSMI for the observed period (1981-2017) at three timescales (3-, 6-, and 12-month).

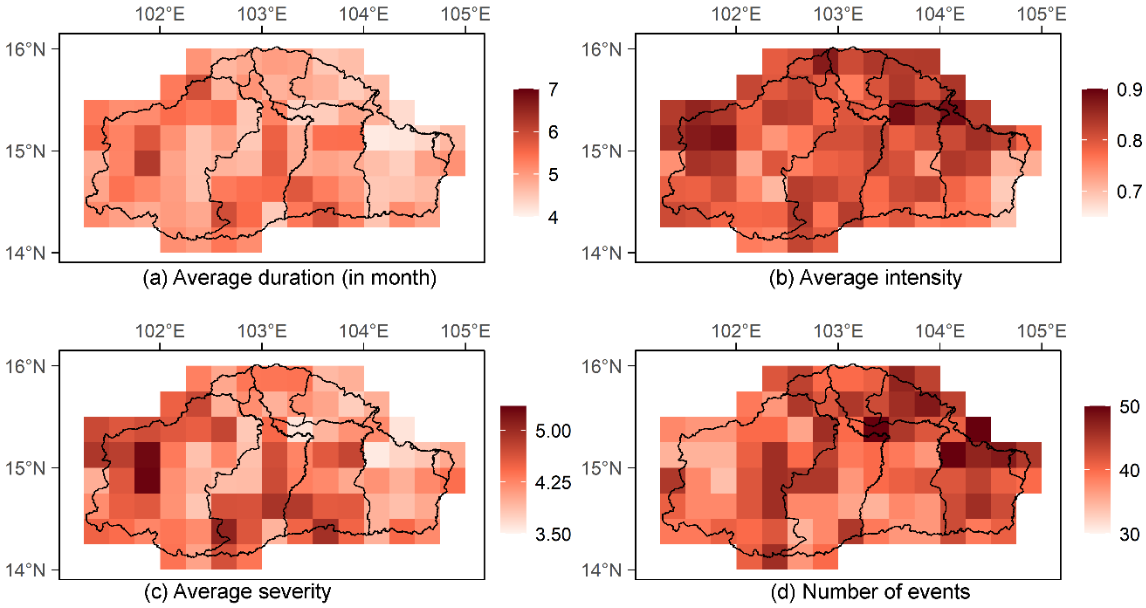

Figure C2- 1 Spatial pattern of the meteorological drought characteristics using SPEI at 3-month timescale. Drought intensities and severities are shown as absolute values.

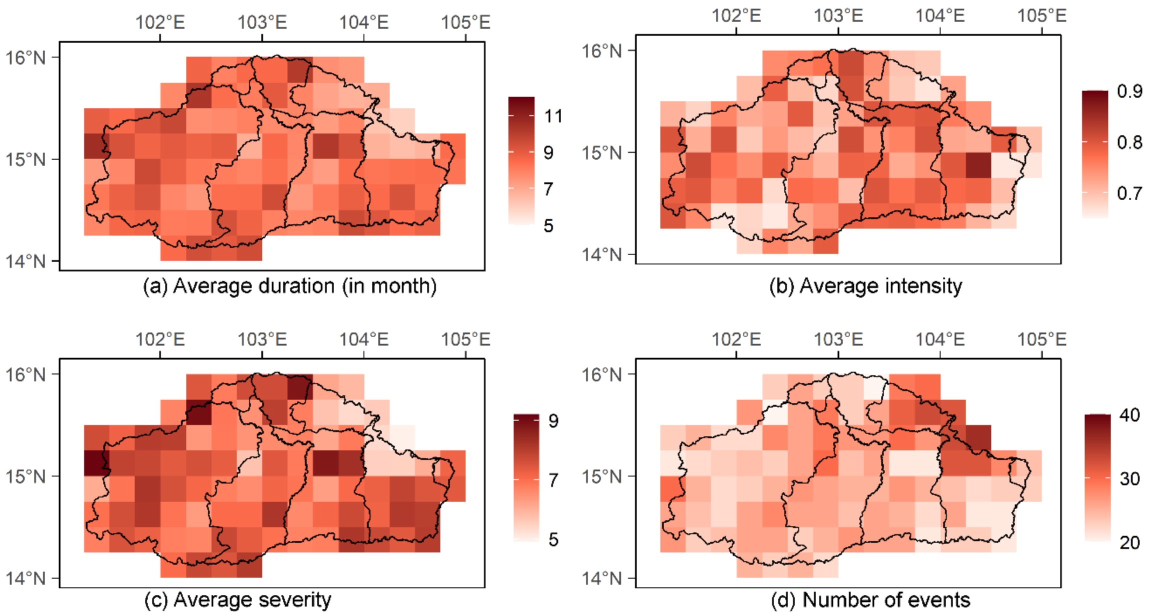

Figure C2- 2 Spatial pattern of the meteorological drought characteristics using SPEI at 6-month timescale. Drought intensities and severities are shown as absolute values.

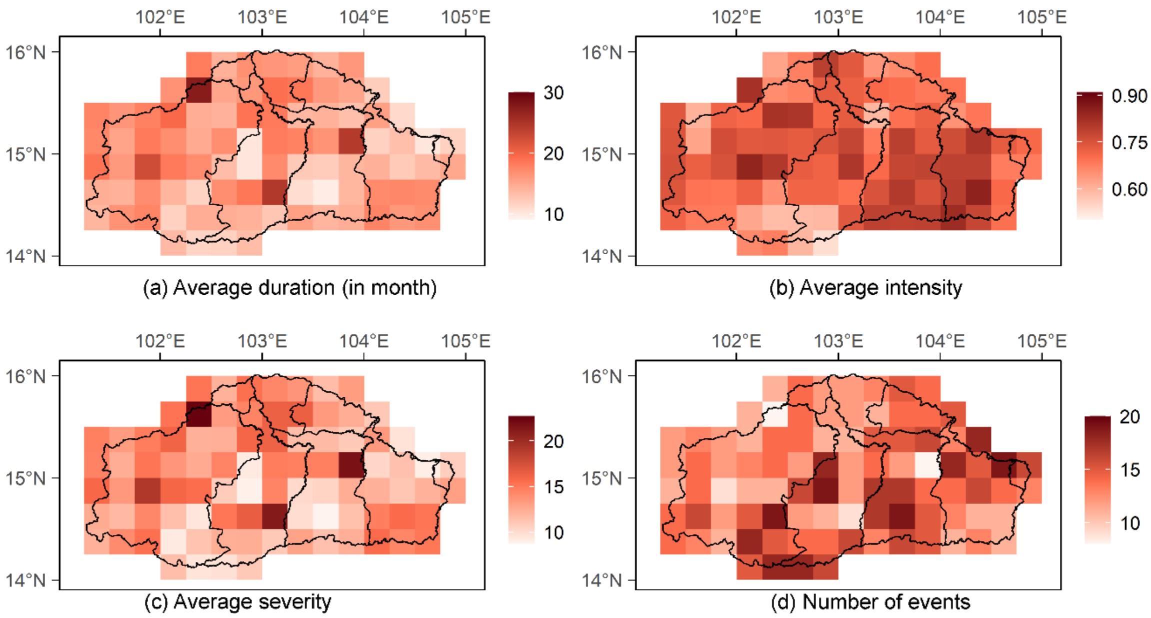

Figure C2- 3 Spatial pattern of the meteorological drought characteristics using SPEI at 12-month timescale. Drought intensities and severities are shown as absolute values.

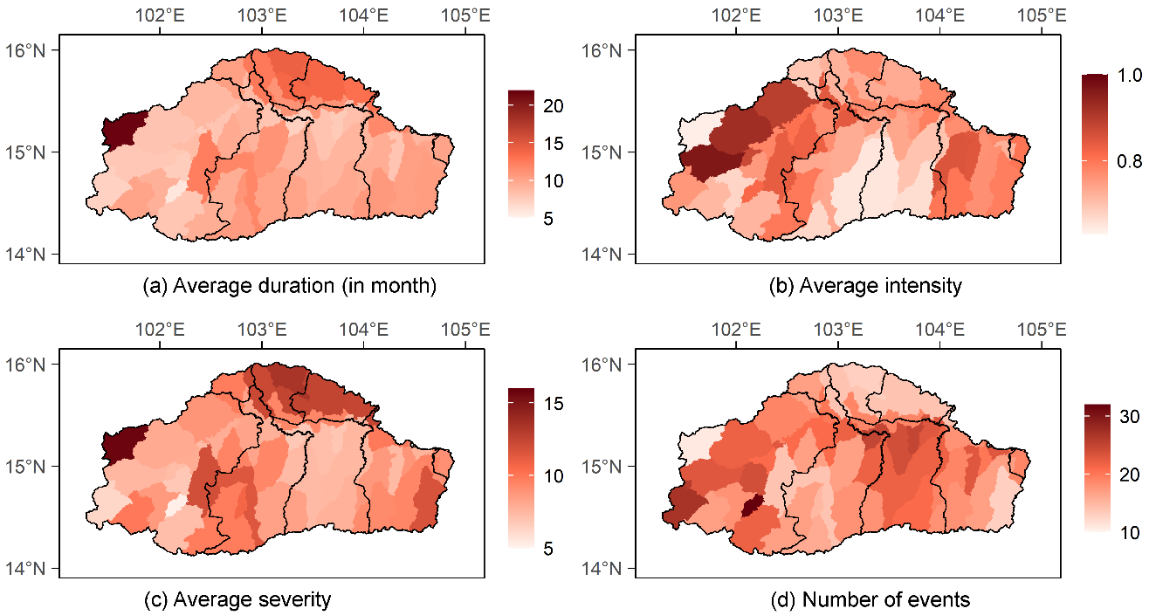

Figure C2- 4 Spatial pattern of the hydrological drought characteristics using SRI at 3-month timescale. Drought intensities and severities are shown as absolute values.

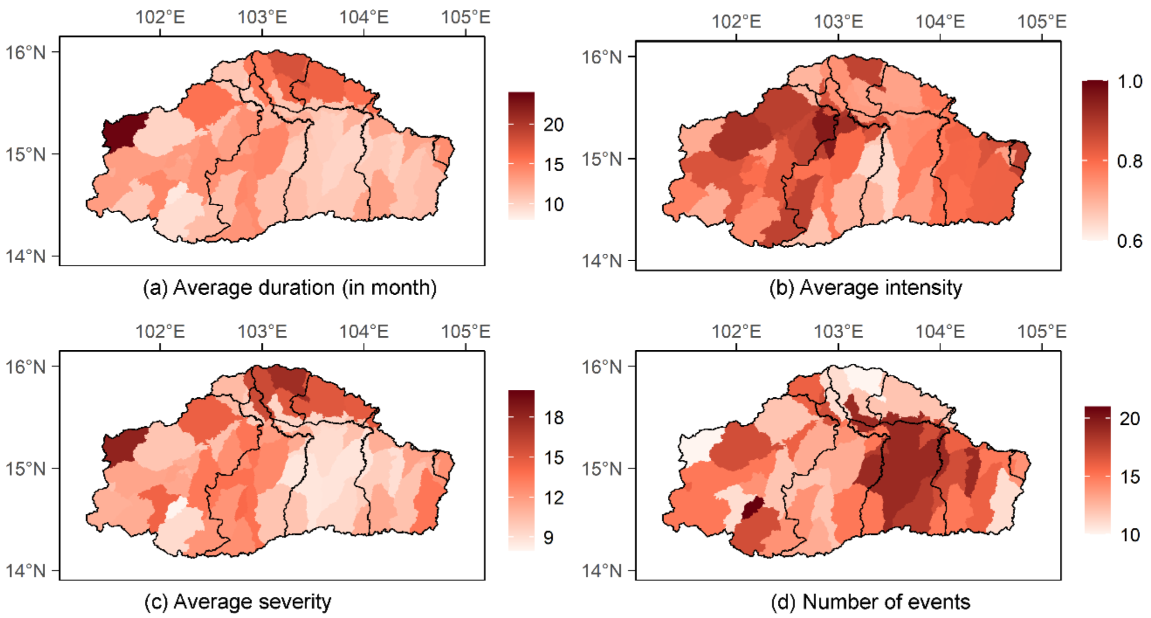

Figure C2- 5 Spatial pattern of the hydrological drought characteristics using SRI at 6-month timescale. Drought intensities and severities are shown as absolute values.

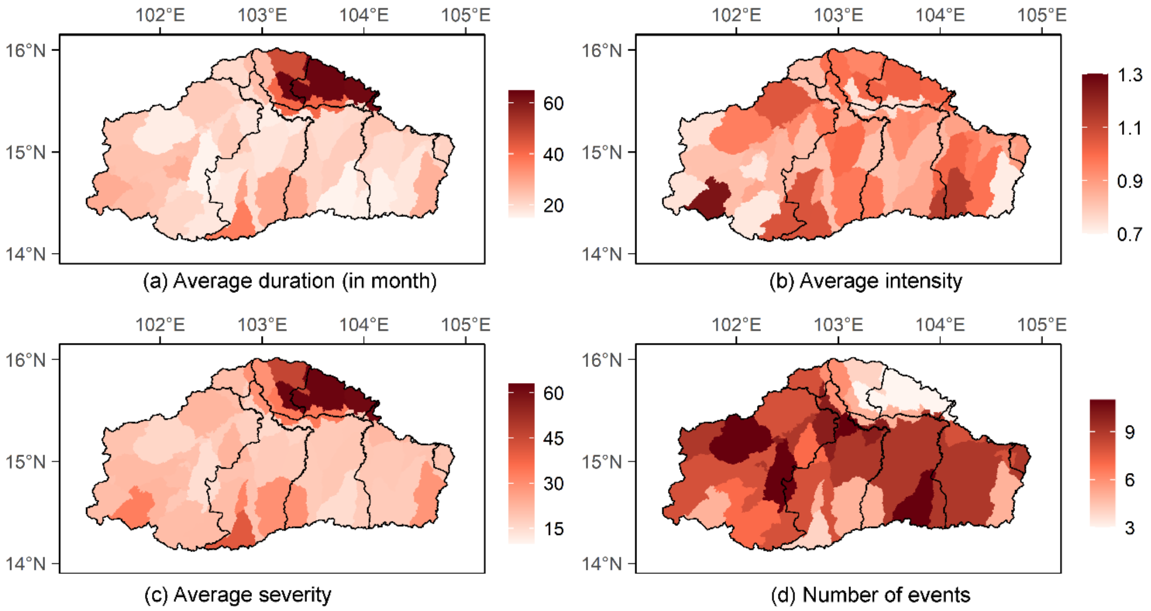

Figure C2- 6 Spatial pattern of the hydrological drought characteristics using SRI at 12-month timescale. Drought intensities and severities are shown as absolute values.

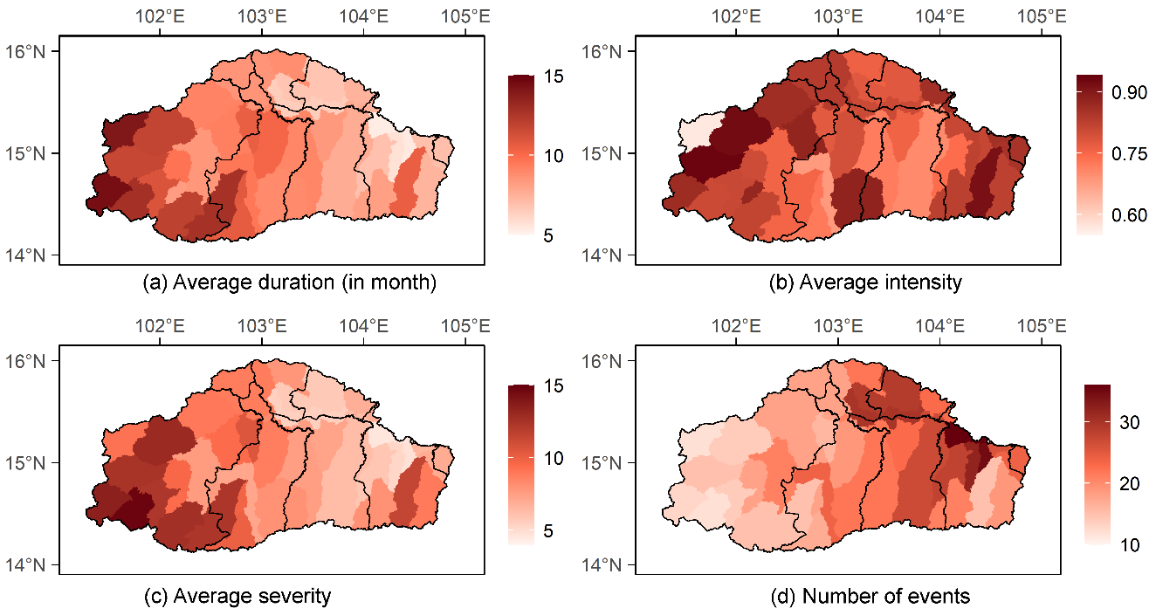

Figure C2- 7 Spatial pattern of the agricultural drought characteristics using SSMI at 3-month timescale. Drought intensities and severities are shown as absolute values.

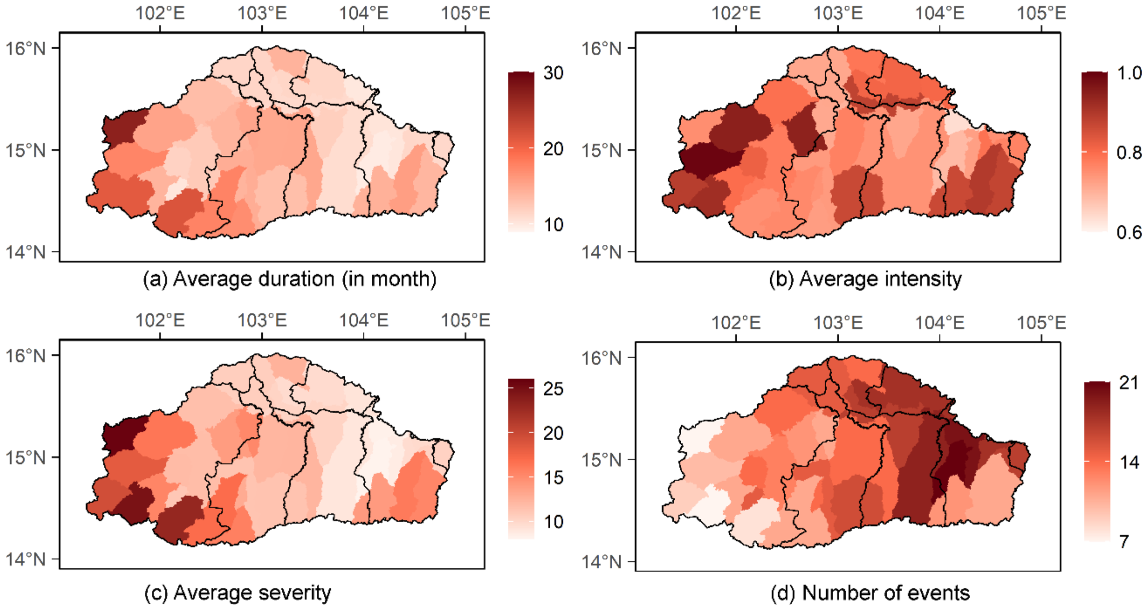

Figure C2- 8 Spatial pattern of the agricultural drought characteristics using SSMI at 6-month timescale. Drought intensities and severities are shown as absolute values.

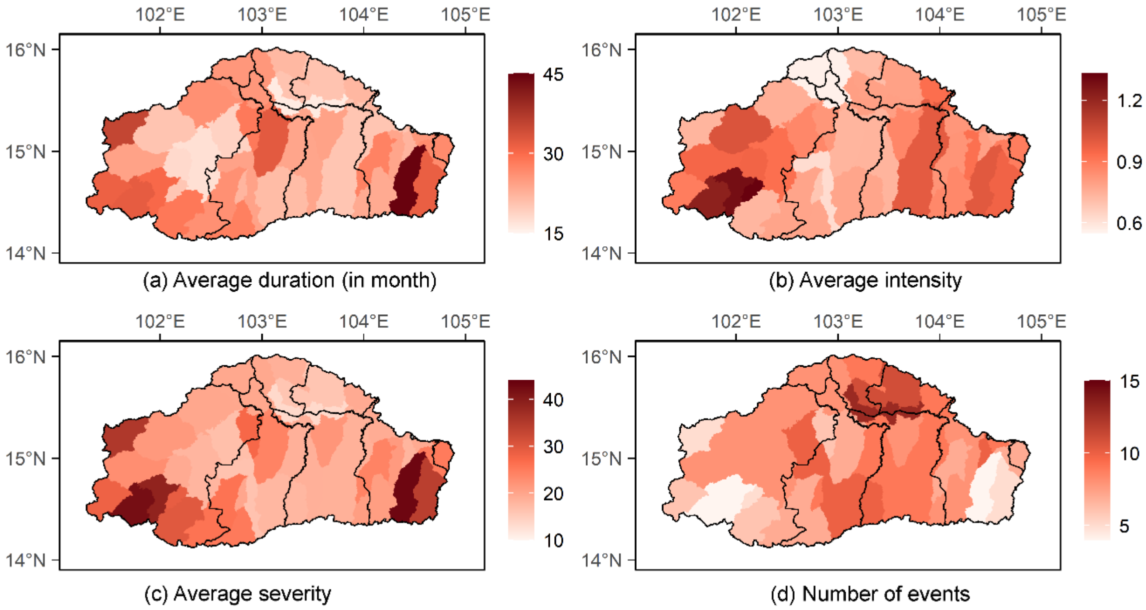

Figure C2- 9 Spatial pattern of the agricultural drought characteristics using SSMI at 12-month timescale. Drought intensities and severities are shown as absolute values.

Appendix C-3 - Spatial patterns of droughts with joint return period of 15-years

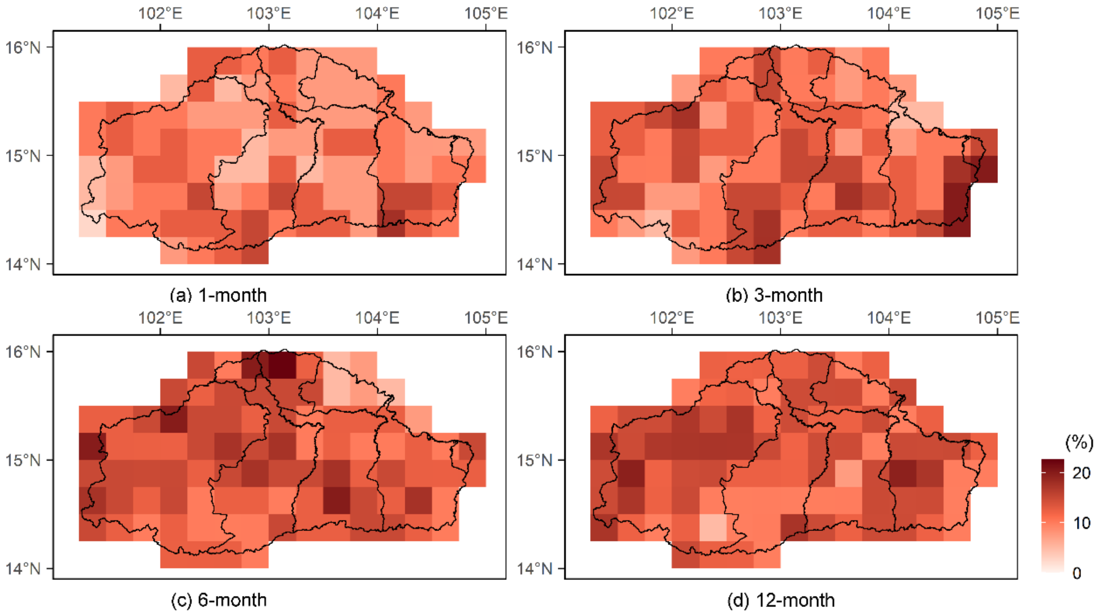

Figure C3- 1 Spatial pattern of the joint occurrence probability (%) of durations and severities of 15-year RVs using (a) SPEI-01, (b) SPEI-03, (c) SPEI-06, and (d) SPEI-12.

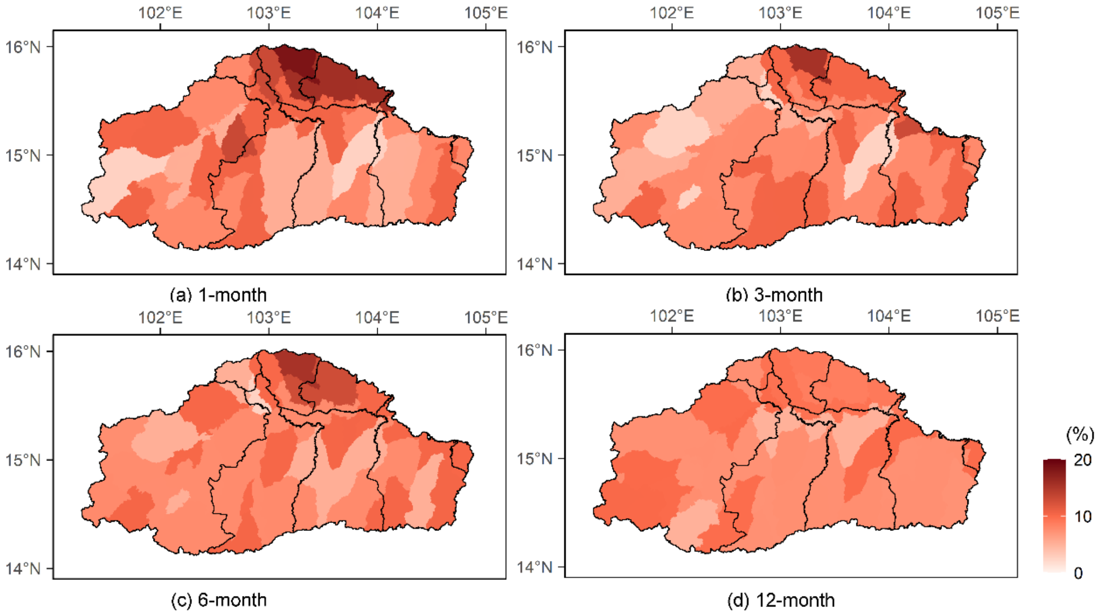

Figure C3- 2 Spatial pattern of the joint occurrence probability (%) of durations and severities of 15-year RVs using (a) SRI-01, (b) SRI-03, (c) SRI-06, and (d) SPEI-12.

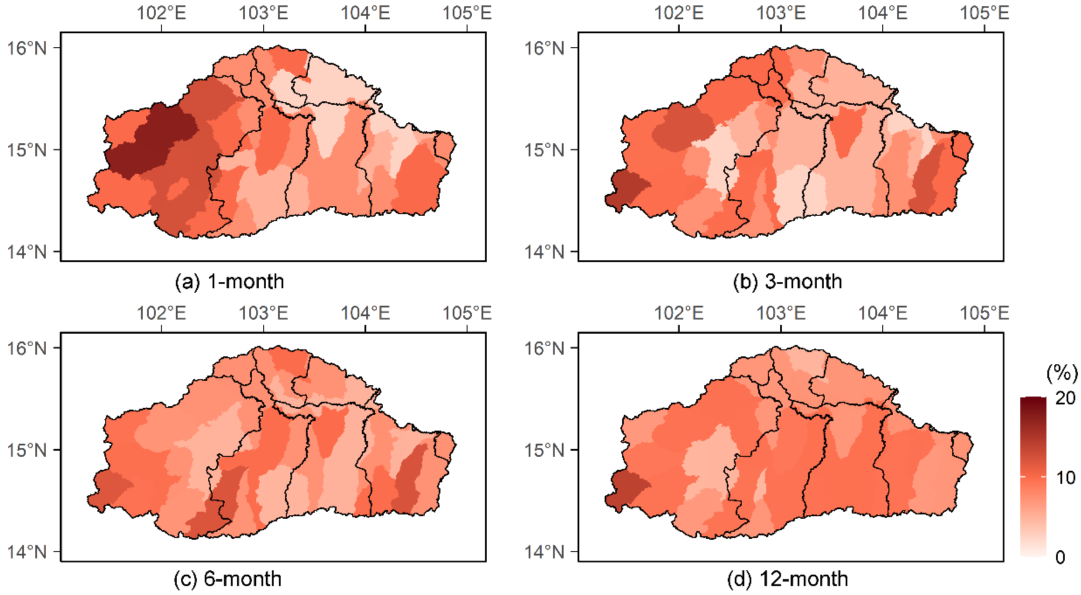

Figure C3- 3 Figure C3-3 Spatial pattern of the joint occurrence probability (%) of durations and severities of 15-year RVs using (a) SSMI-01, (b) SSMI-03, (c) SSMI-06, and (d) SSMI-12.

APPENDIX D

Appendix D-1 – Workshop on Adaptation Strategies and Measures for Improving Resilience to Agricultural Drought by ENRICH project

WORKSHOP
Adaptation Strategies and Measures for Improving Resilience to Agricultural Drought

of

"ENRICH: Enhancing Resilience to future Hydro-meteorological extremes in the Mun river basin in Northeast of Thailand"

18 August 2020

Online workshop

D1-1 Background

The Online Workshop on Adaptation Strategies and Measures for Improving Resilience to Agricultural Drought by ENRICH project was organized on 18 August 2020.

The ENRICH (Enhancing Resilience to future Hydro-meteorological extremes in the Mun river basin in Northeast of Thailand) project has been implemented through 2.5 years research program, starting from October 2018 to March 2021. The overarching objectives of this project are to understand the impact of the combined stressors of climate variability, climate change, and land-use change on hydro-meteorological extremes in the Mun River Basin, and to recommend adaptation measures to enable sustainable management of water resources and improve water security in the coming decades. The project is undertaken by the Asian Institute of Technology (AIT) in Thailand and the University of Exeter in the UK with support from relevant government agencies. The project team from Thailand consists of Prof. Tawatchai Tingsanchali, Prof. Mukand Babel, and Prof. Sangam Shrestha and from the UK of Prof. Slobodan Djordjevic, Prof. Mat Collins and Dr. Albert Chen. The project is designed to have four integrated Work Packages (WPs), which encapsulate the following:

- WP1: Land use changes
- WP2: Climate variability and climate change
- WP3: Hydro-meteorological hazards and risks
- WP4: Adaptation strategies and measures to improve climate resilience

The next-users of the project results are – the Department of Water Resources (DWR), the Royal Irrigation Department (RID), the Department of Disaster Prevention and Mitigation, the Office of National Water Resources, and other agencies of the Thai government. The principal beneficiaries (end users) of the project are the local stakeholders (local administration offices, farmers, industries, local people, etc.) in the Mun river basin.

WP4 involves adaptation strategies and measures to be implemented in the Upper Mun River Basin in Thailand to mitigate droughts and other water-related problems. In recent decades, in addition to frequent floods, there has been a water shortage crisis resulting from the low volume of water in reservoirs and dry rainy seasons, causing damage in rice fields and other crops. There are currently serious concerns whether this will increase in the future because of the impact of climate variability and climate change on the water supply side and from socio-economic development on the water demand side. Solving this puzzle is challenging and requiring cooperation from all levels of water users and management. Ultimately the motivation is to equip local communities, especially farmers, to better adapt to the impacts and to support policymakers in making the science-informed decision on adaptive water management with the participation of local stakeholders. This Workshop is part of the ENRICH project to share stakeholders' expertise and experience in dealing with droughts in Thailand.

D1-2 Workshop Objectives and Structure

D1-2.1 Objectives

The objectives of this Adaptation Workshop were to:

i. Bring together academic and water professionals to discuss adaptation strategies and measures that have been or are being implemented in river basins in Thailand to mitigate drought problems.

ii. Identify possible drought strategies and measures that could be implemented in the Mun River Basin, Thailand.

D1-2.2 Expected outcomes

The Adaptation Workshop were expected to lead to:

i. Improved understanding of adaptation strategies and measures implemented in Thailand and the extent to which measures could cope with droughts.
ii. Potential adaptation strategies and measures for the Mun river basin.

D1-2.3 Modality of the training program

The Adaptation Workshop was highly interactive, actively engaging participants in discussions (See the workshop agenda at the end of this report). It featured two major sessions comprising of presentations and a plenary discussion.

D1-2.4 Participants

Participants of the Adaptation Workshop were senior to middle managerial level authorities or staffs from key water-related government agencies in Thailand who are directly responsible for drought mitigation and management in the agriculture sector. Reputed scientists, academics, international organizations, and international non-governmental organizations, researchers, and research students also participated in the Workshop.

D1-3 Workshop Sessions

D1-3.1 Opening session

A formal opening session was held, and welcome remarks were made by Prof. Tawatchai Tingsanchali on behalf of AIT and the ENRICH project. Then, Prof. Mukand Babel gave a presentation on an overview of the project and briefly described the workshop objectives and expectation. Then, it was followed by introductions by all the participants.

D1-3.2 Presentation by the ENRICH project

Dr. Saowanit Prabnakorn of ENRICH project made a presentation on “Drought adaptation strategies and measures in agriculture: A comprehensive review”. All relevant adaptation strategies and measures were categorized into three scales, namely, regional, basin and farm level.

Examples of drought adaptation measures and strategies include:

<u>Regional scale</u>

- Improved water charging and trade (Iglesias & Garrote, 2015);
- Set clear water use priorities (Iglesias & Garrote, 2015);
- Monitoring and early warning systems (Iglesias & Garrote, 2015; IPCC, 2012);
- Use of climate information to better manage agriculture in drought-prone regions (IPCC, 2012);
- Ecosystem management practices of afforestation, reforestation, and conservation of forests (IPCC, 2012);
- Investment in natural capital and ecosystem-based adaptation (IPCC, 2012);

- Insurance, micro-insurance, and micro-financing; government disaster reserve funds, government-private partnerships involving risk sharing, and new innovative insurance mechanisms (Linnerooth-Bayer & Mechler, 2006; World Bank, 2010)
- Introduction of water reuse technologies, e.g. treatment technology of constructed wetlands (Metcalf & Eddy, 2005).

<u>Basin scale</u>

- Sharing of land for grazing and of access to water (Anderson, Morton, & Toulmin, 2010);
- Water demand management (IPCC, 2012);
- Land use planning (IPCC, 2012);
- Long-range reservoir inflow forecasts (IPCC, 2012);
- Reservoir regulation (Quiroga, Garrote, Fernandez-Haddad, & Iglesias, 2011);
- Introduce new irrigation areas (Iglesias & Garrote, 2015);
- Inter-basin and within-basin water transfer (Rossi, 2000);
- Use of aquifers as groundwater reserve (Rossi, 2000).

<u>Farm level</u>

- Integrating use of surface and groundwater (Hadid & A.F., 2009);
- Introduce drought-resistant crop varieties (IPCC, 2012);
- Breeding programs (short-growth varieties etc.) e.g. Rapeseed (oilseed crop) and Hybrid rice in China (Hu et al., 2017; Ma & Yuan, 2015);
- Mix planting (Hicks, Rahman, Carnol, Verheyen, & Rousk, 2018);
- Change in crops and cropping patterns (Iglesias & Garrote, 2015);
- Altering the timing or location of cropping activities (Hadid & A.F., 2009);
- Adopting intensive farming technologies (Dai & Dong, 2014);
- Roof catchments, wells, water tanks, Small-scale reservoirs on farmland (Iglesias & Garrote, 2015; IPCC, 2012);
- Improve the reservoir capacity (Iglesias & Garrote, 2015);
- Improve soil moisture retention capacity (Iglesias & Garrote, 2015);
- Addition of organic materials into soils (Iglesias & Garrote, 2015);
- Mulching practices (L. F. Wang, Chen, & Shangguan, 2015; Zhang, Yang, & Lovdahl, 2016);
- Basal Nitrogen-fertilizer application at a depth of 6 cm with plastic mulching (X. Wang, Wang, Xing, Yun, & Zhang, 2018)
- Application of (spray) Ocimum leaf extract (proved to enhance drought tolerance of rice in India) (Pandey et al., 2016)

D1-3.3 Presentations by multiple water-related government agencies

<u>Office of the National Water Resources (ONWR)</u>

First, Ms. Chawee Wongprasittiporn, a representative from ONWR, gave a presentation on "Adaptation strategies and measures to mitigate drought problems in agriculture". The ONWR formed optimal adaptation strategies and measures to tackle water problems in Thailand based on Strategic Environmental Assessment (SEA) taking into consideration economic, social and environmental impacts. For the Mun River Basin, it was divided into 3 main areas consisting of 31 subbasins, namely, Upper Mun covering 11 subbasins, Middle Mun covering 9 subbasins, and Lower Mun covering 11 subbasins. Based on that, all relevant studies and analyses were executed and alternative plans and solutions for water resources development in the Mun River Basin for 20 years were developed. They could be categorized 4 major options including:

1) No action/Base line (until 2020)
2) Do as now – separate manner among all water agencies (between 2021-2037)
3) Integrated manner between all agencies
4) Integrated manner and using local wisdom, innovation, and technology.

Department of Water Resources (DWR)

Second, Dr. Supapap Patsinghasanee, the Director of Water Operation Center, gave a presentation on “The challenges of drought management in the rain-fed area in Thailand”. He began with the explanations of hydrological cycle in Thailand (Figure D1- 1), water supply by large, medium and small reservoirs and water demand totalled from all sectors in which agriculture accounted for 75%. Then, the water balance in rainfed area showed that water supplies in all regions are sufficient to fulfil water demand, except in the north and central regions. However, water shortage still occurred in some areas at district levels. To solve the problem, the DWR developed the policy alignment for Thailand related to the Sustainable Development Goals (SDGs). The national policy encompasses water management for consumption, water security for production sectors (agriculture and industry), flood management, water quality management, upstream forest rehabilitation and soil erosion prevention and administrative management. The master plan of DWR includes 3 pillars, namely, rehabilitation of waterbody and wetlands outside irrigation areas, structural measures to increase water distribution and allocation, and non-structural measures such as water crisis management to prevent and mitigate risk areas by installation of real-time monitoring in 6,042 villages. The urgent plans for years 2019-2020 are focusing on drinking water and agricultural water by installation of drinking water stations, water distribution by trucks, installation of pumps to divert water. Together with real-time monitoring systems, about 1,773 stations (41%) were provided by the DWR, mainly locating in rainfed areas in the northern part and highland area.

Moreover, the DWR has implemented a Solar-powered Irrigation System (SIS) project in Nakhon Ratchasima province (upstream part of the Mun River Basin). The project covers the area of 64,000 m^2, and serves 25 households whose their main crops are vegetables. This project can increase annual income of each household approximately 1,560 US$. The DWR hopes that this project will eliminate extreme poverty by 2030.

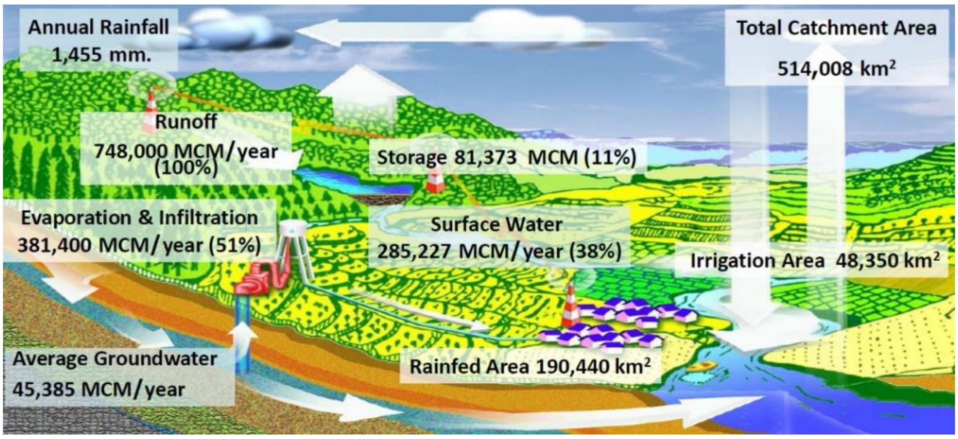

Figure D1- 1 Hydrological cycle in Thailand (Department of Water Resources)

Department of Groundwater Resources (DGR)

Third, Dr. Surin Worakijthamrong, the Director of the Bureau of Groundwater Development, gave a presentation on “Smart groundwater management for agriculture project: new way to mitigate drought problems for agriculture”. He described changes in temperature in Thailand that was forecasted to increase by 1-2 °C in 2050. This will lead the number of hot days (≥ 35°C) increasing all over the country. The conditions together with an increase in irregular rainfall events and a reduction in continuous rainfall event, but higher intensity, accelerate and intensify droughts. As a result, drought prone areas in Thailand will increase, while the majority of agricultural area (83%) is under rainfed condition. The DGR, therefore, has a main mission to assist people in rainfed area.

The DGR has initiated a groundwater development project for agriculture since 2013 from which about 8,000 wells were accomplished. And, the estimated volume of water supply is approximately 316 million m^3 benefiting about 35,789 households. Besides, the DGR has a big and smart groundwater management project for agriculture by integrating the use of solar power for water pumping and distribution (Figure D1- 2). The project was implemented in 6 provinces in all regions, except the southern part. To be sustainable, the DGR asked for cooperation from farmers to be part of the project, particularly in operation and maintenance activities. The project is targeted to be implemented in all districts (1 large-scale groundwater project per 1 district) in Thailand.

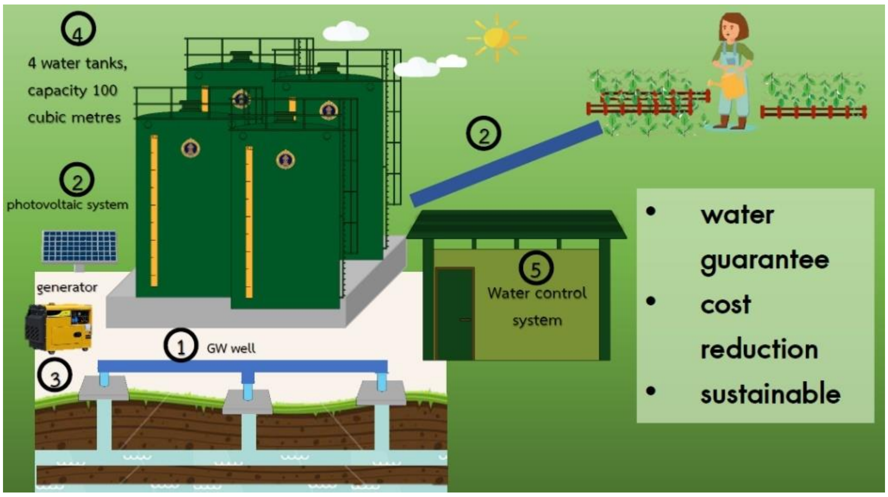

Figure D1- 2 The DGR smart groundwater management project for agriculture

Land Development Department (LDD)

Forth, Ms. Pimpilai Nuallaong, a plan and policy analyst, and Ms. Wirada Chuensombat, a soil surveyor, gave a presentation on “Agricultural drought forecasting in Thailand”. The LDD assessed agricultural droughts in Thailand by considering three main factors, namely, climate change, water retention, and human activity. Climate change was represented by topography and weather data, while water retention was represented by soil data, and lastly human activity was represented by land use data. All data were prepared in a geospatial data format (shapefile format) and then were overlaid in ArcGIS to obtain the final result of agricultural drought (Figure D1- 3). To recheck the result, the LDD performed community participation with farmers in the study area. The LDD has implemented 4 principles to mitigate drought effects as following:

- Information and technology promotion - accessible mobile applications concerning soils and plants;
- Increase water use efficiency – Zoning areas by using Agri-Map web application (entails all relevant information for agriculture i.e., as soil types and their suitability, crops etc.);
- Increase water supply – Building farm ponds;
- Recovery agricultural drought impact areas.

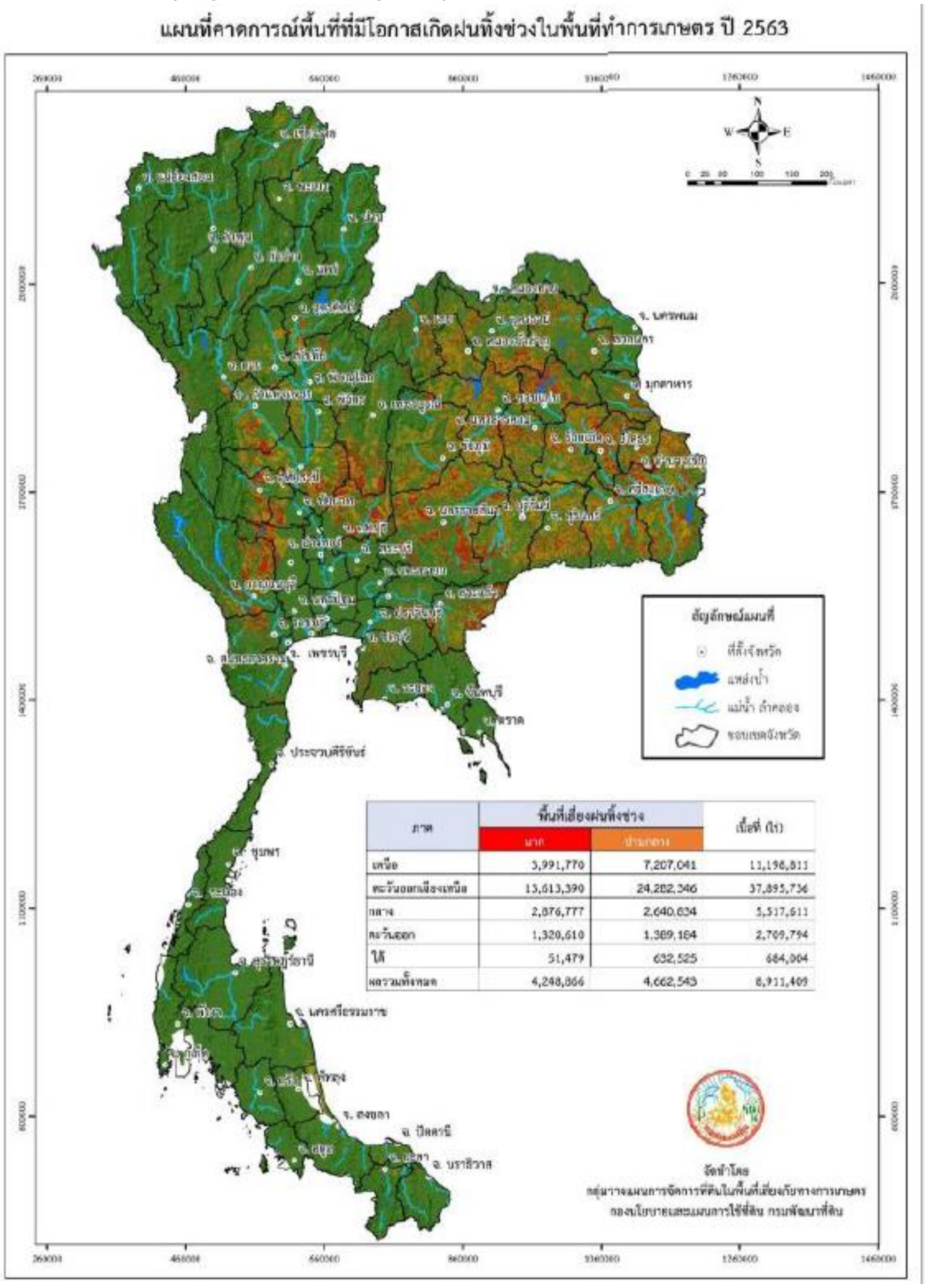

Figure D1- 3 Forecasted agricultural drought map of 2020 by the LDD.

The LDD has carried out 5 ways for agricultural drought preparedness:

- Drought monitoring and will inform people through a website and a Facebook page;
- Soil analysis for selection of suitable plants by using LDD mobile applications;
- Avoid high water-consuming crops by LDD mobile applications;
- Increase water supply by the mean of farm ponds.
- Decrease evapotranspiration by a mulching method.

Department of Agriculture (DOA)

Fifth, Dr. Margaret Yoovatana, a senior policy and plan specialist at Planning and Technical Division, gave a presentation on “Enhanced drought resilience of small-holder farming communities through H.M. the King sufficiency economy and New Theory in Agriculture”. She first introduced the ASEAN Climate Resilience Network (ASEAN CRN), which is a platform for regional exchange, particularly for sharing information, experiences, and expertise on climate smart agriculture. Next, the 15 agricultural policies of the Ministry of Agriculture and Cooperatives (MOAC) in Thailand among which management of water resources is one of the priorities. Examples and explanations of some Royal initiative projects related to soil and water management as well as crop cultivation are then provided such as Khao Cha-ngum Deteriorated Soil Rehabilitation Study Project, Huai Hong Khai Royal Development study Centre, Khao Hin Sorn Royal Development Study Center, Kung Krabaen Bay Royal Development Study Center etc. Each project had different problems, which were successfully solved by different measures. For instance, planting vetiver grass for soil degradation and erosion; forest rehabilitation based on the principle of natural cycle which is simple and cost-saving; development of watershed areas; construction of check dams; promotes animal husbandry such as swine and poultry farming, and integrated fish raising; renovating existing reservoirs and water irrigation systems; upgrading infrastructure and developing delivery system. Examples of measures for crop cultivation included growing organic vegetables in nurseries to use less water during drought periods; cultivating crops in controlled nurseries rather than open fields, use of “water drip” irrigation, and soil nourishment trainings. The knowledge from these examples are valuable that can enhance communities’ resilience to droughts.

Lastly, it is about Philosophy of Sufficiency Economy by His Majesty King Bhumibol Adulyadej. Sufficiency Economy is a philosophy based on the fundamental principle of Thai culture. It is consisted of three pillars:

- Moderation – producing and consuming as a moderate level;
- Reasonableness – decision must be made rationally with consideration of the factors involved and careful anticipation of the outcomes that may be expected from such action;
- Risk Management – preparation to cope with the likely impacts and changes in various aspects by considering the probability of the future situations.

The New Theory in agriculture was developed to be a concrete example of the application of Philosophy of Sufficiency Economy to the agricultural sector. It is associated with water resource development and conservation, soil rehabilitation and conservation, sustainable agriculture and self-reliant community development. To begin with optimizing farmland (Phase I), a farmer’s land is divided into 4 proportions: 30% ponds to store rainwater; 30% rice cultivation; 30% growing fruits and perennial tree, trees, vegetables, field crops and herbs for daily consumption; and 10% accommodation, animal husbandry, roads and other structures (Figure D1- 4). Then, Phase II, it is about communal agriculture (forming groups or cooperatives to carry out farming activities). And, it is related to production, marketing, living conditions, welfare (public health), foundations (schools, scholarships), society and religion. All of them must receive cooperation from all relevant stakeholders, whether government, private sector, members of the community. Phase III involves loan and credit outreach that are obtaining funds from banks or private companies; investment; providing market outlets for farmers; banks or private companies buys farmers' products; formation of cooperatives to sell consumer products at lower cost etc.

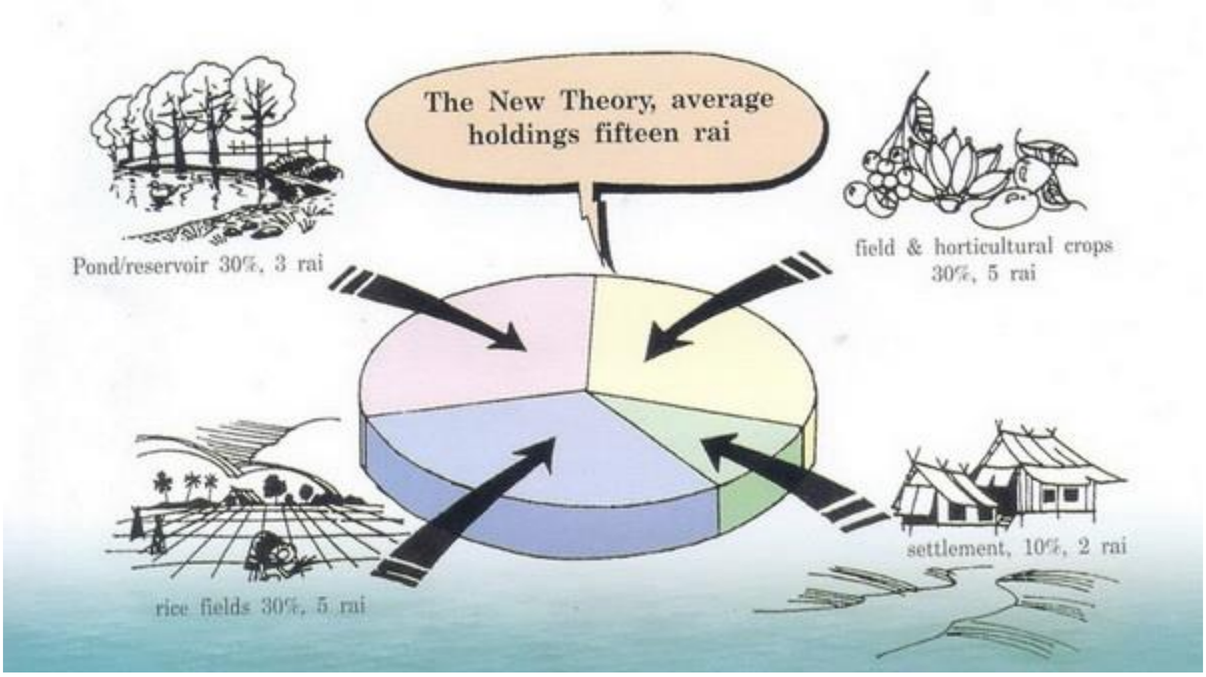

Figure D1- 4 The New Theory: Integrate and Sustainable Agricultural System

Source: https://www.chaipat.or.th/eng/concepts-theories/sufficiency-economy-new-theory.html

In conclusion, the New Theory principles and methods is a production system based on Sufficiency Economy which members of a community unite and cooperate in helping one another. Consequently, there will have enough rice for year-round consumption, and sufficient reserve of water for dry season or during drought spells. According to H.M. the King's calculation to cultivate 1 rai (1,600 m^2.) of land requires about 1,000 m^3 of water. Therefore, for growing 5 rais of rice and 5 rais of field crops or fruit trees (total of 10 rais there must be 10,000 cubic meters of water per year. Further, to the next level – the ideal New Theory system, large reservoirs fill small reservoir, and small reservoirs fill ponds to ensure water availability.

Finally, she provided 8 drought measures of MOAC implemented by Department of Agricultural Extension, the department from the same ministry which could not participate in the workshop. The measures are listed as following:

1. Saltwater invasion surveillance in horticultural areas – in 9 provinces in Nakornpathom, Samutsakorn, Bangkok, Nontaburi, Pathumthani, Samutprakarn, Samutsongram, Ratchaburi, Chachoengsao;
2. Public relation campaigns for the farmers to join hands during droughts;

3. Integration of activities and cooperation in water scarcity areas outside the irrigation zones to promote income generation for the farmers;
4. Promote multiple cropping practices during dry season;
5. Promote cultivation of less water use cash crops to generate income for farmers;
6. Promote planting of field corns as feed to livestock after the main crop;
7. Knowledge transfer and demonstration in the learning center areas to increase the efficiency of agricultural production;
8. Mobile Agricultural Clinics.

D1-3.4 Plenary discussion on possible drought strategies/measures for the Mun River Basin

In this session, Prof. Babel facilitated and moderated a plenary discussion on possible drought strategies and measures for the Mun River Basin. All participants were sharing their experience and opinions on the issue. In summary, the recommended drought-mitigation measures from each expert are listed below:

Table D1- 1 Recommended drought-mitigation measures

Government agency and organization	Recommended measures
ONWR	• Accurate long-term drought forecasting that are easily and publicly accessible; • Proper water allocation (demand management among water users); • Water storages (big, medium, Khok Nong Na Model etc.) • Runoff harvesting.
DWR	• Transfer water within the basin; • Strengthen farmer union; • Strengthen water-user groups (to manage and operate water by themselves).
HII	• Conjunctive use service (groundwater + surface water); • Groundwater banks; • 14-day, 3-month, and 9-month forecasting (performing now at the Chao Phraya River Basin)
DOA	• Water storage, water conservation, water harvesting (an underground water bank); • Climate smart agricultural practices such as soil improvement; • Drought-tolerant crop varieties.
RID	• Reduce farmers' cost and increase their income;

Government agency and organization	Recommended measures
	• More strategies for farmers, not only rely on government subsidy; • Reservoir regulation; • Cropping pattern, shift of rice growing season.
SEI	• Improve drought monitoring and forecasting; • Drought strategies should be specific to the basin; • Alternative livelihood (What farmers should do in case of no water?); • Nature-based solutions.
Khon Kaen University	• Water harvesting (roof, small farm pond, aquifer recharge etc.); • Demand management to increase water use efficiency such as smart agriculture; • Capacity building of farmers.

D1-4 Way Forward

In the closing session of the workshop, it was agreed that presentations and essential information will be shared among the participants. And, the outcomes of the workshop will be considered in the ENRICH Project.

Workshop Agenda

Time	Activity	Responsible
08:50 – 9:00	Participant joining the workshop	
09:00 – 9:10	Welcome, official opening (10 min)	Prof. Tawatchai Tingsanchali
09:10 – 9:40	Presentation 1: ENRICH Project overview including workshop objectives and outputs and Introduction by the participants (30 min)	Prof. Mukand S. Babel
09:40 – 10:10	Presentation 2: Drought adaptation strategies and measures in agriculture: A comprehensive review (30 min)	Dr. Saowanit Prabnakorn
10:10 – 10:30	Coffee break	
10:30 – 12:00	Presentation 3: Adaptation strategies and measures to mitigate drought problems in agriculture (30 min)	Office of the National Water Resources (Ms. Chawee Wongprasittiporn)
	Presentation 4: The challenges of drought management in the rain-fed area in Thailand (30 min)	Department of Water Resources (Mr. Supapap Patsinghasanee)
	Presentation 5: Smart groundwater management for agriculture project: New way to mitigate drought problems for agriculture (30 min)	Department of Groundwater Resources (Dr. Surin Worakijthamrong)
12:15 – 13:30	Lunch break	
13:30 – 14:30	Presentation 6: Agricultural drought forecasting in Thailand (30 min)	Land Development Department (Ms. Pimpilai Nuallaong and, Ms. Wirada Chuensombat)
	Presentation 7: Enhance drought resilience of small-holder farming communities through H.M. self-Sufficiency economy and New Theory in agriculture (30 min)	Department of Agriculture (Dr. Margaret Yoovatana)
14:30 – 14:50	Coffee break	
14:50 – 15:30	Plenary discussion on possible drought strategies/measures for the Mun River Basin	All (Moderated by Prof. M. S. Babel)
15:30 – 15:40	Closing remarks	Prof. Tawatchai Tingsanchali

a. Conclusion from professionals' meetings in August 2020 on drought mitigation strategies and measures in the Mun River Basin

Office of the National Water Resources (ONWR)

The ONWR has developed measures and strategies for mitigating water problems in Thailand based on Strategic Environmental Assessment: SEA, which encompasses domestic water uses, droughts, floods, water quality, forest rehabilitation, and operation & maintenance. For the Mun River Basin, when contemplating solving water issues in the areas, there are possible 4 actions involved:

1) Do nothing
2) Do as now – separate manner among all water agencies
3) Integrated manner between all agencies (as a package)
4) Local wisdom, innovation, technology (for only important cases such as climate change), for example, smart irrigation system which has been applied in Korat, Nakhon Ratchasima)

The selection of a proper action will be carefully decided on a case by case basis as problems, criteria, limitations, etc. in each area are different. For example, at Ubon Ratchathani province (from Kaeng Sa Phue to the Mekong River), drought problems cannot be solved by making ponds because of shallow topsoil. At Thung Kula Ronghai in Roi Et and Maha Sarakham provinces, building ponds will make salts spread out because of the salty soil. Thus, it can be said that the solution is tailor-made measures and strategies.

For risk management, the ONWR also focus on flexibility in measures and strategies. The agency uses average rainfall for planning and designing permanent structures such as on-ground ponds, dikes, ridges. While temporary infrastructure, for example, raising earth bunds in rice fields to create temporary ponds to collect additional rainwater during intense rainfall and it will be used during dry spells, will be provided in areas with high rainfall variations, i.e., 20-30%, 50%.

For the demand side, the agency adopts cropping patterns and zoning for diminishing and managing water uses in the agriculture sector. An example of the former is to allow farmers to grow forest trees that were prohibited in the past. The latter is known as "Khok Nong Na model", which has been applied in many places in Thailand.

Royal Irrigation Department (RID)

The Royal Irrigation Department anticipates the amount of water stored in reservoirs by comparing rainfall quantity nowadays with historical data. If the forecasted amount of water in reservoirs is little, the agency prioritizes water use amongst sectors, ranking from domestic consumption, agriculture, and industry. Then, the agency implements mitigation measures and strategies as follows:

- Request farmers not to grow any crops during dry spells (less cooperation from farmers)
- Request farmers to grow crops that require less water such as maize (less cooperation from farmers)
- Building ponds
- Adopt new farm practices, e.g., alternate wetting and drying (AWD) water management for rice cultivation, which is rarely applied in northeast Thailand.

- Provide extra jobs to farmers such as digging or dredging canals etc.
- Other assistance according to the government policy

Department of Groundwater Resources (DGR)

The Department of Groundwater Resources has developed groundwater resources projects for domestic consumption, agriculture, and industry. For example, the remote groundwater transmission project, which is for domestic water uses. Cooperated farming is a project to support large agriculture. It is a new ongoing project, start implementing in Karat in Nakhon Ratchasima, and Ubon Ratchathani provinces. Some issues need resolving such as large project areas for system installation, which little farmers want to sacrifice part of their plots, electrical expenses, operation and maintenance problems and costs, sources of funding (may be provided by Bank for Agriculture and Agricultural Cooperatives (BAAC)). Aquifer Storage and Recovery (ASR) in the Mun and Chi River Basins – the project attempts to solve flood and drought problems in the basins by collecting floodwater underground and use it during dry spells. The description of the project at year is presented in Table D1- 2.Table D1- 2

Table D1- 2 Details of Aquifer Storage and Recovery (ASR) in the Mun and Chi River Basins (15th December 2006)

Main activity	**Achievement**
1. Study and design an ASR system	
- Pumping test for aquifers	100 wells
- Partial Analysis	600 examples
- Selection of study areas suitable for groundwater	10 places
2. Construction stations for groundwater observation and study of a conjunction use of groundwater and surface	
- Drill observation pits	45 stations
- Electrical well log	120 wells
- Pumping test for 72 hours	10 wells
- Pumping test for 12 hours	100 wells
- Survey groundwater wells	65 wells
- Resistivity	170 points
- Final report	Completed
3. Detail groundwater potential investigation	
- Drill survey/production wells	53 wells in 45 stations
- Electrical well log	120 wells
- Groundwater level measurement and water sampling	431 wells
- Pumping test for 72 hours	30 wells
- Pumping test for 12 hours	110 wells
- Groundwater modeling	In progress (Data import into the model)
- Final report	Completed

Source: Bureau of Groundwater Exploration and Potential Assessment, 2009

Department of Water Resources (DWR)

The Department of Water Resources deals with drought problems in the Mun River Basin by implementing 3 measures:

1) Increasing water resources for the agricultural sector and local domestic consumption through water conservation and restoration projects (e.g., dredging rivers and canals, digging ponds). From 2003 – 2019, there have been 1,701 projects carried out in many provinces in the basin, by which about 178.3 million m^3 of water are abstracted (Table D1- 3).

Table D1- 3 Water conservation and restoration projects in the Mun River Basin

Province	**Number of projects**	**Cost (million baht)**	**Water quantity (million m^3)**
Nakhon Ratchasima	521	1,718.6	40.0
Buriram	290	1,422.6	29.9
Surin	375	2,009.0	42.6
Si Sa Ket	319	1,062.6	26.9
Ubon Ratchathani	86	424.1	18.7
Amnat Charoen	33	125.4	4.4
Yasothon	77	319.0	15.8
Total	**1,701**	**7,081.3**	**178.3**

Source: Water Resources Regional Office 5

2) Water distribution using solar energy for low-water agriculture projects. 58 projects have been conducted in 2017 covering 4 provinces: Nakhon Ratchasima, Buriram, Surin, and Si Sa Ket.

3) Mobile water pumping and distribution (by trucks) for domestic consumption and agriculture.

Moreover, the Water Crisis Prevention Center, which is established under the Department of Water Resources, has performed the following activities to mitigate water crisis problems:

- Execute a drought risk map using the Normalized Difference Water Index (NDWI), taking into account the effects of El Niño and historical droughts since 2016.
- Water balance analysis during the dry season at the district level, water monitoring and forecasting
- Discover additional water resources (e.g., Num Kut Talad Yao water resources conservation project in Phutthaisong District, Buriram).
- Water resources conservation and reservation and water distribution.
- Prepare and provide a budget, pumps, mobile pumps, and water distribution by trucks for domestic consumption during dry spells.
- The study analyzes, monitoring drought conditions in Thailand.
- A public announcement about water conditions and ask for cooperation from people to the economical use of water.
- Cooperate with other water-related agencies and departments to tackle water problems in Thailand.
- Nature-based solutions or Eco-based solutions, e.g., water treatment by aquatic plants.

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Appendix D-2 - Literature Review on Drought Adaptation Strategies and Measures

Literature Review

on

Drought Adaptation Strategies and Measures

of

"ENRICH: Enhancing Resilience to future Hydro-meteorological extremes in the Mun river basin in Northeast of Thailand."

29 October 2021

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D2-1 Introduction

Climate change can be identified by changes in the mean and/or the variability of its properties, and that persists typically for decades or longer. In recent decades, climate change has caused impacts on natural and human systems on all continents. And over the 21st century, climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions, intensifying competition for water among sectors (Iglesias & Garrote, 2015; IPCC, 2014).

Among the impacts of climate change on geophysical systems, including floods, droughts, and sea-level rise, drought is the most damaging environmental phenomena. It covers large areas; more than one-half of the terrestrial earth is susceptible to drought each year (Kogan, 1997). Not only in arid and drought-prone areas are facing droughts, but also in regions with abundant rainfall (Pereira, Cordery, & Iacovides, 2002). Consequently, productive lands worldwide can lose millions of tons of agricultural production annually.

Drought is a temporary natural hazard concerning persistent below-average rainfall. It can also be a man-affected phenomenon, i.e., over-farming, excessive irrigation, deforestation, overexploitation of available water etc. (Rossi, 2000; Tonini, 2013). As a result, it brings about: a reduction in water resources (surface and sub-surface) availability, a declining carrying capacity of ecosystems, degenerated water quality, crop failure, reducing crop yields, disturbed riparian habitats and suspended recreation activities. (Mishra & Singh, 2010; Pereira et al., 2002).

The occurrence of droughts is primarily under the influence of temperatures (minimum and maximum), high winds, low relative humidity, rain timing and characteristics, distribution of rainy days during crop growing periods, rain intensity and duration, and the outset and end of precipitation (Mishra & Singh, 2010). From 1950-2019, the number of drought events worldwide was relatively low, approximately 5% of total natural disasters. However, the number of deaths and affected people resulting from droughts ranked second place (after floods) at 2.2 million people (29%) and 2,712 million people (33%), respectively (Centre for Research on the Epidemiology of Disaster (CRED), 2020). The figures, therefore, emphasize the significance of this natural disaster and its detrimental impact.

Droughts are generally classified into four types: meteorological or climatological, hydrological, agricultural, and socio-economic drought (American Meteorological Society, 2013; quoted Mishra & Singh, 2010; quoted Wilhite, 1993; Wilhite & Glantz, 1985):

1. Meteorological or climatological drought is described as the rainfall deficiencies over a region for a period of time (the degree of dryness and the duration of dry period (Wilhite, 1993; Wilhite & Glantz, 1985). The analysis of meteorological drought has been commonly performed by using precipitation data (T. J. Chang, 1991; Eltahir, 1992; quoted Mishra & Singh, 2010; Pinkayan, 1966; M. A. Santos, 1983);
2. Agricultural drought is defined as a period with soil water deficiency resulting in crop failure without reference to surface water resources (Mishra & Singh, 2010). This drought links various characteristics of meteorological and hydrological droughts to agricultural impacts. It emphasizes rainfall deficiency, the difference between actual evapotranspiration and potential evapotranspiration, soil water deficit, and so forth (Wilhite, 1993). As a result, it affects both irrigated and dryland crop production, as well

as livestock industries that rely on non-irrigated pasture or surface run-off (American Meteorological Society, 2013);

3. Hydrological drought is referred to a period with inadequate surface and subsurface water supplies originating from precipitation shortfall. (T. J. Chang & Stenson, 1990; Clausen & Pearson, 1995; Frick, Bode, & Salas, 1990; quoted Mishra & Singh, 2010). The phenomena associated with and influences of hydrological drought are usually out of phase or lag those of meteorological drought but may precede those of agricultural drought (American Meteorological Society, 2013);
4. Socio-economic drought is caused by a shortage of water supply to fulfil a demand for economic goods (American Meteorological Society, 2013; Sandford, 1979). The need for those goods is increasing because of the growing population and per capita consumption, whereas the supply is weather dependent (Mishra & Singh, 2010; The National Drought Mitigation Center (NDMC), n.d.; Wilhite, 1993).

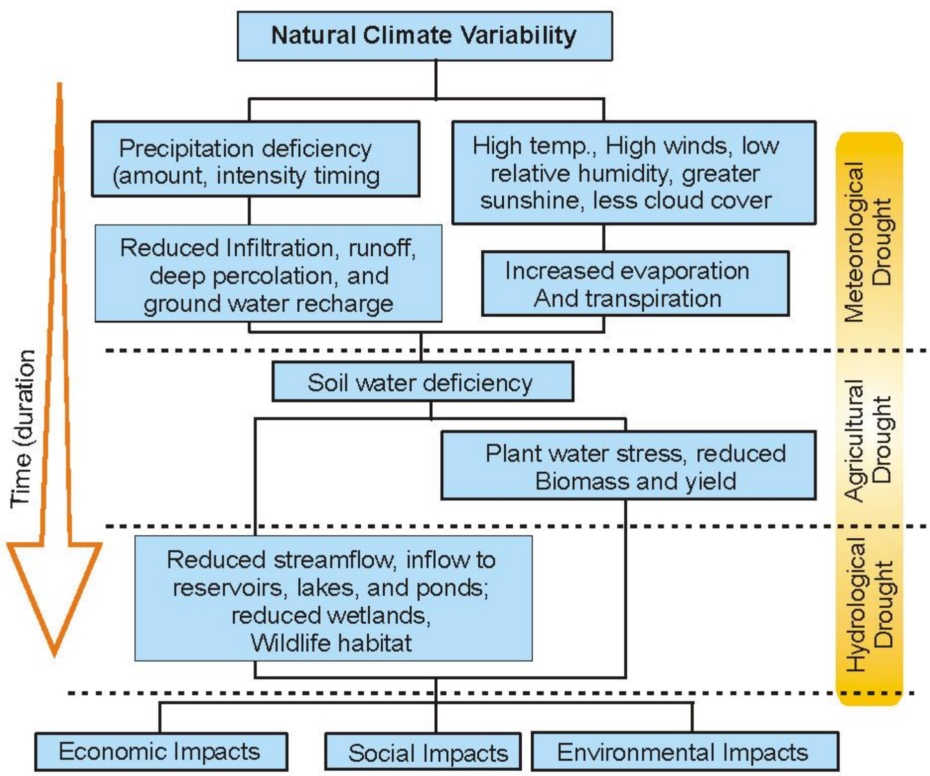


Figure D2- 1 The sequence of drought occurrences and impacts for commonly accepted drought types

Source: National Drought Mitigation Center, University of Nebraska-Lincoln, U.S.A., 2014

The first three categories of droughts are defined by physical, hydro-meteorological, or biological parameters. Whereas the last one deals with drought in terms of supply and demand, tracking the effects of water shortfall as it ripple through socio-economic systems (American

Meteorological Society, 2013; The National Drought Mitigation Center (NDMC), n.d.). Figure D2-1 portrays the chronology of drought occurrences and their associated effects.

D2-2 Drought in Thailand and study area

Thailand locates in an area with abundant precipitation with an average annual rainfall of about 1700 mm. However, seasonal droughts still occur regularly, causing widespread crop failure that can affect farmers' incomes, particularly the rural poor, constituting about 40% of the population (Pavelic et al., 2012). The numbers of affected people, provinces, agricultural areas and the total damage values impacted by historical droughts in Thailand are presented in Table D2- 1.

Table D2- 1 Number of affected provinces, casualties and damage from droughts in Thailand accounted between 1900 and 2014

Year	Number of affected provinces (province)	Number of affected (people)	Total affected cultivated areas (km^2)	Total damage (million US$)
1989	29	1,760,192	2,070.8	4.06
1990	48	2,107,100	3,153.1	3.07
1991	59	4,926,177	1,659.6	8.73
1992	70	8,100,916	8,535.2	5.86
1993	68	9,107,675	3,264.7	6.62
1994	66	8,763,014	2,868.5	3.29
1995	72	12,482,502	4,802.3	5.91
1996	61	10,967,930	163.0	9.63
1997	64	14,678,373	2,290.1	8.29
1998	72	6,510,111	2,862.9	2.30
1999	58	6,127,165	5,031.9	50.62
2000	59	10,561,526	756.3	21.36
2001	51	18,933,905	2,740.3	2.40
2002	68	12,841,110	3,314.5	16.94
2003	63	5,939,282	774.7	5.80
2004	64	8,388,728	2,368.3	6.35
2005	71	11,147,627	21,978.7	251.86
2006	61	11,862,358	926.0	16.49
2007	66	16,754,980	2,160.2	6.60
2008	61	15,298,895	840.0	3.46
2009	62	17,353,358	951.1	3.61
2010	64	15,740,824	2,747.0	47.11
2011	55	16,560,561	1,298.7	4.39
2012	53	15,235,830	2,378.4	13.29
2013	58	9,070,144	3,850.7	97.04
2014	49	9,066,185	6,835.7	605.06

Source: Department of Water Resources of Thailand (2016)

D2-3 Objectives

The objectives of this adaptation study are:

a) To review and analyze the existing literature regarding drought adaptation strategies and measures.

b) To recommend suitable adaptation strategies and measures for the study area.

D2-4 Review of literature

Adaptation is a process of deliberate adjustment in response to actual or expected climate and its effects by which strategies to mitigate and tackle the consequences of climatic events are developed and implemented (IPCC, 2014; Selvaraju & Baas, 2007; Stringer et al., 2009). Throughout history, a number of adaptation strategies and measures have been carried out, and they are evolving over time. In this section, those strategies and measures to mitigate drought impacts implemented worldwide and ones that carried out by the government and state authorities in Thailand are compiled as follows:

D2-4.1 Global studies

Based on extensive databases, adaptation measures and strategies across regions are reviewed and summarised in Table D2- 2.

Table D2- 2 Reviews of drought mitigation and adaptation measures and strategies

Strategies/ Measures	Description	Case study	References
Strategy -1: Policy planning and management			
Measure 1.1	Development of drought policy and planning (National, regional, provincial and local levels)	Australia, South Africa, Namibia, the United States, Kenya, Somalia, Uganda, Djibouti, Eritrea, Namibia, South Africa, India, Israel	UN/ISDR (2007) UNISDR (2009) Bogan (2014)
Measure 1.2	Improve water charging and trade	Kenya, Italy, India, Pakistan, Nepal, Morocco, Macedonia	UNISDR (2009) Pérez-Blanco, Standardi, Mysiak, Parrado, and Gutiérrez-Martín (2016) Cornish, Bosworth, Perry, and Burke (2004)
Measure 1.3	Set clear water use priorities, water allocation	Tajikistan, Arab countries, Italy	UNISDR (2009) Abou-Hadid (2009) Pérez-Blanco et al. (2016)
Strategy -2: Enhancing water supply and water efficiency			
Measure 2.1	Increase more surface water storages such as constructing reservoirs, farm ponds, re-excavation of canals and other conveyance structures, strengthening field bunds etc.	Buri Ram in North-eastern Thailand, Bangladesh, Vietnam, South Africa, Africa	van Steenbergen, Tuinhof, Knoop, and Kauffman (2011) Selvaraju and Baas (2007) UNISDR (2009) Eludoyin, Eludoyin, and Eslamian (2017)

Strategies/ Measures	Description	Case study	References
Measure 2.2	Implement the subsurface floodwater harvesting system (Manage aquifer Recharge: M.A.R.)	Australia, Southwest Iran, Lower Northern Thailand, India, and Uzbekistan	Charlesworth et al. (2002) Pavelic, Dillon, Barry, and Gerges (2006) Pavelic et al. (2006) Pavelic et al. (2012) Sharda, Kurothe, Sena, Pande, and Tiwari (2006) Karimov et al. (2013) Holländer, Mull, and Panda (2009) Glendenning, Van Ogtrop, Mishra, and Vervoort (2012)
Measure 2.3	Reservoir regulation and inter-basin and within-basin water transfers	China, the United States, Lancang-Mekong River Basin (China, Vietnam, Laos, Thailand, and Cambodia), Botswana, South Africa, India, South Korea	Wu et al. (2018) J. Chang et al. (2019) Wan et al. (2017) Yun et al. (2021) Stringer et al. (2009) Eludoyin et al. (2017) Kumar and Verma (2020) Choi, Ahn, Ji, Lee, and Yi (2020)
Measure 2.4	Conjunctive use of surface and groundwater (low-quality water)	Eastern Spain, Northern India, The upper Central Plain Thailand, India, Vietnam, the United States	Pulido-Velazquez, Garrote, Andreu, Martin-Carrasco, and Iglesias (2011) Kaledhonkar, Sharma, Tyagi, Kumar, and Van Der Zee (2012) Bejranonda, Koontanakulvong, Koch, and Suthidhummajit (2007) Kaledhonkar et al. (2012) UNISDR (2009)
Measure 2.5	Rainwater harvesting techniques	Malawi, Kenya, Vietnam, India, Jamaica, Rwanda, Sub-Saharan Africa, Turkey	Stringer et al. (2009) Ngigi, Savenije, and Gichuki (2007) UNISDR (2009) Mudatenguha, Anena, Kiptum, and Mashingaidze (2014) Critchley and Gowing (2012) Dile, Karlberg, Temesgen, and Rockström (2013) Kuzucu (2017)
Measure 2.6	Reduce evaporation rate from the reservoir by applying floating or suspended covers, thermal mixing, floating plants etc.	U.S.A., India, Australia, Southern Spain, South Africa, Singapore, Southern Algeria, Thailand, Saudi Arabia	Youssef and Khodzinskaya (2019) Yao, Zhang, Lemckert, Brook, and Schouten (2010)
Measure 2.7	Water conservation through ecosystem management practices of afforestation, reforestation, wetlands	Botswana, Kenya, Vietnam, Tajikistan, India, Niger, Arab countries	Stringer et al. (2009) UNISDR (2009) Abou-Hadid (2009)

Strategies/ Measures	Description	Case study	References
	conservation, agroforestry etc		
Strategy-3: Drought monitoring, forecasting, and warning system			
Measure 3.1	Development and improvement of drought monitoring, forecasting, and early warning system	Botswana, Swaziland, Eastern Africa, China, South Africa, Sudan, Eritrea, Ethiopia, Rwanda, Burundi, Somalia, Kenya, Uganda, Eritrea, Djibouti, Tanzania, Portugal, Australia, the United States, India, Mali, Tajikistan	Stringer et al. (2009) UN/ISDR (2007) UNISDR (2009)
Strategy-4: Institutional strengthening and capacity building			
Measure 4.1	Capacity building for drought risk reduction	Swaziland, Botswana, Kenya, Uganda, Djibouti, Eritrea, Vietnam, Tajikistan, India	Stringer et al. (2009) UNISDR (2009)
Measure 4.2	Building resilience through knowledge, research, innovative technologies, training etc.	Swaziland, Malawi, Southern Africa, Zimbabwe, the United States, Brazil, Southern Africa, Vietnam, Tajikistan, India, El Salvador	Stringer et al. (2009) UN/ISDR (2007) UNISDR (2009)
Strategy-5: Development of or introduction of innovative approaches			
Measure 5.1	Improved water reuse technologies for crop irrigation	Botswana, the United States, Israel	Stringer et al. (2009) UNISDR (2009) Bogan (2014)
Measure 5.2	Crop breeding to drought, disease, or salinity tolerance, high yielding, short-growth varieties.	China, Swaziland, Botswana, Malawi, Bangladesh, Vietnam, Tajikistan, Arab countries	Hu et al. (2017) YUAN (2015) Stringer et al. (2009) Selvaraju and Baas (2007) UNISDR (2009) Abou-Hadid (2009)
Measure 5.3	Innovative market-based solutions such as index-based weather insurance, crop insurance, microinsurance	Malawi, Kenya, Morocco, India	UNISDR (2009) Bogan (2014) Linnerooth-Bayer and Mechler (2015)
Strategy-6: Change or improve farm management practices			
Measure 6.1	Shift the beginning of the growing season	Surin in Thailand, Malawi, Bangladesh, Nigeria	Jaidee (2010) Stringer et al. (2009) Eludoyin et al. (2017)
Measure 6.2	Shift to short-duration varieties or less water consumptive crops	Swaziland, Botswana, Malawi, Bangladesh, Tajikistan	Stringer et al. (2009), Selvaraju and Baas (2007) UNISDR (2009)
Measure 6.3	Adopt new farm management practices such as rice-ratooning, Alternate wetting and drying (AWD).	Rice-ratooning – China, India, Japan, Swaziland, U.S.A., Colombia, Philippines, Indonesia, Ethiopia, Puerto Rico, Brazil, Taiwan and Thailand AWD – Philippines, Bangladesh, Vietnam, India,	A. Santos, Fageria, and Prabhu (2003) Faruq, Taha, and Prodhan (2014) W. Wang et al. (2020) Ishfaq et al. (2020)

Strategies/ Measures	Description	Case study	References
		China, Laos, Thailand, Myanmar, Indonesia, the United States, Iran, Uganda, Japan, Senegal, Vietnam, Australia, Nepal, Brazil, and Malawi	
Measure 6.4	Mix planting, intercropping, cropping patterns	Belgium, Swaziland, Malawi, Arab countries	Hicks, Rahman, Carnol, Verheyen, and Rousk (2018) Stringer et al. (2009) Abou-Hadid (2009)
Measure 6.5	Soil moisture management, mulching practices, vegetation	China, Vietnam, Swaziland, Nigeria	L. F. Wang, Chen, and Shangguan (2015) Zhang, Yang, and Lovdahl (2016) Stringer et al. (2009) Eludoyin et al. (2017)
Measure 6.6	Increase soil fertility by adding organic materials into soils, annual crop rotations practices, manures etc.	Swaziland, Malawi, Bangladesh, Vietnam, Tajikistan	Stringer et al. (2009) Selvaraju and Baas (2007) UNISDR (2009)
Measure 6.7	Sprinkler or drip irrigation	Nepal, Vietnam, China, Brazil, the United States,	UNISDR (2009) Adekoya, Liu, and Vered (2014) Brum et al. (2021) Schuck, Frasier, Webb, Ellingson, and Umberger (2005)

D2-4.2 Studies in Thailand

In Thailand, all water-related projects carried out by all government agencies are compiled as follows:

Office of the National Water Resources (ONWR)

The ONWR has formed optimal adaptation strategies and measures to tackle water problems, encompassing: domestic water uses, droughts, floods, water quality, forest rehabilitation, and operation & maintenance, in Thailand based on Strategic Environmental Assessment (S.E.A.), taking into consideration economic, social and environmental impacts. For the Mun River Basin, it was divided into 3 main areas consisting of 31 subbasins, namely, Upper Mun covering 11 subbasins, Middle Mun covering 9 subbasins, and Lower Mun covering 11 subbasins. Based on that, all relevant studies and analyses were executed, and alternative plans and solutions for water resources development in the basin for 20 years were developed. They could be categorized 4 major options, including:

1) No action/Baseline (until 2020)
2) Do as now – separate manner among all water agencies (between 2021-2037)

3) Integrated manner between all agencies (as a package)

4) Integrated manner and using local wisdom, innovation, and technology (for only important cases such as climate change), for example, smart irrigation system which has been applied in Korat, Nakhon Ratchasima)

The selection of a proper action will be carefully decided on a case-by-case basis as problems, criteria, limitations, etc., in each area are different. For example, at Ubon Ratchathani province (from Kaeng Sa Phue to the Mekong River), drought problems cannot be solved by making ponds because of shallow topsoil. At Thung Kula Ronghai in Roi Et and Maha Sarakham provinces, building ponds will make salts spread out because of salty soil here. Thus, it can be said that the solution is tailor-made measures and strategies.

For risk management, the ONWR also focus on flexibility in measures and strategies. The agency uses average rainfall for planning and designing permanent structures such as on-ground ponds, dikes, ridges. While, temporary infrastructure, for example, raising earth bunds in rice fields to create temporary ponds to collect additional rainwater during intense rainfall and it will be used during dry spells, will be provided in areas with high rainfall variations, i.e., 20-30%, 50%.

The agency adopts cropping patterns and zoning for diminishing and managing water uses in the agriculture sector for the demand side. An example of the former is to allow farmers to grow forest trees that were prohibited in the past. The latter is known as the “Khok Nong Na model”, already applied in many places in Thailand.

Moreover, recently, the ONWR just publicized Ministerial Regulation on Water User Organization, B.E. 2564 (2021) and encouraged people to form water user organizations.

Royal Irrigation Department (R.I.D.)

The Royal Irrigation Department anticipates the amount of water stored in reservoirs by comparing rainfall quantity nowadays with historical data. If the forecasted amount of water in reservoirs is tiny, the agency prioritizes water use amongst sectors, ranking from domestic consumption, agriculture, and industry. Then, the agency implements mitigation measures and strategies as follows:

1) Request farmers not to grow any crops during dry spells (less cooperation from farmers)
2) Request farmers to grow crops that require less water, such as maize (less cooperation from farmers)
3) Building ponds
4) Adopt new farm practices, e.g., alternate wetting and drying (AWD) water management for rice cultivation, which rarely applied in northeast Thailand.
5) Provide extra jobs to farmers such as digging or dredging canals etc.
6) Other assistance according to the government policy

Department of Water Resources (DWR)

To solve water shortage in some areas at a district level, the DWR developed the policy alignment for Thailand related to the Sustainable Development Goals (S.D.G.s). The national policy encompasses water management for consumption, water security for production sectors (agriculture and industry), flood management, water quality management, upstream forest rehabilitation and soil erosion prevention and administrative management. The master plan of DWR includes 3 pillars: restoration of water body and wetlands outside irrigation areas, structural measures to increase water distribution and allocation, and non-structural measures such as water crisis management to prevent and mitigate risk areas by installing real-time monitoring in 6,042 villages. The urgent plans for 2019-2020 focus on drinking water and agricultural water by installing drinking water stations, water distribution by trucks, and installing pumps to divert water. With real-time monitoring systems, about 1,773 stations (41%) were provided by the DWR, mainly located in rainfed areas in the northern and highland areas.

Moreover, the DWR has implemented a Solar-powered Irrigation System (S.I.S.) project in Nakhon Ratchasima province (upstream part of the Mun River Basin). The project covers an area of 64,000 m^2 and serves 25 households whose main crops are vegetables. This project can increase the annual income of each household by approximately 1,560 US$. The DWR hopes that this project will eliminate extreme poverty by 2030.

Department of Groundwater Resources (D.G.R.)

The Department of Groundwater Resources has a primary mission to assist people in the rainfed area. The Department of Groundwater Resources has developed groundwater resources projects for domestic consumption, agriculture and industry, including

1) The remote groundwater transmission project is for domestic water uses.
2) Aquifer Storage and Recovery (A.S.R.) in the Mun and Chi River Basins – the project attempts to solve flood and drought problems in the basins by collecting floodwater underground and use it during dry spells. The description of the project at year is presented in Table D2- 3.

Table D2- 3 Details of Aquifer Storage and Recovery (A.S.R.) in the Mun and Chi River Basins (December 15 2006)

Main activity	Achievement
Study and design an A.S.R. system	
Pumping test for aquifers	100 wells
Partial Analysis	600 examples
Selection of study areas suitable for groundwater recharge	10 places
Construction stations for groundwater observation and study of a conjunction use of groundwater and surface water	
Drill observation pits	45 stations
Electrical well log	120 wells
Pumping test for 72 hours	10 wells
Pumping test for 12 hours	100 wells
Survey groundwater wells	65 wells
Resistivity	170 points
Final report	Completed
Detail groundwater potential investigation	
Drill survey/production wells	53 wells in 45 stations

Main activity	Achievement
Electrical well log	120 wells
Groundwater level measurement and water sampling	431 wells
Pumping test for 72 hours	30 wells
Pumping test for 12 hours	110 wells
Groundwater modelling	In progress (Data import into the model)
Final report	Completed

Source: Bureau of Groundwater Exploration and Potential Assessment, 2009

3) Water wells for agriculture, from 2013, about 8,000 wells were accomplished. The estimated volume of water supply is approximately 316 million m^3 benefiting about 35,789 households.

4) A smart groundwater management project for large agriculture integrates solar power for water pumping and distribution (Figure D2- 2). It is a new ongoing project, starting in Karat in Nakhon Ratchasima and Ubon Ratchathani provinces. Now, the project has been implemented in 6 provinces in all regions, except the southern part. To be sustainable, the D.G.R. asked for cooperation from farmers to be part of the project, particularly in operation and maintenance activities. The project is targeted to be implemented in all districts (1 large-scale groundwater project per 1 district) in Thailand.

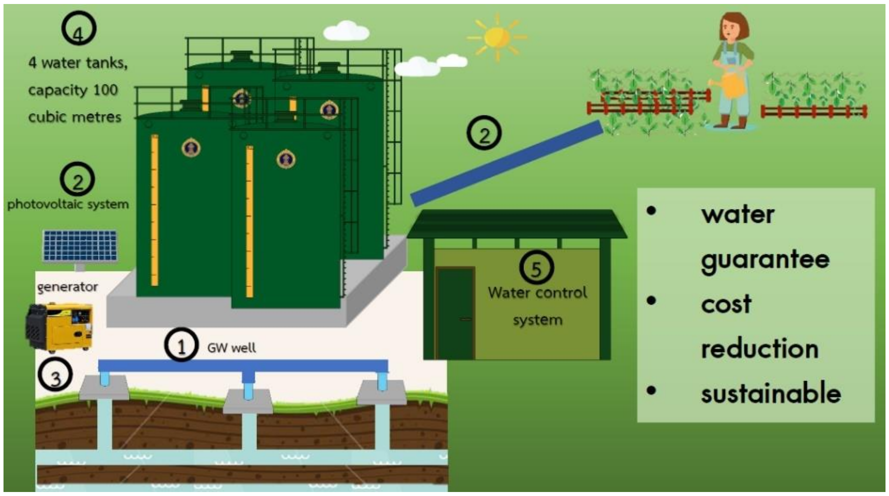


Figure D2- 2 The D.G.R. smart groundwater management project for agriculture

Land Development Department (L.D.D.)

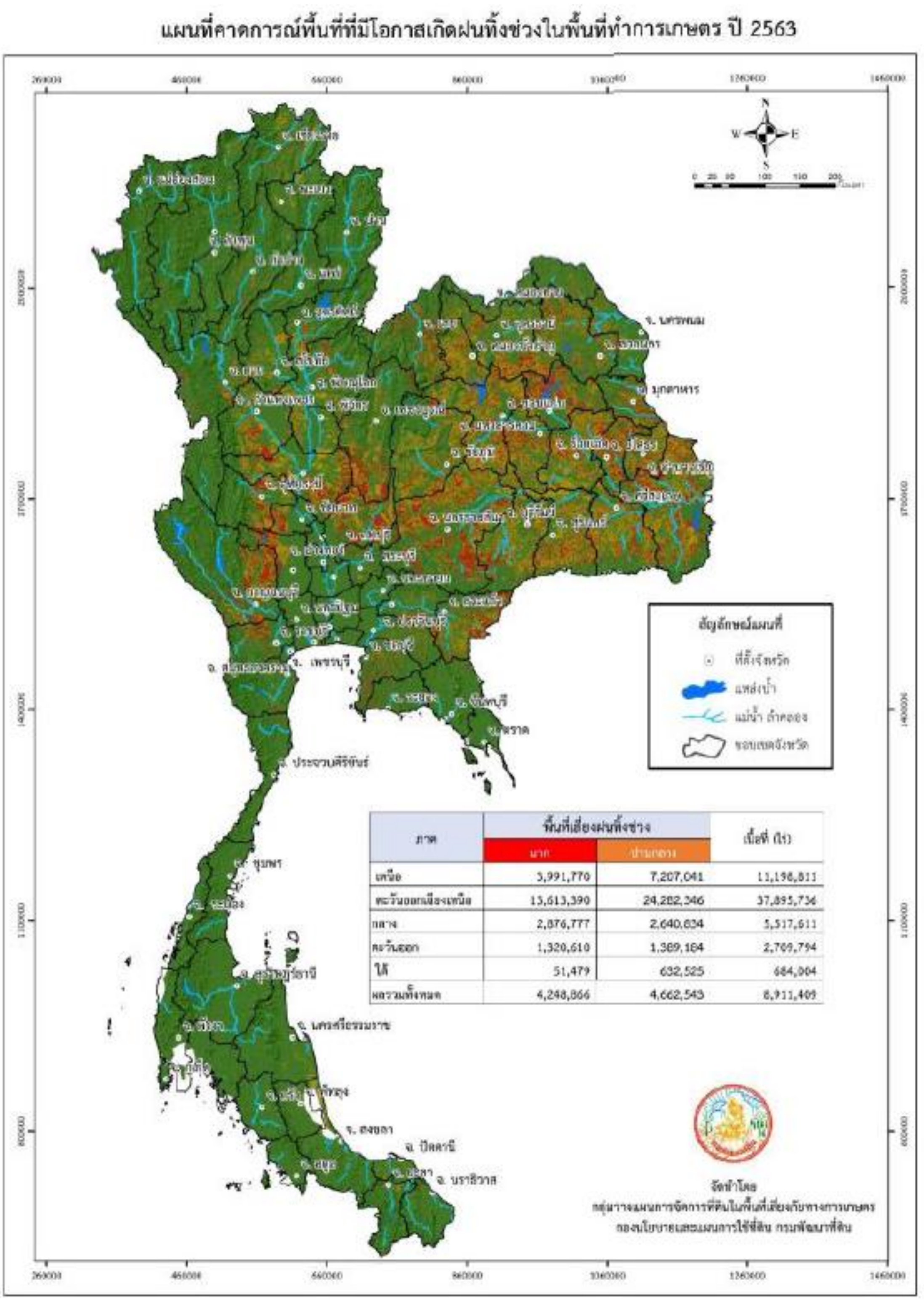
The L.D.D. assessed agricultural droughts in Thailand by considering three main factors: climate change, water retention, and human activity. Climate change was represented by topography and weather data, while soil data represented water retention, and lastly, human activity was represented by land-use data. All data were prepared in a geospatial data format (shapefile format) and then were overlaid in ArcGIS to obtain the final result of agricultural drought (Figure D2- 3). To recheck the consequence, the L.D.D. performed community participation with farmers in the study area.

The L.D.D. has implemented 4 principles to mitigate drought effects as follows:

- Information and technology promotion - accessible mobile applications concerning soils and plants;
- Increase water-use efficiency – Zoning areas by using Agri-Map web application (entails all relevant information for agriculture, i.e., as soil types and their suitability, crops etc.);
- Increase water supply – Building farm ponds;
- Recovery agricultural drought impact areas.

The L.D.D. has carried out 5 ways for agricultural drought preparedness:

- Drought monitoring and will inform people through a website and a Facebook page;
- Soil analysis for selection of suitable plants by using L.D.D. mobile applications;
- Avoid high water-consuming crops by L.D.D. mobile applications;
- Increase water supply by the mean of farm ponds.
- Decrease evapotranspiration by a mulching method.



ภาค	พื้นที่เสี่ยงฝนทิ้งช่วง		เนื้อที่ (ไร่)
	มาก	ปานกลาง	
เหนือ	3,991,770	7,207,041	11,198,811
ตะวันออกเฉียงเหนือ	13,613,390	24,282,346	37,895,736
กลาง	2,876,777	2,640,834	5,517,611
ตะวันออก	1,320,610	1,389,184	2,709,794
ใต้	51,479	632,525	684,004
ผลรวมทั้งหมด	4,248,866	4,662,543	8,911,409

Figure D2- 3 Forecasted agricultural drought map of 2020 by the L.D.D.

Department of Agriculture (D.O.A.)

The Ministry of Agriculture and Cooperatives (MOAC) enhance the drought resilience of small-holder farming communities in Thailand through H.M. the King sufficiency economy and New Theory in Agriculture. Examples of some Royal initiative projects associated with soil, water management and crop cultivation include Khao Cha-ngum Deteriorated Soil Rehabilitation Study Project, Huai Hong Khai Royal Development study Centre, Khao Hin Sorn Royal Development Study Center, Kung Krabaen Bay Royal Development Study Center etc. Each project had different problems, which were successfully solved by various measures. For instance, planting vetiver grass for soil degradation and erosion; forest rehabilitation based on the principle of a natural cycle which is simple and cost-saving; development of watershed areas; construction of check dams; promote animal husbandries such as swine and poultry farming, and integrated fish raising; renovating existing reservoirs and water irrigation systems; upgrading infrastructure and developing delivery system. Examples of measures for crop cultivation include growing organic vegetables in nurseries to use less water during drought periods, cultivating crops in controlled nurseries rather than open fields, use of "water drip" irrigation, and soil nourishment training. The knowledge from these examples is valuable that can enhance communities' resilience to droughts.

The New Theory in agriculture was developed to be a concrete example of applying the Philosophy of Sufficiency Economic to the agricultural sector. It is associated with water resource development and conservation, soil rehabilitation and conservation, sustainable agriculture and self-reliant community development. Begin with optimizing farmland (Phase I), a farmer's land is divided into 4 proportions: 30% ponds to store rainwater; 30% rice cultivation; 30% growing fruits and perennial tree, trees, vegetables, field crops and herbs for daily consumption; and 10% accommodation, animal husbandry, roads and other structures (Figure D2- 4). Then, Phase II is about communal agriculture (forming groups or cooperatives to carry out farming activities). And, it is related to production, marketing, living conditions, welfare (public health), foundations (schools, scholarships), society and religion. They must receive cooperation from all relevant stakeholders, whether government, private sector, or community members. Phase III involves loan and credit outreach that obtains funds from banks or private companies; investment; providing market outlets for farmers; banks or private companies buy farmers' products; formation of cooperatives to sell consumer products at a lower cost etc.

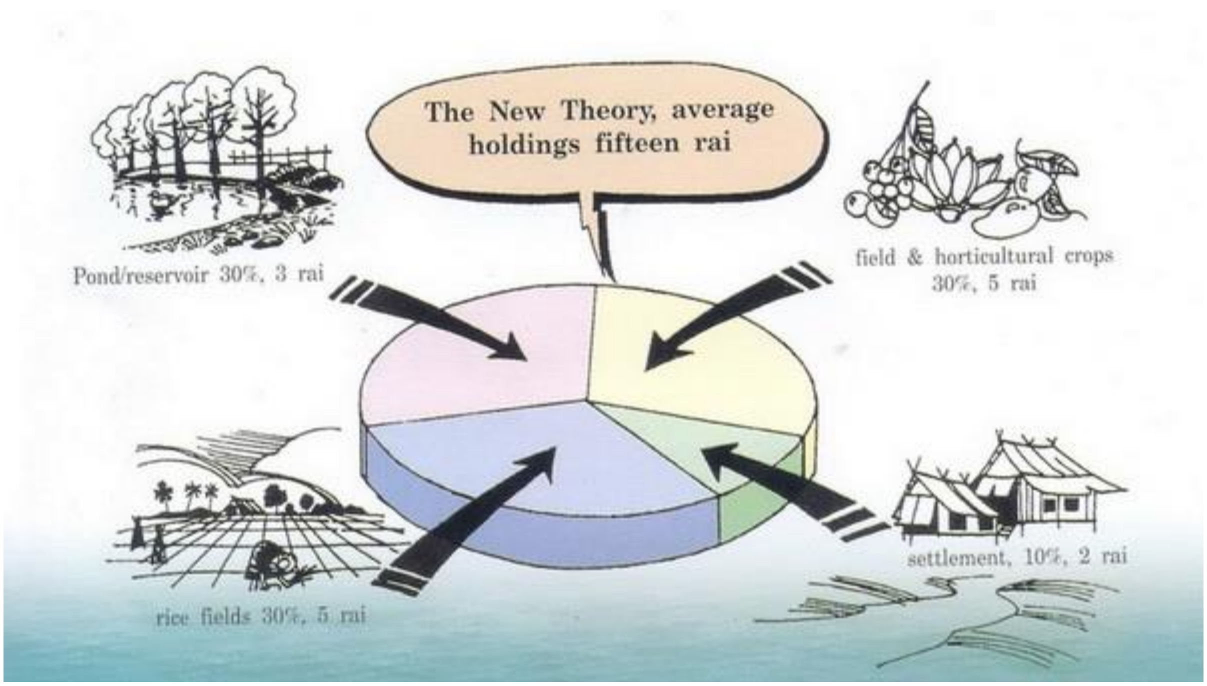


Figure D2- 4 The New Theory: Integrate and Sustainable Agricultural System.

Source: https://www.chaipat.or.th/eng/concepts-theories/sufficiency-economy-new-theory.html

In conclusion, the New Theory principles and methods is a production system based on the Sufficiency Economy in which members of a community unite and cooperate in helping one another. Consequently, there will have enough rice for year-round consumption and sufficient reserve of water for a dry season or during drought spells. According to H.M., the King's calculation to cultivate 1 rai (1,600 m^2.) of land requires about 1,000 m^3 of water. Therefore, for growing 5 rais of rice and 5 rais of field crops or fruit trees (a total of 10 rais there must be 10,000 cubic meters of water per year. Further, to the next level – the ideal New Theory system, large reservoirs fill the small reservoir, and small reservoirs fill ponds to ensure water availability.

Department of Agricultural Extension (DOAE)

The DOAE has implemented 8 drought mitigation measures as following (provided by a representative from D.O.A.):

1) Saltwater invasion surveillance in horticultural areas – in 9 provinces in Nakornpathom, Samutsakorn, Bangkok, Nontaburi, Pathumthani, Samutprakarn, Samutsongram, Ratchaburi, Chachoengsao;
2) Public relation campaigns for the farmers to join hands during droughts;
3) Integration of activities and cooperation in water scarcity areas outside the irrigation zones to promote income generation for the farmers;
4) Promote multiple cropping practices during the dry season;
5) Promote cultivation of less water use cash crops to generate income for farmers;
6) Promote planting of field corns as feed to livestock after the main crop;

7) Knowledge transfer and demonstration in the learning centre areas to increase the efficiency of agricultural production;

8) Mobile Agricultural Clinics.

D2-5 Synthesis of adaption strategies and measures

D2-5.1 Analysis of literature

All reviewed drought adaptation measures and strategies can be categorized into 3 levels, namely regional, basin, and farm levels, as follows:

Table D2- 4 Reviewed drought adaptation strategies and measures.

Level	Strategy	Measure
Regional	Policy planning and management	1. Development of drought policy and planning (National, regional, provincial and local levels)
		2. Improve water charging and trade
		3. Set clear water use priorities, water allocation
	Enhancing water supply and water efficiency	1. Reservoir regulation and inter-basin and within-basin water transfers
	Drought monitoring, forecasting, and warning system	1. Development and improvement of drought monitoring, forecasting, and early warning system
	Institutional strengthening and capacity building	1. Capacity building for drought risk reduction
		2. Building resilience through knowledge, research, innovative technologies, training etc.
	Development of or introduction of innovative approaches	1. Improved water reuse technologies for crop irrigation
		2. Crop breeding to drought, disease, or salinity tolerance, high yielding, short-growth varieties.
		3. Innovative market-based solutions such as index-based weather insurance, crop insurance, microinsurance
Basin	Enhancing water supply and water efficiency	1. Increase more surface water storages such as constructing reservoirs, farm ponds, re-excavation of canals and other conveyance structures, strengthening field bunds etc.
		2. Reduce evaporation rate from the reservoir by applying floating or suspended covers, thermal mixing, floating plants etc.
		3. Implement the subsurface floodwater harvesting system (Manage aquifer Recharge: M.A.R.)
		4. Water conservation through ecosystem management practices of afforestation, reforestation, wetlands conservation, agroforestry etc
Farm	Enhancing water supply and water efficiency	1. Increase more surface water storages such as constructing reservoirs, farm ponds, re-excavation of canals and other conveyance structures, strengthening field bunds etc.

Level	Strategy	Measure
		2. Conjunctive use of surface and groundwater (low-quality water)
		3. Rainwater harvesting techniques
	Change or improve farm management practices	1. Shift the beginning of the growing season
		2. Shift to short-duration varieties or less water consumptive crops
		3. Adopt new farm management practices such as rice-ratooning, Alternate wetting and drying (AWD).
		4. Mix planting, intercropping, cropping patterns
		5. Soil moisture management, mulching practices, vegetation
		6. Increase soil fertility by adding organic materials into soils, annual crop rotations practices, manures etc.
		7. Sprinkler or drip irrigation

D2-5.2 Assessment Framework on Adaptation Measures at Farm Level on Agricultural Production under Future Climate and Land Use in Upper Mun River Basin

The detail of the assessment framework on adaptation measures is described in the final report of WP4 in section 5.5. Below are the topics of adaptation measures considered at farm level.

- Water management practice by shifting from rainfed to irrigated cropping system

- Nutrient management, i.e., changing the rate of Nitrogen application on crop yields

-Integrated water and nutrient management practices

-Shifting planting date and its effect on crop yields

-Changing rice cultivar to facilitate shifting planting date.

D2-5.3 Field Survey of adaptation measures and strategies for drought mitigation in the Upper Mun River Basin

The field survey of existing drought adaptation measures and strategies implemented in the Upper Mun River Basin are conducted to identify potential measures and their capacities. The target areas (hotspots) are selected based on the hazard and vulnerability maps. The vulnerability map consists of 2 primary components, namely physical and socio-economic susceptibility and adaptation capacity. The susceptibility is therefore selected as other criteria because it represents inherent characteristics of the areas. The two hotspots are:

1) Dan Khun Thot - high hazard, very high susceptibility and very low vulnerability.
2) Phlapphla Chai – very high hazard, high susceptibility and very high vulnerability.

The study uses a questionnaire survey to gather data from individual people in the two hotspots to determine currently adopted adaptation measures in that area. The questionnaire consists of two parts: general information of respondents and adaptation measures that have been executed during droughts, including their coping capacities.

The results from 122 respondents in 2 districts, 60 respondents from Dan Khun Thot and 62 respondents from Phlapphla Chai, are analyzed and presented in Figure D2- 5 & Table D2- 5.

In Dan Khun Thot, 51.7% males and 48.3% females and about 60% are of working age. Almost all of them are farmers, who are more affected by drought. Approximately 65% are indigenous, who know how to cope with droughts. However, a majority of them have a relatively low education level, 68.3% at the elementary level, below the current Thai national compulsory education of 9 years (Office of the Education Council, 2014). The number of families is not significant, and on average, there are 4-6 people in a family, of which 1-3 people are of working age. About 80% own their farms with an area of 5-10 rai. Rice, cassava, maize, sugarcane, and vegetable are typical crops here.

Table D2- 5 General information of respondents

Information	Dan Khun Thot (people)	(%)	Phlapphla Chai (people)	(%)
Gender				
- Male	31	51.7	26	41.9
- Female	29	48.3	36	58.1
Age (year)				
- 15-22	0	0.0	0	0.0
- 23-35	2	3.3	4	6.5
- 36-50	11	18.3	9	14.5
- 51-59	22	36.7	20	32.3
- Above 60	25	41.7	29	46.8
Occupation				
- Farmer	59	98.3	56	90.3
- Government official	0	0.0	0	0.0
- Private job holder	0	0.0	1	1.6
- Employees	0	0.0	1	1.6
- Freelancer	1	1.7	3	4.8
- Other	0	0.0	1	1.6
Education Level				
- Less than elementary	2	3.3	4	6.5
- Elementary	41	68.3	43	69.4
- High school	16	26.7	10	16.1
- Bachelor's degree	0	0.0	1	1.6
- Graduate degree	1	1.7	0	0.0
- Other	0	0.0	4	6.5

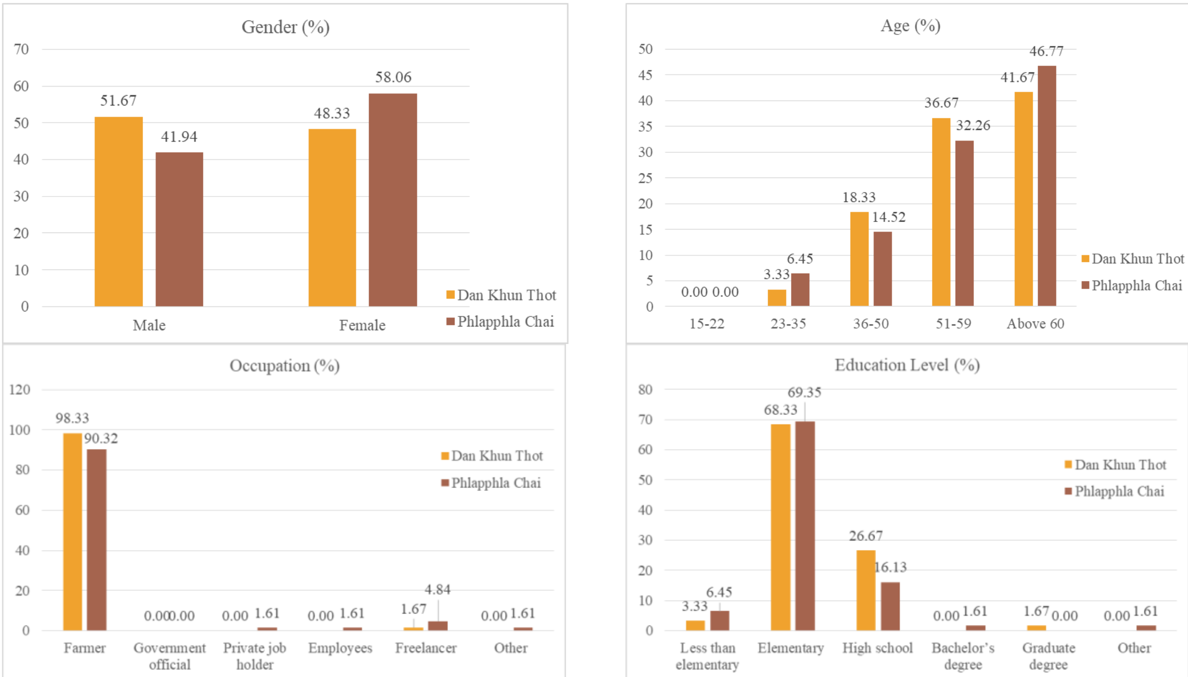


Figure D2- 5 General information of respondents

Similarly, in Phlapphla Chai, 41.9% males and 58.1% females, and about 53% are of working age. A vast majority of them are farmers, and about 58.1% is indigenous, who know how to cope with droughts. Their education levels are relatively low, 69.4% at the elementary level, below the current Thai national compulsory education of 9 years (Office of the Education Council, 2014). The number of people per family and working people are the same as in Dan Khun Thot. About 77.4% own their farms with an area of 5-10 rai. Rice and sugarcane are typical crops here.

For the adaptation measures section, people in Dan Khun Thot have implemented a more variety of measures to tackle droughts than those in Phlapphla Chai (Figure D2- 6 & Figure D2- 7). From the percentages, it is clear that people in Dan Khun Thot are more vigorous and knowledgeable in drought adaptation measures than those in Phlapphla Chai. This could be a reason for low vulnerability in Dan Khun Thot, although the hazard and susceptibility are high and very high, respectively.

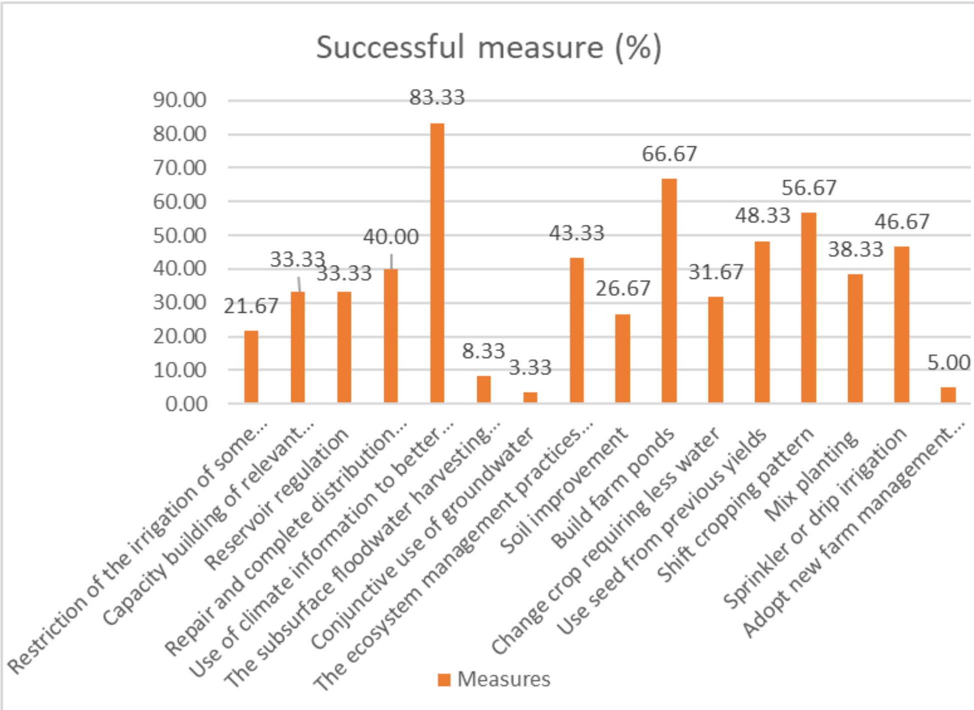


Figure D2- 6 Productive measure of Dan Khun Thot

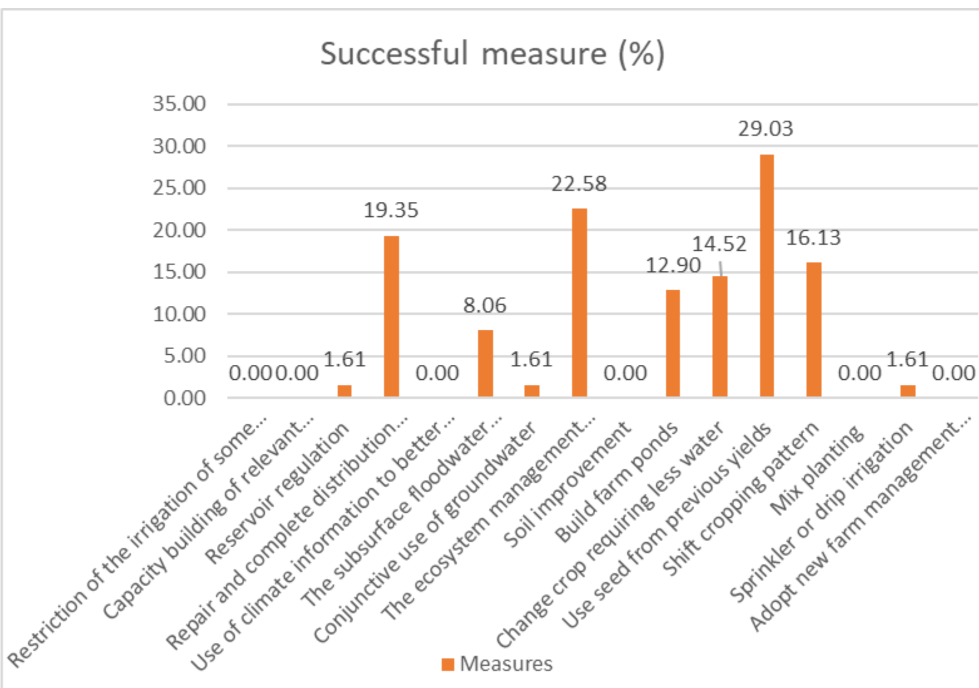


Figure D2- 7 Productive measure of Phlapphla Chai

Table D2- 6 presents the top 5 effective adaptation measures for mitigating drought in Dan Khun Thot and Phlapphla Chai. Shift cropping pattern and Use seed from previous yields are adopted in both districts.

Table D2- 6 Top 5 effective drought adaptation measures in Dan Khun Thot and Phlapphla Chai

No.	Dan Khun Thot	Phlapphla Chai
1	Use of climate information to better manage agriculture in drought-prone regions	Use seed from previous yields
2	Build farm ponds	The ecosystem management practices
3	Shift cropping pattern	Repair and complete distribution system of existing irrigation projects.
4	Use seed from previous yields	Shift cropping pattern
5	Sprinkler or drip irrigation	Change crop requiring less water

D2-6 Recommended adaptation strategies and measures for the study area

Overall, we recommend adopting the potential adaptation strategies and measures to mitigate droughts impacts in the Upper Mun River Basin as described below:

Table D2- 7 Recommended drought adaptation strategies and measures in the Upper Mun River Basin

<table>
<tr><th>S.N.</th><th>Strategies/
Measures</th><th>Description</th><th>Examples
(If any)</th><th>References</th></tr>
<tr><td rowspan="4">1</td><td colspan="4">Strategy -1: Enhancing water supply and water efficiency</td></tr>
<tr><td>Measure 1.1</td><td>Farm ponds</td><td rowspan="2">Buri Ram in North-eastern Thailand, Bangladesh, Vietnam, South Africa, Africa</td><td rowspan="2">van Steenbergen, Tuinhof, Knoop, and Kauffman (2011)
Selvaraju and Baas (2007)
UNISDR (2009)
Eludoyin, Eludoyin, and Eslamian (2017)</td></tr>
<tr><td>Measure 1.2</td><td>Repair and complete distribution system of existing irrigation projects.</td></tr>
<tr><td></td><td>Implement the subsurface floodwater harvesting system (Manage aquifer Recharge: M.A.R.)</td><td>Australia, Southwest Iran, Lower Northern Thailand, India, and Uzbekistan</td><td>Charlesworth et al. (2002)
Pavelic, Dillon, Barry, and Gerges (2006)
Pavelic et al. (2006)
Pavelic et al. (2012)
Sharda, Kurothe, Sena, Pande, and Tiwari (2006)
Karimov et al. (2013)
Holländer, Mull, and Panda (2009)
Glendenning, Van Ogtrop, Mishra, and Vervoort (2012)</td></tr>
<tr><td rowspan="3">2</td><td colspan="4">Strategy-2: Change or improve farm management practices</td></tr>
<tr><td>Measure 2.1</td><td>Shift the beginning of the growing season</td><td>Surin in Thailand, Malawi, Bangladesh, Nigeria</td><td>Jaidee (2010)
Stringer et al. (2009)
Eludoyin et al. (2017)</td></tr>
<tr><td>Measure 2.2</td><td>Shift to short-duration varieties or less water consumptive crops</td><td>Swaziland, Botswana, Malawi, Bangladesh, Tajikistan</td><td>Stringer et al. (2009),
Selvaraju and Baas (2007)
UNISDR (2009)</td></tr>
</table>

The explanations of each measure are detailed as follows:

D2-6.1 Shifting the beginning of the rice-growing season

In 2009, Surin Rice Research Center in Surin province conducted on-farm research on KDML105 jasmine rice yields at different growing periods by changing the beginnings of the growing seasons monthly from May 12 to October 12 (Figure D2- 8 and Table D2- 8). As a result, the growing season between July 12 – November 12 (Jaidee, 2010) yielded the highest cost reduction due to short growth duration (124 days). The harvest date (November 12) came earlier than November 25 and November 20 documented by the Bureau of Rice Research and Development (BRRD) (n.d.) and Chanoknumchai (n.d.) from the Department of Agricultural Extension, respectively. Moreover, the new harvest date in early November coincides with the harvesting date in many rice fields in the Northeast region that is recently observed.

Figure D2- 8 Examples of experimental plots of KDML105 rice in Surin Rice Research Center. (Source: Jaidee (2010))

Table D2- 8 Results of KDML105 yields at different growing periods.

No	Beginning	Flowering	Harvesting	Growing Period (day)	Height (cm)	Good grain/ Undeveloped kernels	Number of rice spike/ 1 m^2	Length of rice spike (cm)	Weight of 100 grains (g)	Yield at 14% moisture content (kg/rai)	Yield Difference
1	12 May 09	1 Oct. 09	9 Nov. 09	182	161.16	86.1/14.95	183.7	22.17	2.80	476.4	80.44%
2	12 Jun 09	16 Oct. 09	11 Nov. 09	153	146.88	83.5/18.01	228	22.07	2.93	485.8	82.03%
3	12 Jul 09	24 Oct. 09	12 Nov. 09	124	141.78	70.25/6.2	196.8	20.12	2.90	592.2	100.00%
4	12 Aug 09	4 Nov. 09	27 Nov. 09	108	117.11	75.2/15.1	203.8	22.44	2.82	488.2	82.53%
5	12 Sep 09	15 Nov. 09	9 Dec. 09	89	105.19	71.8/33.9	189.5	22.67	2.59	337.6	57.01%
6	12 Oct 09	5 Dec. 09	6 Jan. 10	87	80.96	35.05/25.7	344.3	18.08	2.45	249.0	42.04%

Source: Jaidee (2010)

D2-6.2. Change to less water consumptive crops

While rice, cassava, maize, and sugarcane are the four main crops typically found in the Upper Mun River Basin, other alternative crops are also seen. For example, soybean in Si Sa Ket and Khon Kaen; tomato in Amnat Charoen, Ubon Ratchathani, Si Sa Ket, Buri Ram, Roi Et, Khon Kaen, and Nakhon Ratchasima; shallot in Yasothon, Ubon Ratchathani, Si Sa Ket, Surin, and Buri Ram; and garlic in Si Sa Ket and Nakhon Ratchasima (Office of Agricultural Economics, n.d.). These crops differ in total growing periods and crop water requirement as tabulated in Table D2-9. Generally, the alternative crops require less water to grow and mature than the major crops, except for sweet corn, which has the shortest growth duration.

Table D2- 9 Total growing periods and crop water needs for selected crops in Northeast Thailand

No.	Name	Total growing period (day)	Total water use		
			mm	m^3/rai	m^3/ha
1	Rice (RD)	100	733	1,172	7,325
2	Rice (KDML105)	100	658	1,053	6,581
3	Cassava*	210	796	1,274	7,963
4	Sugarcane	300	1,035	1,656	10,350
5	Maize	100	372	594	3,713
6	Sweet corn	75	290	464	2,900
7	Soybean	100	395	632	3,950
8	Tomato	110	524	838	5,238
9	Shallot	85	322	515	3,219
10	Garlic	110	285	456	2,850

Source: Smart Water Operation Center (SWOC) (2020), *Nakhon Sawan Field Crops Research Center (2016)

The levels of soil suitability for the major crops and alternative crops in the northeast region are presented in Table D2- 10. At the moderate level, sandy loam and loamy sand are commonly used for cultivation. Sandy loam is a soil material that contains 20% or less clay, 52% or more of sand, and the percentage of silt plus twice the percentage of clay exceeds 30%. And the second definition of sandy loam is a soil material of less than 7% of clay, less than 50% of silt, and sand is between 43-52%. While, loamy sand has two limits, an upper and a lower. Upper limit loamy sand has 85-90% of sand. The percentage of silt plus 1.5 times the percentage of clay will never be less than 15. At its lower limit, loamy sand will not contain less than 70-85% sand, and the percentage of silt plus twice the percentage of clay will not exceed 30% (University of Michigan, 2003). In conclusion, sandy loam contains less sand but more clay and silt compared to loamy sand. Nevertheless, the soil textures of these two soil types are somewhat similar, and they can therefore be a substitute for each other for growing the crops in this area.

Table D2- 10 Soil suitability levels for selected crops in Northeast Thailand

No.	Name	Soil suitability level				
		Very Good	Good	Moderate	Poor	Unsuitable
1	Rice		silt loam, loam, sandy clay loam	loamy sand, sandy loam	sand, silt	
2	Cassava			Sand, loamy sand		
3	Sugarcane			sand – loamy sand		
4	Corn			sandy loam	sand, loamy sand	
5	Soybean			sandy loam	sand, loamy sand	
6	Tomato*	Clay loam, sandy loam				
7	Shallot*	Loam, well-drained				
8	Garlic*	Loam, well-drained				

Source: Soil Resources Survey and Research Division (2000), *Department of Agriculture Extension (2013)

The timely information for proper growing durations of some selected crops in Northeast Thailand is illustrated in

D2-6. Some crops' growing seasons start at the beginning of the rainy season, for example, rice, sweet corn, soybean, and shallot. While the three main field crops, i.e., cassava, sugarcane and maize, begin just a few months before the onset of rainfall, they last almost a whole year, except maize. Other minor crops such as sweet corn, soybean and shallot can be grown 2-3 times a year, starting in rainy or dry seasons. In contrast, tomato and garlic need to begin in the winter months.

Table D2- 11 Crop calendars for selected crops in Northeast Thailand

No	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Rice												
2	Cassava[1]		Start			Start					Start		
3	Sugarcane[2]			Start							Start		
4	Maize[3]												
5	Sweet corn[4]												
6	Soybean[5]												
7	Tomato[6]												
8	Shallot[7]												
9	Garlic[7]												

Remark: Green = 1st Planting, light blue = 2nd Planting, and pink = 3rd Planting.

Source: [1] joothangka (2008)

[2] Mitr Phol ModernFarm (2020)

[3] Nakhon Ratchasima Provincial Agriculture and Cooperatives Office (2018)

[4] National Farmers Council (2018)

[5] Ittipong and Sopha (n.d.)

[6] Sitathani (2002)

[7] Department of Agriculture Extension (2013)

Thus, in years of water scarcity, some crops such as maize, sweet corn, soybean, shallot, etc., can be grown instead of the key crops that consume more water or need water for a longer period. Besides, soybean, tomato, shallot, and garlic could be promoted to be a second crop after in-season rice in place of upland rice or off-season rice due to less water consumption. However, a detailed study regarding this issue is necessary because many other factors, e.g., farmers' knowledge, price, and market, are involved in introducing new crop farming.

D2-6.3. Farm pond

At the Mun River Basin, precipitation is the primary source of agriculture. If the rainwater is efficiently caught and stored, there would have been enough for the wet-season rice. If there is surplus water, farmers can gain additional benefits from other second crops such as soybeans, watermelons, and vegetables suitable to the season, requiring less water than dry-season rice.

According to the 'New theory' agriculture developed by King Bhumibol Adulyadej of Thailand, after the large-, medium-, and small- reservoirs, distribution canals, and systems were constructed, villagers should build small farm ponds and connect to the constructed reservoirs to be able to efficiently manage the water and their farmland (The Chaipattana Foundation, n.d.). The pilot project was carried out at Ban Limthong, a village with 108 households in Buri Ram province in the Mun River Basin, where floods and droughts periodically occur. The results reveal that by adopting the 'New theory,' the flood and drought problems that plagued the community for decades are solved, and it also created a stable buffer for the village (van Steenbergen et al., 2011).

Farmers themselves are the key driver for farm pond development. However, due to their low income, they still need financial support, i.e., funding loans or subsidies from the government, foundations, or private sectors, to carry out relevant activities. Also, cooperation with local government agencies to construct irrigation canal systems, data support and consulting (van Steenbergen et al., 2011).

Figure D2- 9 Individual farm ponds

D2-6.4 Manage aquifer Recharge: MAR

The M.A.R. concept is to harvest surplus surface run-off during the wet season to recharge subsurface storage or groundwater depletion. The water is recovered as groundwater for agricultural uses during the dry season. For decades, various M.A.R. types have been carried out in many countries (Dillon, 2005), as tabulated in Table D2- 12. The pilot trial was conducted in the Lower Yom River Sub-basin of the Chao Phraya River Basin in Thailand. The findings reveal that the M.A.R. reduced the magnitude of flooding in the wet season. Besides, the captured groundwater used for irrigated rice during the dry season could generate approximately USD 250 M/year in farm earnings (Pavelic et al., 2012).

This approach can be adopted to mitigate a drought problem in the Mun River Basin. However, some parts of the basin, especially the Mun River upstream and the tributaries in the upper part of the basin, have salinity problem. It is not worth the investment to conduct the M.A.R. because of no recovery benefit for productive use in these areas. Consequently, the M.A.R. should be implemented at the tributaries upstream at the lower and the eastern parts of the basin, where fewer or no salinity hazards is observed or affected. Thus, a detailed study of the M.A.R.'s implementation in the Mun River Basin is of necessity.

The whole system establishment, operation, and maintenance cost are too high for the farmers alone. The local government agencies' support is necessary in terms of budget availability and technical and administrative work. The farmers also play an essential role in the ongoing operational performance and maintenance of the M.A.R. Financial or incentives maybe need to soliciting their contribution and continuing participation (Pavelic et al., 2012).

The Department of Groundwater Resources (D.G.R.) has adopted the concept of M.A.R. and adapted it as Aquifer Storage and Recovery (A.S.R.) in the Mun and Chi River Basins since 2006.

Table D2- 12 Description of M.A.R. implementation in some case studies.

Parameter	Case studies						
	1	2	3	4	5	6	7
Region	Northern Australia	Southern Australia	Southwest Iran	Lower Northern Thailand	Western India	Uzbekistan	Eastern India
Recharge water type	River water	Stormwater run-off	Floodwater	Canal water	Catchment run-off	River water	Run-off from fields
Recharge technology	Ponds and trenches	Injection well	Floodwater spreading system	Basins	Ponds, check dams	Infiltration basin	Aquifer storage and recovery (A.S.R.) well
Volume recharged	100 x 10^6 m^3/year	0.25 x 10^6 m^3 over 4 years	<1 to >20 x 10^6 m^3/year	5,000 m^3 in 30 days	374 x 10^3 m^3/year	58,000 m^3 over 1.5 months (potentially 100 Mm^3/year at scale)	220 mm/year
Aquifer	Alluvial, unconfined	Limestone, confined	Alluvial, unconfined	Alluvial, unconfined	Fractured basalts	Coarse alluvium	Alluvial, semi-confined
Setting	River delta	Peri-urban	Arid plain	Alluvial plains, humid tropics	Semi-arid	Semi-arid valley	Hilly to gentle plains and coastal area
M.A.R. objective	Scheme to reduce groundwater overuse/ seawater intrusion to sustain sugar production	Pilot to test creating new freshwater for landscape irrigation and reduce the coastal discharge of run-off	Harvest floodwater to offset groundwater overuse	The pilot aimed to reverse groundwater depletion	Evaluation of recharge from micro-watersheds over several years	Pilot to enhance groundwater use sustainably for irrigation to overcome dry season water shortfalls downstream	Utilize excess monsoon run-off to meet irrigation demands
Problems experienced	Unlicensed groundwater abstraction	Well clogging	A decline in groundwater persists due to huge demand, sediment deposition and flood damage to the system	A large area of land used as a wetland for pre-treatment; long-term performance is unclear	None reported	None reported	Clogging of injection wells
Implementing agency	Water boards (regional government organization)	State government		Central government			
Source	Charlesworth et al. (2002)	Pavelic et al. (2006)	Hashemi, Berndtsson, and Persson (2015)	Pavelic et al. (2012)	Sharda et al. (2006)	Karimov et al. (2013)	Holländer et al. (2009)

Source: Controlling floods and droughts through underground storage: from concept to pilot implementation in the Ganges River Basin (Pavelic et al., 2015).

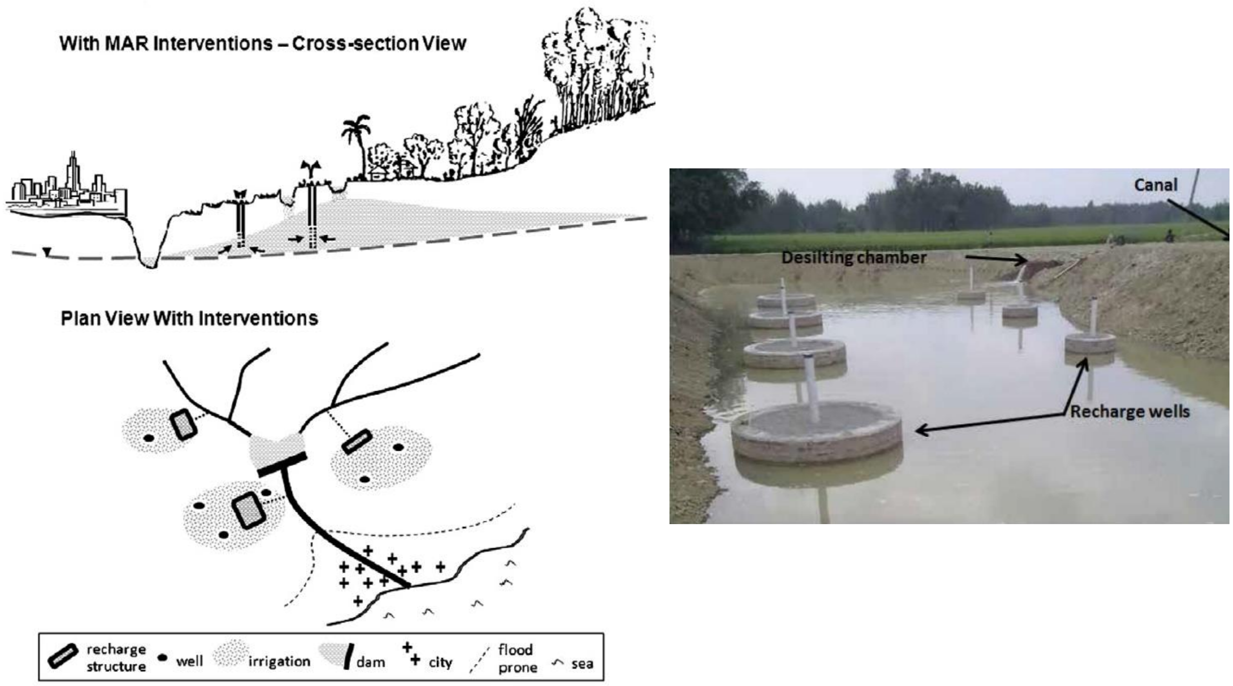


Figure D2- 10 Example of implementation of subsurface harvesting system. The left is a cross-section view with M.A.R. intervention in a sub-basin of the Chao Phraya River Basin, Thailand (Source: Pavelic et al. (2012)). The right presents a photo of the pilot site of M.A.R. implementation in Jiwai Jadid village, Rampur District, India (Source: Pavelic et al. (2015))

D2-6.5. Repair and complete distribution system of existing irrigation projects.

There is evidence that the construction of water storage in the basin is not paralleled by a linear expansion of irrigation service areas along with lacks of regular inspection and maintenance programs leading to most of the schemes do not function properly, and many of the systems were incomplete, non-existent, or in poor condition (Floch, Molle, & Loiskandl, 2007; Hydro and Agro Informatics Institute, 2012; Patamatamkul, 2001; State Audit Office of the Kingdom of Thailand, 2016). Thus, the construction of designed distributed canals and systems, repair or rehabilitation of the deteriorated elements and schemes should be accomplished, increasing water storage capacity in the basin.

Additionally, it is necessary to have a plan of routine inspection and maintenance in which the division of duties between the local government and farmers should be clearly described. The local government should develop and implement the maintenance plan in collaboration with local farmers. The involvement of farmers is essential for maximizing returns from irrigation projects, and this should receive high priority (Jurriëns and Jain, 1993). Local water-user groups can devise institutions to manage the irrigation system sustainably as their livelihoods depend on that common property; they thus have the greatest incentives to maintain it over time (Bromley, 1992; Meinzen-Dick et al., 2002). To make farmers involvement effective, legislative backing and financial incentives will be required in the initial years (Jurriëns and Jain, 1993).

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Appendix D-3 – Analytic hierarchy process (AHP)

The Analysis Hierarchy Process (AHP) is a multi-objective decision-making method combining quantitative and qualitative analysis, proposed by a United States scientist of operational research in the early 1970s. This approach is logical, systematic, concise, and practical, and it is a systematic approach to deal with complex issues through the decompounding layer by layer and comparing. Based on the nature and objectives of the problem, AHP delaminates the problem to form a ladder-shaped and orderly hierarchical structure model; then describes the relative importance of factors at each level in the model quantitatively, and then determines all factors' weights of the relative importance order in each level through the mathematical method; finally calculates the combination weights of the relative importance order of factors at all levels synthetically, and takes them as a basis evaluating and selecting the program. AHP expresses people's subjective judgments in quantitative form, so it reduces the disadvantages resulted from human subjectivity and makes evaluation results more credible. However, due to the uncertainty and ambiguity of things, experts often cannot make complete reasonable judgments on the evaluation index.

The importance weights w_i of impact factors V_i on the target *u* are different. We compare *n* factors of target *u* according to their impact degree. The result of the comparison is denoted by matrix *A*, as following

$$A = \begin{pmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{pmatrix}$$

A is a judgment matrix. If A satisfies the consistency conditions, we calculate the characteristic value $A_w = \lambda w$ and obtain $w = (w_1, w_2, \ldots, w_n)^T$; and then we normalize it and makes the result as the weight of the impact factors $V_1, V_2, \ldots, V$m of target vulnerability.

The Analytic Hierarchy Process (AHP) is aiming to quantify qualitative preferences and indicators or categories between components or subcomponents using intelligent comparisons of sets of objects to estimate weight interactively with its components. Wise judgment scoring follows Saaty (1987) rules with a 9-point system from 1 to 9 as shown in Table D3-1.

Table D3- 1 Pairwise comparison scale

Intensity of importance	Explanation
1	Two criteria contribute equally to the objective
3	Experience and judgment slightly favored one over another
5	Experience and judgment strongly favored one over another
7	The criteria are strongly favored and its dominance is demonstrated in practice
9	The importance of one over another affirmed on the highest possible order
2,4,6,8	Used to represent a compromise between the priorities listed above

The AHP decision consists of three steps.

Step 1: pair - Wise comparison matrices were formed in hierarchical order. After the hierarchy is created for each indicator, a double comparison was applied to the entire hierarchy. A "match comparison" must be generated n (n-1) / 2 times if no element already exists. When using eigenvectors, the relative weights of each metric were obtained according to the following equation:

$$A = (aij)_{nxn} = \begin{bmatrix} a_{11} & a_{12} \cdots & a_{1n} \\ a_{21} & a_{22} \cdots & a_{2n} \\ a_{n1} & a_{n2} \cdots & a_{nn} \end{bmatrix}$$

Step 2: The matrix from step 1 was normalized by totaling each column and dividing each matrix element by the total value of each column. Each total value of each column was equal to 1. Relative weights were calculated from each matrix normalized. The relative weighting is given by eigenvector (w) corresponding to the largest eigenvalue (λ_{max}) as:

$$AW = \lambda_{max} W$$

Step 3: Consistency check was carried out which consists of three minor steps; calculating the consistency measures (λ_{max}), calculating the Consistency Index (CI) and calculating the Consistency Ratio (CR).

The CI was synthesized from λ_{max} and the order of the matrix. Using the results of the consistency ratio (CR) consistent evaluation can be concluded. CR was calculated as the ratio of CI and random index (RI). If CR's value was less than 0.1, the judgment matrix was considered consistent, and the weights were available.

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

$$CR = \frac{CI}{RI}$$

RI is a function of n in the relationship defined by as shown below in Table D3-2 .

Table D3- 2 RI values

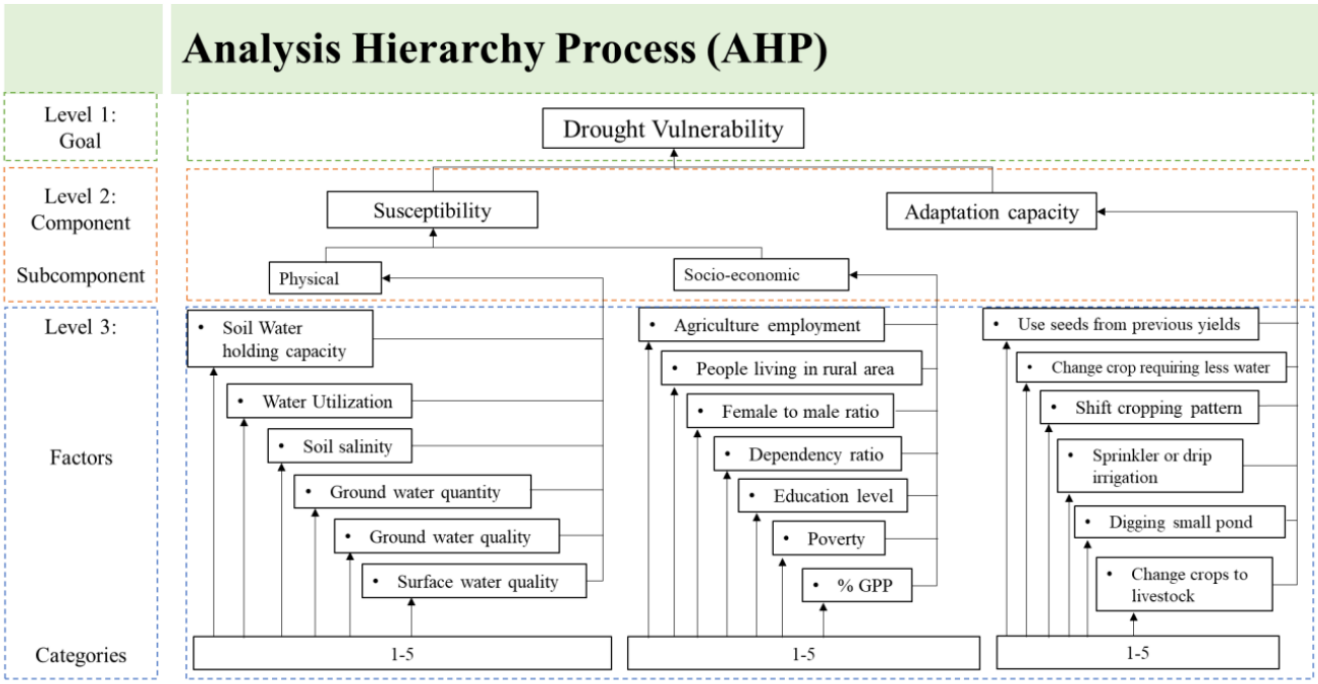
n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.0	0.0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Development of Hierarchy

To develop the AHP, the components, subcomponents, factors and categories were arranged in three levels as shown in Figure 2. The goal level represents drought vulnerability analysis of UMRB. The 2nd level describes the two main components, such as susceptibility and adaptation capacity. Susceptibility is then formulated from two subcomponents: physical and socio-economic. The 3rd level presents the factors for susceptibility and adaptation capacity. The physical subcomponent of susceptibility is mainly composed from six factors such as soil water holding capacity, water utilization by agricultural, soil salinity, groundwater quantity, groundwater quality and surface water quality.

The socio-economic subcomponent of susceptibility is referred to agriculture employment, people living in rural area, female to male ratio, dependency ratio, education level, poverty rate and percent of gross provincial product. All the factors are divided into 5 categories as indicated in Figure 2.

Figure D3- 1 Framework of Analytical Hierarchy Process



At each level, a score of importance was given for the questionnaire by using pairwise comparison while separating the importance level into nine levels at the beginning. After obtaining the comparison score according to the opinions of managers, experts or relevant personnel, the weights of importance factor in the same analysis, from top to bottom were calculated. All the factors were assigned the total importance score of the alternative according to the specified criteria.

To obtain the threshold index of each factor, each collected data was normalized between 0 to 1 at first. Secondly, spatial map layer for each factor was generated by the Geographic Information System (GIS). Then the normalized data was inputted as attribute data correspondence to spatial map layer. Thus, the collected data were obtained in form of GIS layers. Five levels of threshold factor index were determined by classifying attribute data using "Equal interval" which was one of the data classification methods from GIS technique. Finally, all GIS layers were converted from vector image to raster image in order to merge them into corresponding components equation.

Thus, in vulnerability analysis, a questionnaire based on the AHP technique is designed to collect the respondents' opinions and assess the relative importance (weight) between 2 factors.

AHP Questionnaire

School of Engineering and Technology
Water Engineering and Management

Questionnaire Survey Vulnerability Assessment in the Upper Mun River Basin, Thailand

Dear Respondent,

I am currently undertaking a research project into the Drought Risk Assessment in the Upper Mun River Basin, Thailand.

As part of this research, I am conducting a multi criteria analysis in order to elicit expert' opinions for weighting various factors affecting the vulnerability in the study area.

The past studies indicate that most of drought risk assessment focus on hazard and vulnerability, less focusing on exposure. Exposure and vulnerability are independent from each other. Exposure is determined by several indicators, such as population and livestock density, land use, and so on while vulnerability is to identify place where people will be most dramatically affected by a drought and to analyse the reasons why these groups are less able then others to cope with the impacts of the hazard.

The purpose of this study is to assess the drought vulnerability to the agricultural sector, assess the drought risk in the study area and investigate the currently adopted adaptation measures by the local people in selected high-risk areas in the study basin.

In the following pages we would like to obtain your opinion as an expert through a survey questionnaire, in which you are requested to prioritise various factor with respect to project goal.

The information you provide will be of great value for this research, and accordingly, your participation is anticipated and very much appreciated.

I sincerely hope you can assist.

Lapanploy Chawrua
Master Student
School of Engineering and Technology
Water Engineering and Management
Asian Institute of Technology
St119427@ait.ac.th

Questionnaire Survey
Vulnerability Assessment in the Upper Mun River Basin, Thailand

Section-A – Information of Participants

Respondents

Experts is identified as key participants of this study. Experts include those identified as having an extensive knowledge, or ability in drought assessment, policy and planning, as related to the development and implementation of adaptation strategies. Experts are expected to include government, organization, university academics, professional engineers, etc.

Time to Complete Survey: The survey will take approximately 30 minutes tocomplete.

Conducting Survey

The survey will be conducted by:

- Delivering the questionnaires in person to the participants, explain the study, and then collect the questionnaires at a date after completion.
- An electronic survey by email, questionnaires directly to participants and asking the respondent to e-mail the survey back when completed.

Confidentiality

The information provided by participants will not be disclosed. Participant's name, address data will be removed from the questionnaire and not known to others. The answers gives will be only used for research purposes and for writing a report.

Information (Respondent)

1.1 Name……………………………………………………………………………………..…..

1.2 Gender ❑ 1. Male ❑ 2. Female

1.2 Age..............................year

1.3 Work Information
Please specify the name of your organization……………………………………………………..

………………………….………………………………………………………………………………

Working position……...……………………………………………………………………………...

1.4 Work experience

❑ < 5 year ❑ 5-10 years ❑ 11-20 years ❑ > 20 years

Section-B – MULTI-CRITERIA ANALYSIS FOR WEIGHTING VARIOUS FACTOR

Introduction

The past studies indicate that most of drought risk assessment focus on hazard and vulnerability, less focusing on exposure. Exposure and vulnerability are independent from each other. Exposure is determined by several indicators, such as population and livestock density, land use, and so on while vulnerability is to identify place where people will be most dramatically affected by a drought and to analyze the reasons why these groups are less able then others to cope with the impacts of the hazard (Hugo and Paulo,2015). A common understanding of the factors of drought risk is crucial for the identification and planning of drought risk reduction and adaptation. This study will investigate drought vulnerability and drought risk in the Upper Mun River Basin that consists of 8 provinces: Nakhon Ratchasima, Buri Ram, Surin, Si Sa Ket, Khon Kaen, Maha Sarakram, Roi Et, Ubon Ratchathani.

In this context, the purpose of this research project is to assess the drought vulnerability to the agricultural sector, assess the drought risk in the study area and investigate the currently adopted adaptation measures by the local people. With this research, I exploring expert'opinions for weighting various factors. As part of assess drought vulnerability, we are undertaking a multi-criteria analysis. Through a survey questionnaire, we intend to evaluate 2 components, 3 subcomponents and 14 factors. For a multi-criteria analysis, Analytic Hierarchy Process (AHP) is employed. The AHP is method designed to help in prioritizing very complex decision alternatives involving multiple goals. Pair-wise comparisons are the fundamental buildings blocks of AHP. By using the questionnaire, the participants compare the relative importance of the decision factors of pair-wise with respect to Drought Vulnerability Assessment framework for Upper Mun River Basin (Figure 2).

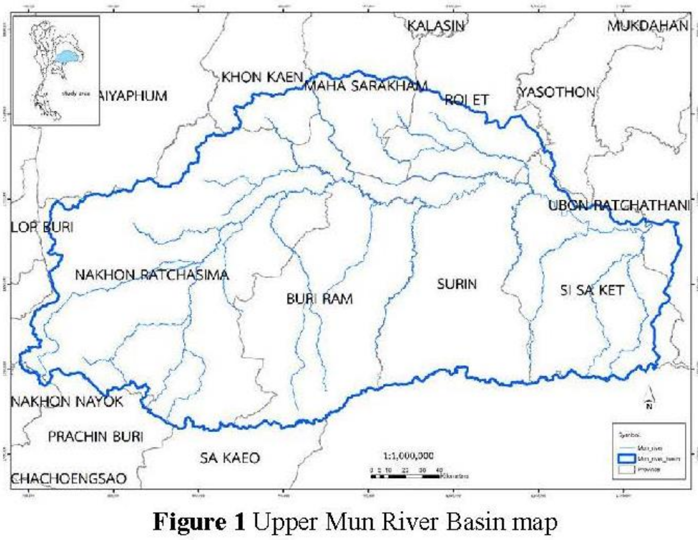


Figure 1 Upper Mun River Basin map

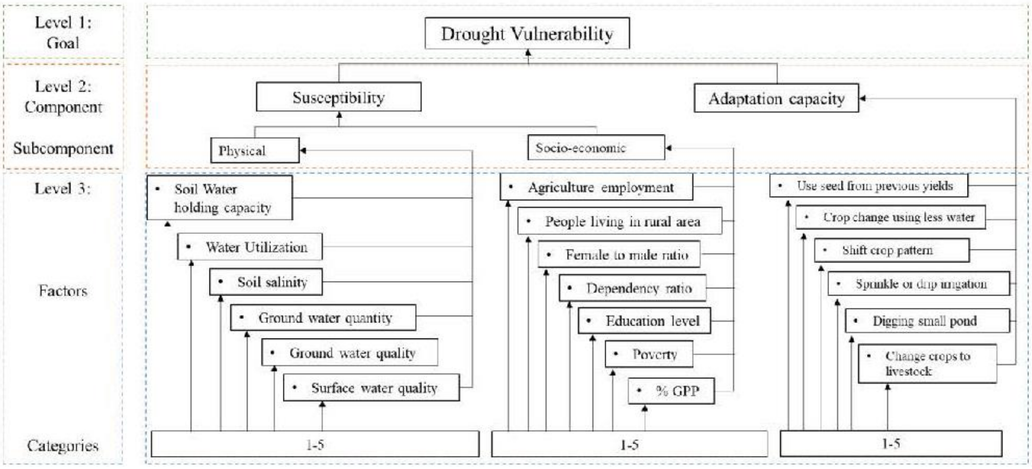


Figure 2 - Drought Vulnerability Assessment framework for Upper Mun River Basin

In the following sheets, we would like to elicit your opinion in order to select amongst the factors. The pair wise comparison scale is used to express the importance of one element over another (Table 1).

Explanation	Numeric Values
If Option A and Option B are equally important : Mark/Insert	1
If Option A is moderately more important than Option B : Mark/Insert	3
If Option A is strongly more important than Option B : Mark/Insert	5
If Option A is very strongly more important than Option B : Mark/Insert	7
If Option A is extremely more important than Option B : Mark/Insert	9
Use even numbers for intermediate judgements	2, 4, 6, 8

Table 1 - Saaty Comparison Scale

Example:

Given Options A & B, you can judge their relative importance as shown below example:

if you think the option 'Physical' in column **A** is strongly more important than the option 'Socioeconomic' in column **B**, then you mark 5 with (X) on the left hand side.

if you think the option 'Adaptation capacity ' in column **B** is extremely more important than the option 'Socioeconomic' in column **A**, then you mark 9 with (X) on the right hand side.

A Options	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	B Options
Physical	9	8	7	6	X	4	3	2	1	2	3	4	5	6	7	8	9	Socioeconomic
Socioeconomic	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	X	Adaptation capacity

With respect to **Physical**,
Using the scale from 1 to 9 (where 9 is extremely and 1 is equally important),
please indicate (X) the relative importance of options **A** (left column) to options **B** (right column).

A Options	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	B Options
Soil Water holding capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water Utilization
Soil Water holding capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Soil salinity
Soil Water holding capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ground water quantity
Soil Water holding capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ground water quality
Soil Water holding capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Surface Water quality
Water Utilization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Soil salinity
Water Utilization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ground water quantity
Water Utilization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ground water quality
Water Utilization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Surface Water quality
Soil salinity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ground water quantity
Soil salinity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ground water quality
Soil salinity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Surface Water quality
Ground water quantity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ground water quality
Ground water quantity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Surface Water quality
Ground water quality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Surface Water quality

With respect to **Socioeconomic**,
Using the scale from 1 to 9 (where 9 is extremely and 1 is equally important),
please indicate (X) the relative importance of options **A** (left column) to options **B** (right column).

A Options	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	**B** Options
Agriculture employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	People living in rural area
Agriculture employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Female to male ratio
Agriculture employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Dependency ratio
Agriculture employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Education level
Agriculture employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Poverty rate
Agriculture employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	% Gross Provincial Product
People living in rural area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Female to male ratio
People living in rural area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Dependency ratio
People living in rural area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Education level
People living in rural area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Poverty rate
People living in rural area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	% Gross Provincial Product
Female to male ratio	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Dependency ratio
Female to male ratio	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Education level
Female to male ratio	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Poverty rate
Female to male ratio	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	% Gross Provincial Product
Dependency ratio	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Education level
Dependency ratio	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Poverty rate
Dependency ratio	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	% Gross Provincial Product
Education level	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Poverty rate
Education level	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	% Gross Provincial Product
Poverty rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	% Gross Provincial Product

With respect to **Adaptation capacity**, Using the scale from 1 to 9 (where 9 is extremely and 1 is equally important), please indicate (X) the relative importance of options **A** (left column) to options **B** (right column).																		
A Options	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	**B Options**
Use seed from previous yields	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Crop change using less water
Use seed from previous yields	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shift crop pattern
Use seed from previous yields	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sprinkle or drip irrigation
Use seed from previous yields	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Digging small pond
Use seed from previous yields	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Change crops to livestock
Crop change using less water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shift crop pattern
Crop change using less water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sprinkle or drip irrigation
Crop change using less water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Digging small pond
Crop change using less water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Change crops to livestock
Shift crop pattern	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sprinkle or drip irrigation
Shift crop pattern	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Digging small pond
Shift crop pattern	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Change crops to livestock
Sprinkle or drip irrigation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Digging small pond
Sprinkle or drip irrigation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Change crops to livestock
Digging small pond	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Change crops to livestock

With respect to **Susceptibility**, Using the scale from 1 to 9 (where 9 is extremely and 1 is equally important), please indicate (X) the relative importance of options **A** (left column) to options **B** (right column).																		
A Options	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	**B Options**
Physical	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Socioeconomic

With respect to **Drought Vulnerability**,
Using the scale from 1 to 9 (where 9 is extremely and 1 is equally important),
please indicate (X) the relative importance of options **A** (left column) to options **B** (right column).

A Options	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	**B Options**
Susceptibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Adaptation Capacity

Explanation

Goal: To assess drought vulnerability

Component: Two component were chosen in the AHP evaluation: There are susceptibility and adaptation capacity. Two Subcomponent were identified: There are physical and socio-economic

Factors: The physical subcomponent is considered in 6 factors, the socioeconomic subcomponent 7 factors and adaptation capacity subcomponent 6 factors. The table below is the summary factors that if the X put in the field of Larger the better, that factors is more, the chance of being vulnerability will less. Likewise, if the X put in the field of Smaller the better, that factors is less, vulnerability will less as well.

Factors	Chance of being ***Low Vulnerability***	
	Larger the better	**Smaller the better**
Physical		
Soil water holding capacity	X	
Water utilization		X
Soil salinity		X
Ground water quantity	X	
Ground water quality	X	
Surface water quality	X	
Socioeconomic		
Agriculture employment		X
People living in rural area		X
Female to male ratio		X
Dependency ratio		X
Education level	X	
Poverty rate		X
% Gross Provincial Product	X	
Adaptation capacity		
Use seed from previous yields	X	
Crop change using less water	X	
Shift crop pattern	X	
Sprinkle or drip irrigation	X	
Digging small pond	X	
Change crops to livestock	X	

Appendix D-4 – Local Stakeholders' Meetings

Background information

In parallel to the top-down approach using the DSSAT model, a bottom-up approach is accomplished by local stakeholders' meetings using questionnaire surveys to overview the general responses of the stakeholder's issues relating to climate change, land use change, physical hydro-environmental condition, socio-economic condition and adaption measures. Two local stakeholders' meetings were organized, the first meeting was organized at Nakhon Ratchasima province in 20 March 2019 and the second meeting was organized online on 3 August 2021 (due to Covid-19 pandemic).

First Stakeholders' meeting

The first meeting was organized to introduce the project objective, methodology, initial investigation results of the study and to obtain initial feedback and suggestions from the participants. Forty-two participants from central offices, regional offices including the representatives from provinces, districts and sub-districts, universities, and headmen of the village/communities took part in the questionnaire survey. The local participants were from 3 provinces, Nakhon Ratchasima, Buriram and Surin provinces. Thirty-eight sets of completed questionnaires were returned by the participants which makes about 90% of the total number of distributed questionnaires.

44% of respondents recognized that the technical measures to increase supply e.g. reservoir volumes, farm pond, water transfers are most effective measures. Most of respondents recognized that other water management practices such as increasing efficiency of water use, landscape planning measures to improve water use efficiency and improving monitoring, forecast and dissemination of information on rainfall and temperature are moderately effective measures in their opinions. Most of respondents recognized that the changing crop and cropping practices and changing farm management practices are moderately effective measures for adaptation solutions

THE FIRST STAKEHOLDERS' MEETING

"ENRICH: ENhancing ResIlienCe to future Hydro-meteorological extremes in the Mun river basin in Northeast of Thailand"




8 March 2019

Nakhon Ratchasima Province, Northeast Thailand

Summary of outcome of the first stakeholders' meeting
The outcome of the one-day first stakeholders' meeting can be summarized as follows.

i. The participants from Surin province have been observing change in climate such as gradual increase in temperature and reduction in annual rainfall over last few decades. Cultivation practice are shifting from paddy field to sugar cane, cassava because of limited water availability due to drought. They have recognized that drought events are increasing and flood events reducing in recent period. Changing crop and cropping practices are most effective adaptation measures for their area.

ii. The participants from Buriram province have also observed increase in temperature decrease in rainfall in their area. Forest areas have been changed to paddy field and paddy field have been change to sugar cane, cassava to adapt to droughts. There are some agency/organizations to support development projects in their area such as Ministry of Agricultures and Cooperatives, Hydro and Agro Informatics Institute (HAII), Royal Irrigation Department (RID), Land Development Department (LDD) and Military. They have recognized that drought events are increasing and flood events reducing in recent periods. They have suggested improving monitoring, forecast and dissemination of information on rainfall and temperature and making this information available to local farmers.

iii. The participants from Nakhon Ratchasima have also observed increase in temperature and decrease in rainfall in last few decades. In this province, paddy field are being converted to sugar cane, cassava, papaya, durian, and mulberry. For Nong Mai Phai sub-district, the farmers are using groundwater for agriculture purpose with drip irrigation system. Agency/organizations supporting these are Department of Groundwater Resources and Ministry of Energy.

iv. The participants from local organizations/agencies provided the following suggestions:
   -Drought risk map for agriculture area
   -Wider coverage of the meteorological stations and improve the efficiency of the data collection and forecast system.
   -Efficient dissemination system of information related to climate change
   -Explore state of the art technology for efficient agriculture practice
   -Strengthening and improving capacity of the local community

Second local stakeholders' meeting

A one-day period second local stakeholders' meeting was organized online due to COVID-19 pandemic in August 2021 to report the results of the study and the feedback and suggestions from the participants on the finding of the study. The second meeting was attended by 44 participants mostly from the provinces in the river basin and from various central and local agencies, academicians, provincial, district and sub-district officers, village and community leaders and farmers. Twenty-two filled-in questionnaire survey forms were received from the participants. The responses to the questionnaires can be finally summarized as follows.

1. About 90% of respondents preferred future land use change according combined Business as Usual land use type and land use type according to soil properties.

2. 95 % of respondents felt that the weather is getting hotter than in the past 30 years and observed that the number of rainy days is decreased and affects crop production.

3. 90% of respondents reported that the droughts become more severe, more frequent with longer duration.

4. 84 % of the respondents reported that increase of water resources, water use efficiency, land use appropriation, and drought forecast are very effective or effective.

5. 74 % of respondents reported that change in crop cultivation practices is very effective or effective.

6. 73% of respondents reported that managing crop fertilizer is very effective or effective.

7. More than 95% of the respondents highly appreciate financial support, loan and credit measures, joint investment in agricultural activities and financial counseling service.

8. 95 % of respondents strongly support seminars/workshops on agricultural technology with training practices

9. Nearly 100 % of respondents strongly accept social support and mentoring for the communities.

10. 93% fully support legal measures such as crop damage compensation and household living support.

11. Nearly 100% of the respondents are very pleased and satisfied with the organization of the local stakeholders' meetings.

Discussions and Conclusions

As a bottom-up approach in assessing and recommending adaptation measures, two local stakeholders' meeting were accomplished in series to gather information and feedback for participants on the past and current adaptation measures and their suggestion for further improvement. In concurrent to the occurrence of more frequent and severe droughts, the maps of drought risk and of its components namely: hazard map, exposure map and vulnerability map are considered essential. These maps are developed in this study and they found to be very useful for the analysis of adaptation measures for policy planning and implementation purposes.

In both first and second meetings, the participants consistently reported that development of supplementary water resources during dry periods such as by digging farm ponds or pumping of groundwater are of most effective measures in improving and stabilizing crop yield and production. Due to frequent water shortages and limited water resources, changing rice crop cultivation to other field crops such as maize, cassava and sugarcane, etc., are being practiced and considered as the changing trend. Most participants preferred the future land use change in the study area in view of combined land use change according to the prevailing trend of Business as Usual and in accordance to soil characteristics. Participants mainly agreed that the management of nutrient or crop fertilizer is very effective and its integration with water resources management would enhance more effectiveness. The above-mentioned comments from the stakeholders' meetings are considered in the top-down approach in the assessment and recommendation on the adaptation strategies and measures as described in Chapter 5 in this project report.

Moreover, most of the participants strongly support the following:

- seminars/workshops on agricultural technology with training practices.
- social support and mentoring for the communities.
- financial support, loan and credit measures, and financial counseling service
- legal measures such as crop damage compensation and insurance

The participants were very pleased and satisfied with the organization of the two local stakeholders' meetings.
