Water Resources Planning Institute
Water Resources Agency
Ministry of Economic Affairs

Strengthening Water Supply System Adaptive Capacity to Climate Change in Taiwan

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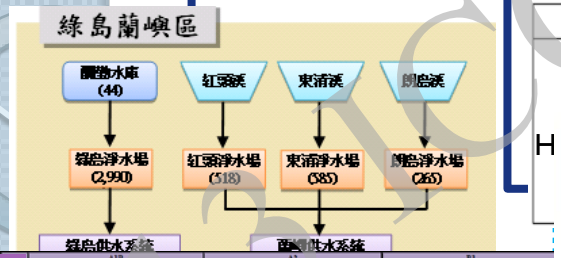
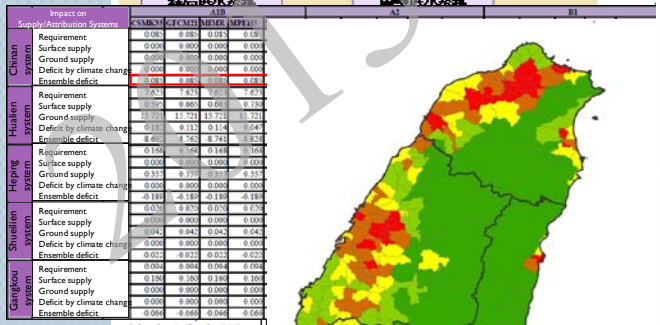
- Goals
- Framework
- Impacts of Climate Change on Water Resources
- Vulnerability, hazard and Risk assessment
- Action Plans for Adaptation under Climate Change
- Final Remarks and suggestions

Goals

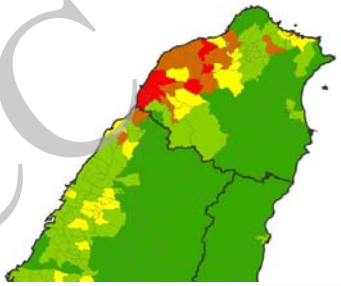
Evaluate and map the risk distribution (generated by vulnerability and hazard) of water resources impacted by climate change not just only in eastern area, but also in Taiwan and outlying islands for making strategies and plans that strengthens adaptive capacity on water resources.

Research Framework





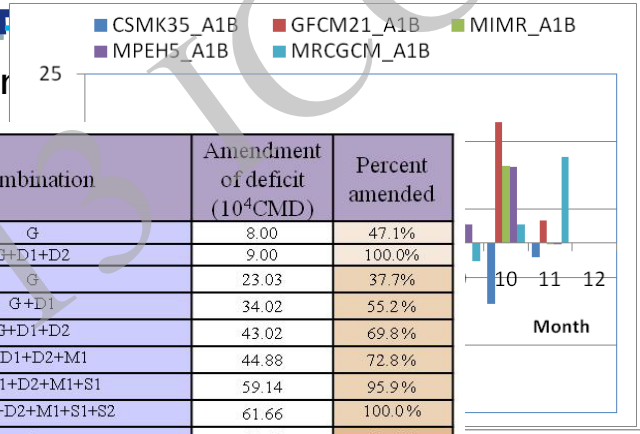
綠島淨水場



eference Collection

Alternatives
Adaptation Pl

e Change Scenario



Region	Adaptation plan	Combination	Amendment of deficit (10^4CMD)	Percent amended
North	Declared action plan	G	8.00	47.1%
	Combination 1	G+D1+D2	9.00	100.0%
Central	Declared action plan	G	23.03	37.7%
	Combination 1	G+D1	34.02	55.2%
	Combination 2	G+D1+D2	43.02	69.8%
	Combination 3	G+D1+D2+M1	44.88	72.8%
	Combination 4	G+D1+D2+M1+S1	59.14	95.9%
	Combination 5	G+D1+D2+M1+S1+S2	61.66	100.0%
South	Declared action plan	G	89.68	69.6%
	Combination 1	G+D1	92.68	72.0%
	Combination 2	G+D1+D2	102.68	79.7%
	Combination 3	G+D1+D2+D3	107.68	83.6%
	Combination 4	G+D1+D2+D3+M1	113.37	88.0%
	Combination 5	G+D1+D2+D3+M1+M2	127.53	99.0%
	Combination 6	G+D1+D2+D3+M1+M2+M3	128.03	99.4%
	Combination 7	G+D1+D2+D3+M1+M2+M3+M4	128.79	100.0%
East	Declared action plan	G	0.00	0%
	Combination 1	G+D1	0.08	47.0%
	Combination 2	G+D1+D2	0.14	80.0%
	Combination 3	G+D1+D2+D3	0.16	91.0%
	Combination 4	G+D1+D2+D3+D4	0.18	100.0%
Outlying Islands	Declared action plan	G	1.10	97.4%
	Combination 1	G+D1	1.12	99.3%
	Combination 2	G+D1+D2	1.13	100.0%

Ranks	
1	ent
3	MK35
1	CM21
2	MR
2	EH5
1	CGCM
1	cm2_3_2a
3	
1	
1	
2	
3	

Assessment by Combination of Plans

Strategic Plan for Adaptation

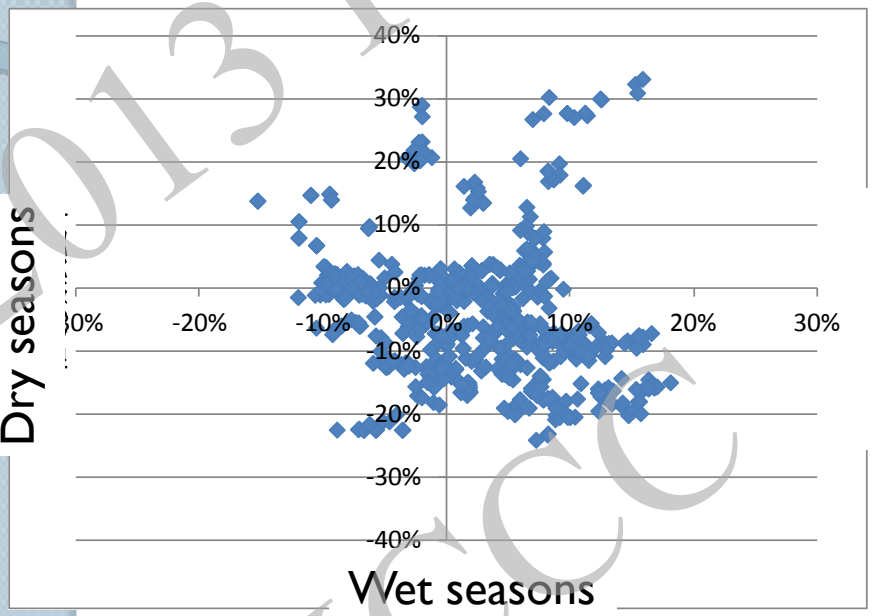
Impact of Climate Change on Water Resources

- Climate change scenarios and downscaling
- Assessment of available amount
- Evaluating future requirement
- Assessment of impacts by climate change

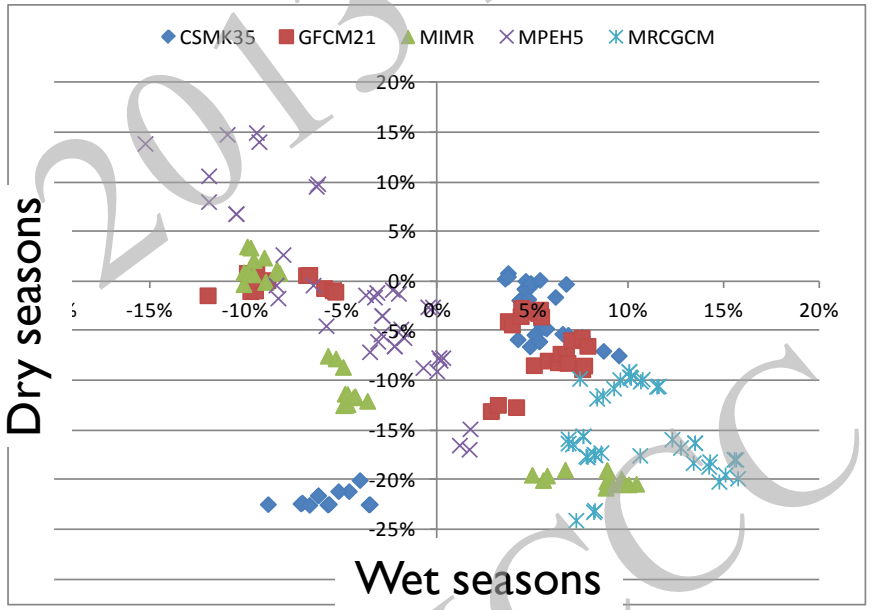
Rainfall change by GCMs simulated for years 2020~2039

Ex. Eastern Region

17 candidate GCMs



5 GCM by WRA



To meet the end for water resources management, the 5 GCMs by WRA are considered.

Available amount: surface water

Capability of attribution systems

Ex. Eastern Region

Rate of Deficit=0.07

(10^4 Cubic meter/day)

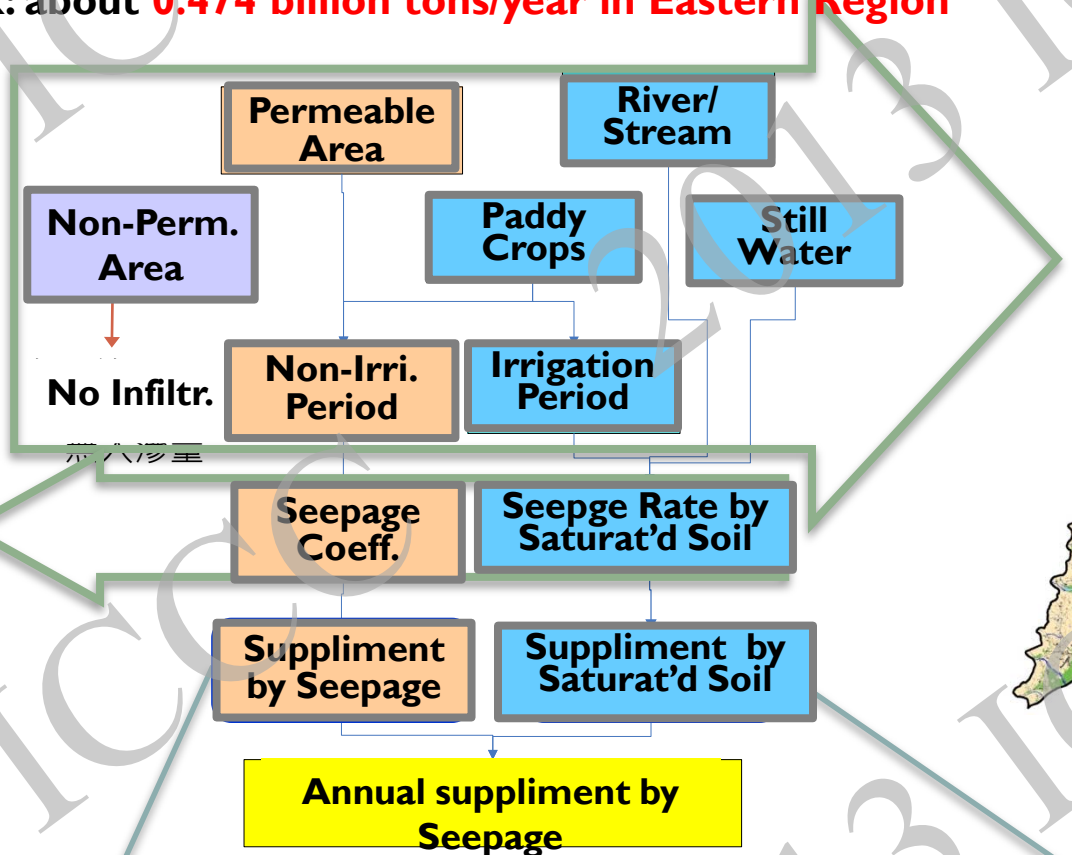
County/City	Scenario / GCM Models	Scenario of no climate change	A1B				
			CSMK35	GFCM21	MIMR	MPEH5	MRCGCM
Hualien	Requirement	10.868	10.868	10.868	10.868	10.868	10.868
	Supply by surface water	4.482	4.3	4.37	4.368	4.435	4.289
	Supply by ground water	19.334	20.685	20.685	20.685	20.685	20.685
	Deficit due to climate change	-	0.182	0.112	0.114	0.047	0.193
	Ensemble deficit	-12.948	-14.116	-14.186	-14.185	-14.252	-14.106
Taitung	Requirement	6.884	6.884	6.884	6.884	6.884	6.884
	Supply by surface water	3.317	2.854	2.617	2.826	3.21	2.464
	Supply by ground water	8.024	7.979	8.175	8.126	8.084	8.184
	Deficit due to climate change	-	0.464	0.7	0.492	0.107	0.853
	Ensemble deficit	-4.458	-3.949	-3.908	-4.068	-4.41	-3.764

Available amount: underground

Capacity of ground water

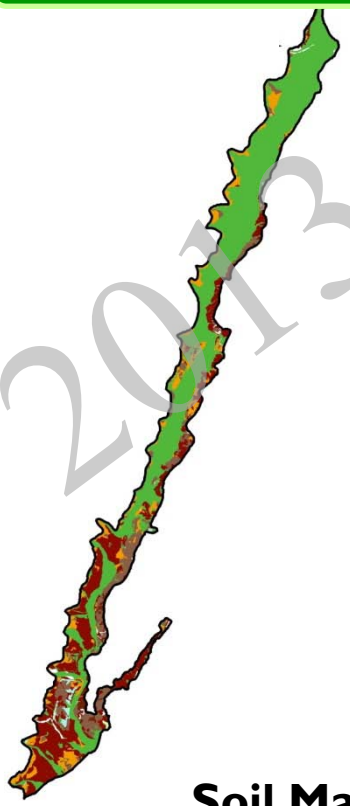
Annual capacity

Ex: about 0.474 billion tons/year in Eastern Region



Land Use Map

Soil Map



$$Q = A \cdot P \cdot \alpha_{soil} \qquad Q = A \cdot t \cdot \Phi soil$$

A:Area[L^2] ; t: Duration[T] ; P:Monthly Precip.[L] ;

Φ_{soil}: Seepage Rate by the Type of Saturated Soil [L/T] ;

α_{soil}:Seepage Coeff. by the Type of Soil [dimensionless].

Requirement by Domestic Use

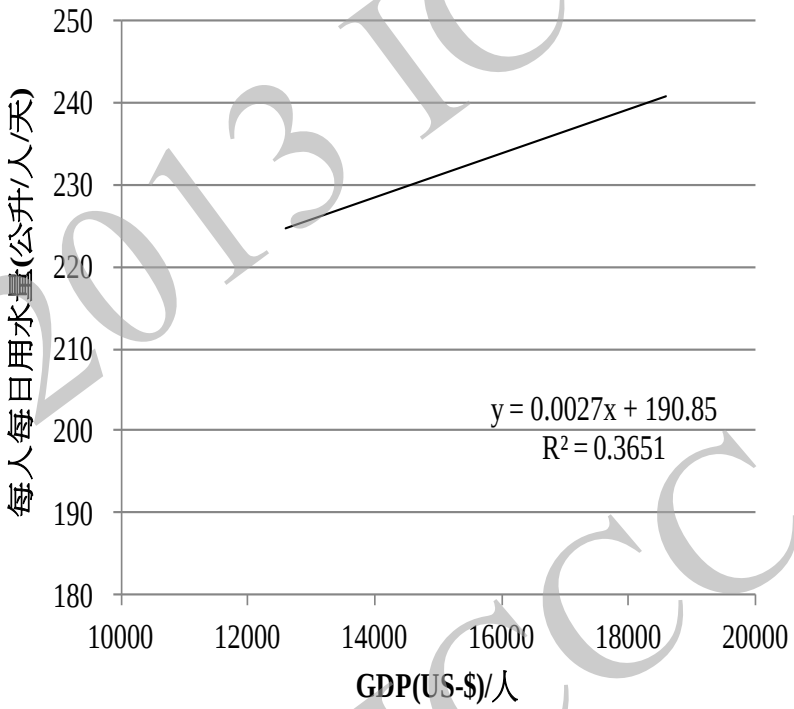
- $LPCD_{31}^{*} = LPCD_{31} +$ GDP adjustment + Temp. adjustment
  - LPCD：Liters Per Capita per Day
  - $LPCD_{31}$ ：LPCD by population growth at 2031
- GDP and temperature adjustments
  - Plot the relation between LPCD and GDP/temp.
  - Adjust LPCD if $R^2 > 0.36$ Calculated for each county

Requirement by Industrial Use

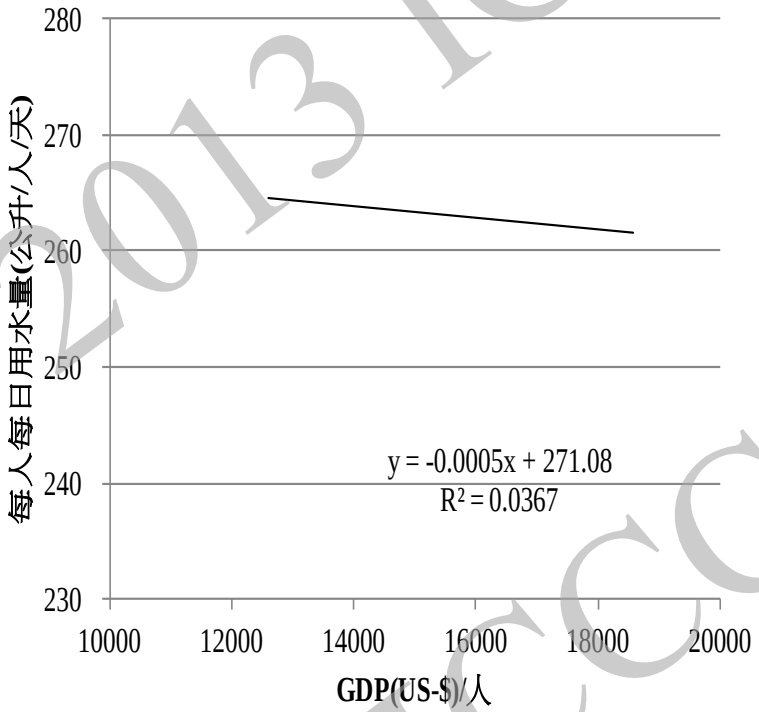
- The growth of industrial requirement implicitly includes the trend of GDP.
- Assumes no impact by temperature.
- No adjustment has been made.

Plot of LPCD vs. GDP

Ex. Eastern Region



Taitung

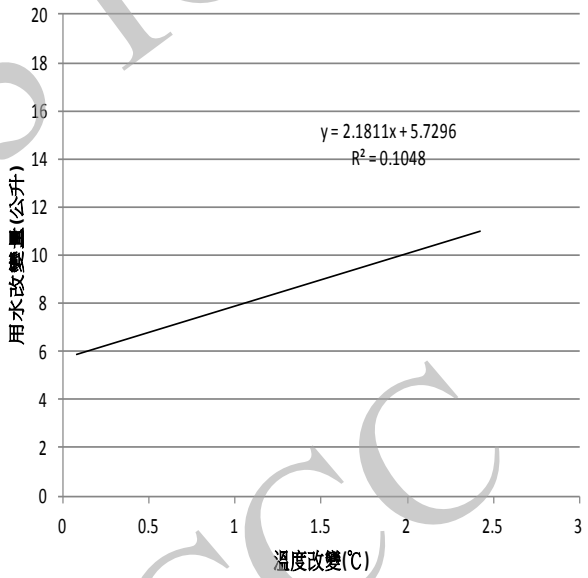


Hualien

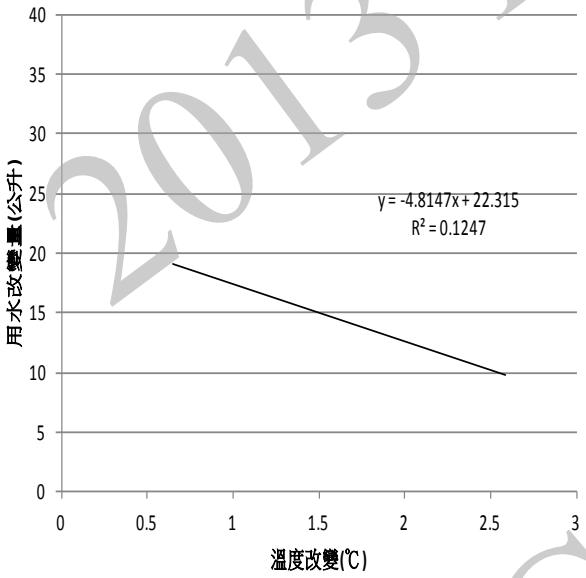
No adjustment would be made (small R^2 for both counties).

Plot of LPCD vs. Temperature

Ex. Eastern Region



Taitung



Hualien

No adjustment would be made (small R^2 for both counties).

Assessment of impact by climate change

Analysis of Supply Potential on Attributing Systems

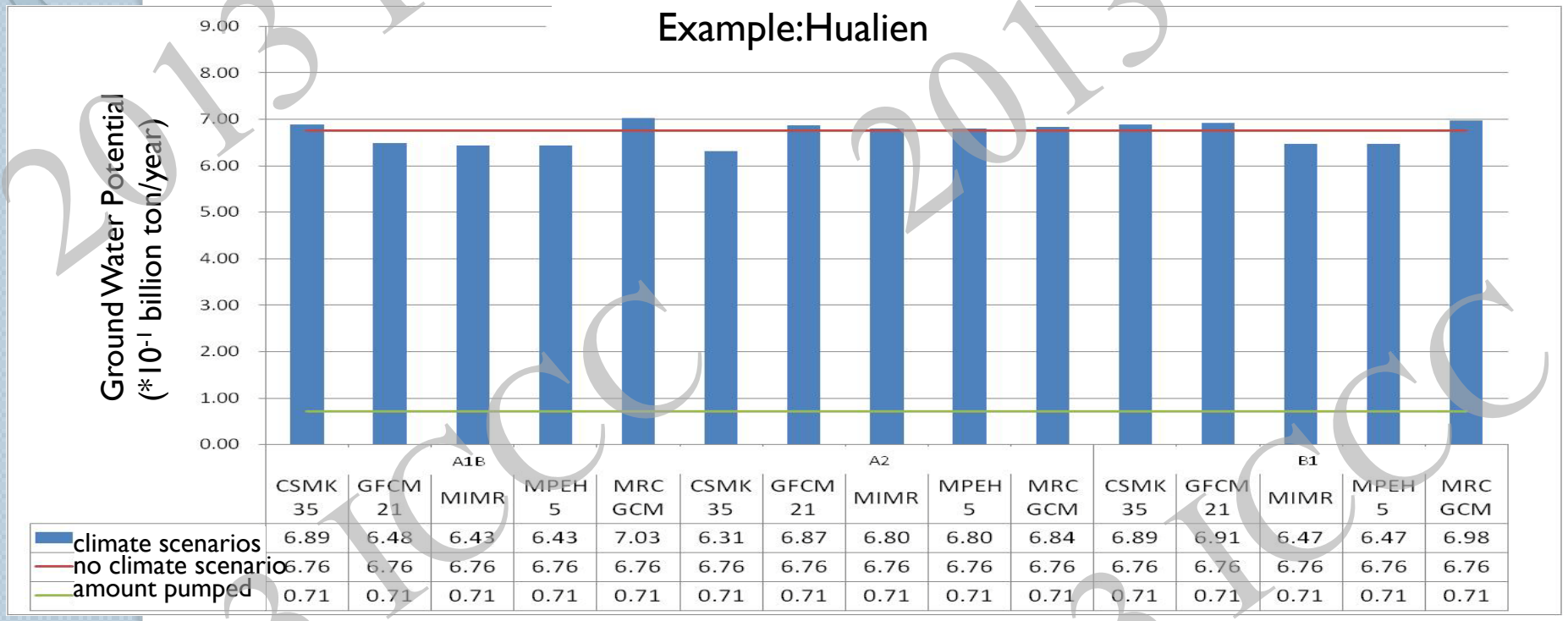
Ex: Hua-lien

units：*10^4 CMD

Impact on Supply/Attribution Systems		A1B					A2					B1				
		CSMK35	GFCM21	MIMR	MPEH5	MRCGCM	CSMK35	GFCM21	MIMR	MPEH5	MRCGCM	CSMK35	GFCM21	MIMR	MPEH5	MRCGCM
Chinan system	Requirement	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085
	Surface supply	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ground supply	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Deficit by climate change	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ensemble deficit	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085
Hualien system	Requirement	7.623	7.623	7.623	7.623	7.623	7.623	7.623	7.623	7.623	7.623	7.623	7.623	7.623	7.623	7.623
	Surface supply	0.595	0.665	0.663	0.730	0.584	0.464	0.626	0.453	0.468	0.566	0.608	0.664	0.538	0.565	0.607
	Ground supply	15.721	15.721	15.721	15.721	15.721	15.721	15.721	15.721	15.721	15.721	15.721	15.721	15.721	15.721	15.721
	Deficit by climate change	0.182	0.112	0.114	0.047	0.193	0.313	0.151	0.325	0.310	0.212	0.170	0.113	0.240	0.212	0.171
	Ensemble deficit	-8.692	-8.762	-8.761	-8.828	-8.682	-8.562	-8.723	-8.550	-8.565	-8.663	-8.705	-8.762	-8.635	-8.663	-8.704
Heping system	Requirement	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168
	Surface supply	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ground supply	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357
	Deficit by climate change	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ensemble deficit	-0.189	-0.189	-0.189	-0.189	-0.189	-0.189	-0.189	-0.189	-0.189	-0.189	-0.189	-0.189	-0.189	-0.189	-0.189
Shueilien system	Requirement	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
	Surface supply	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ground supply	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
	Deficit by climate change	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ensemble deficit	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022
Gangkou system	Requirement	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
	Surface supply	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160
	Ground supply	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Deficit by climate change	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ensemble deficit	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066

Assessment of impact by climate change

Ground Water Potential



	A1B					A2					B1				
	CSMK 35	GFCM 21	MIMR	MPEH 5	MRC GCM	CSMK 35	GFCM 21	MIMR	MPEH 5	MRC GCM	CSMK 35	GFCM 21	MIMR	MPEH 5	MRC GCM
climate scenarios	6.89	6.48	6.43	6.43	7.03	6.31	6.87	6.80	6.80	6.84	6.89	6.91	6.47	6.47	6.98
no climate scenario	6.76	6.76	6.76	6.76	6.76	6.76	6.76	6.76	6.76	6.76	6.76	6.76	6.76	6.76	6.76
amount pumped	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71

Vulnerability, hazard and Risk

- Analysis of vulnerability by usage
- Analysis of hazard under climate change
- Map of risk under climate change

Level of vulnerability

Domestic use: level by population density

Level of vulnerability	1	2	3	4	5
Population Density (per km^2)	<174	174~468	468~967	967~2771	>2771

Industrial use: level by yearly gross product

Level of vulnerability	1	2	3	4	5
Gross product (*10^3 NT$)	<618,692	618,692~ 2,399,779	2,399,779~ 8,943,901	8,943,901~ 25,455,521	>25,455,521

Agribultural use: level by area of paddy fields

Level of vulnerability	1	2	3	4	5
Area of paddy fields (hacters)	<97	97~607	607~1387	1387~2221	>2221

Level of hazard

- **Public use (civil + industrial):**
  - **Defined by DPD (Deficit Percent Day) index**

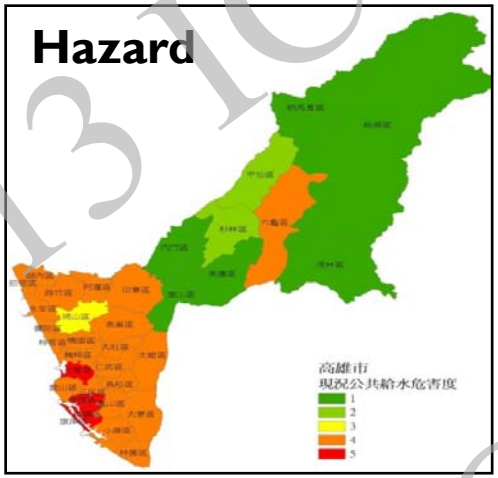
Level of Hazard	1	2	3	4	5
Deficit percent day at 2-Year Return Period	<100	100~600	600~1500	1500~3500	>3500
Severity	Low	Acceptable	Tolerable	Severe	Very Severe

- **Agricultural use:**
  - **Defined by water shortage rate (%)**

Level of Hazard	1	2	3	4	5
Water shortage (%) at 2-Year Return Period	<15	15~20	20~30	30~40	>40
Severity	Low	Acceptable	Tolerable	Severe	Very Severe

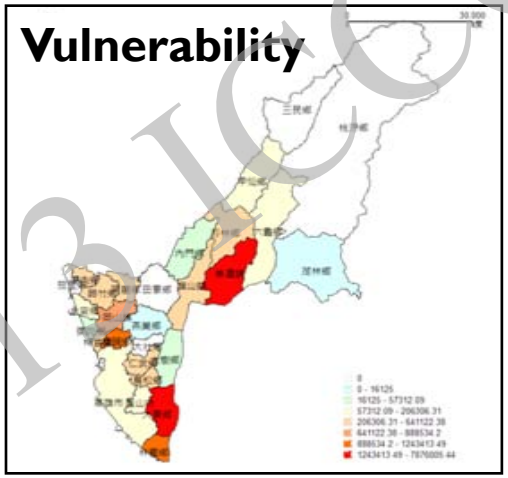
Risk ranking matrix

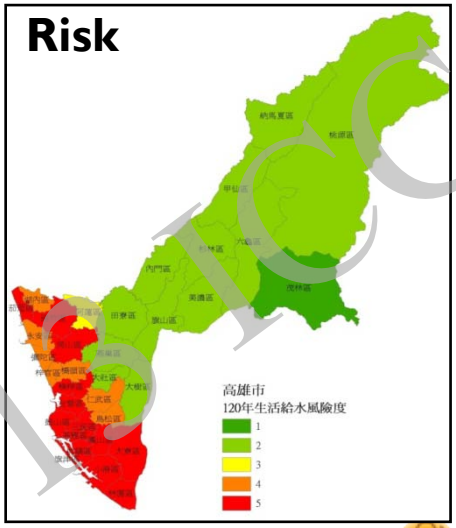
- Combines the information from vulnerability and hazard



Risk ranking matrix

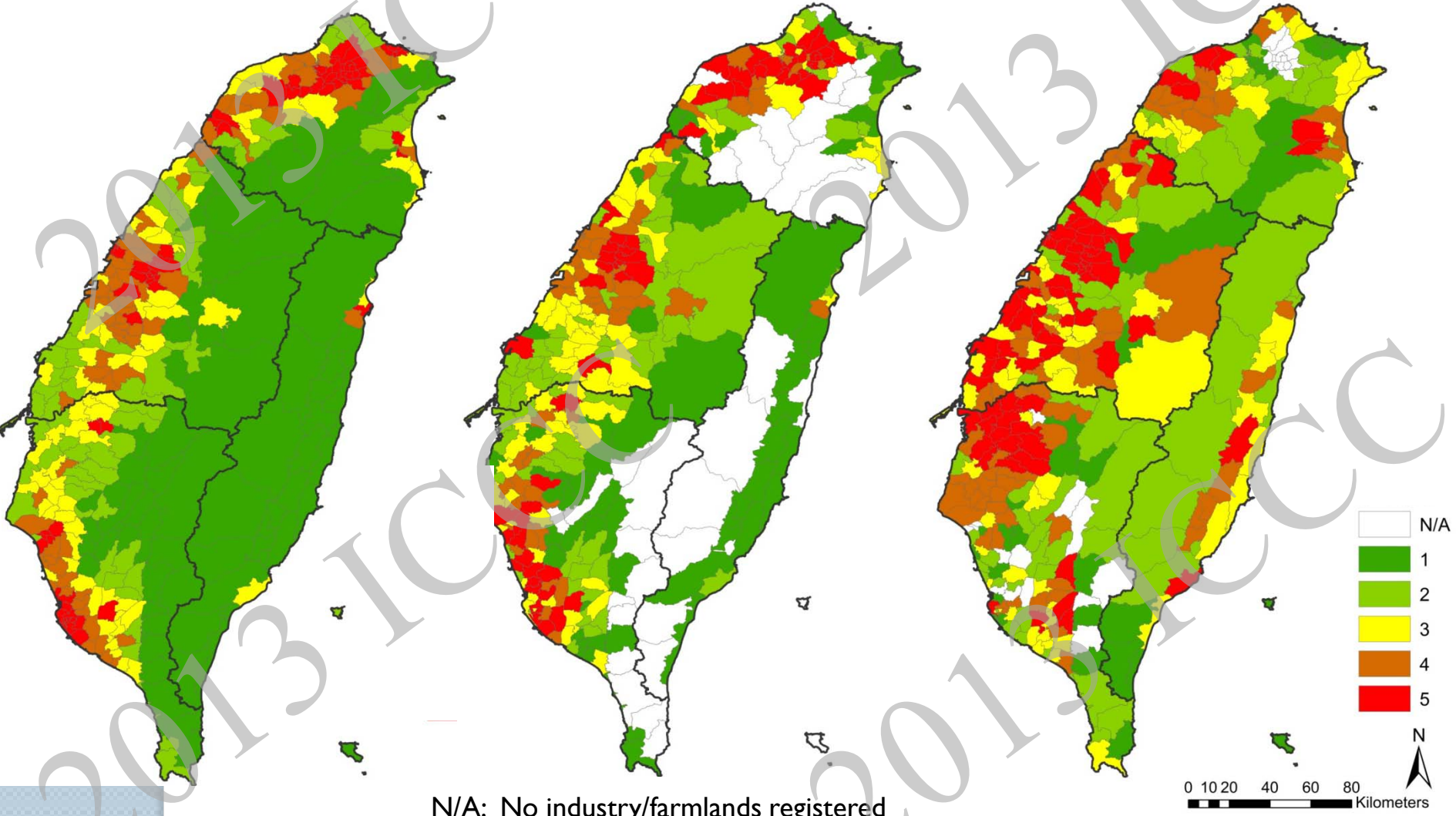
		Vulnerability				
		1	2	3	4	5
Hazard	1	1	1	1	1	2
	2	1	1	2	2	3
	3	1	2	2	3	4
	4	1	2	3	4	5
	5	2	3	4	5	5





Maps of vulnerability level

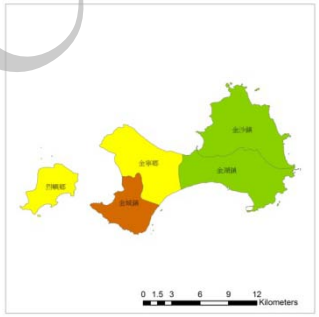
Domestic Use **Industrial Use** **Agricultural Use**

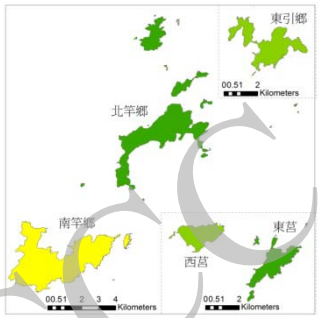


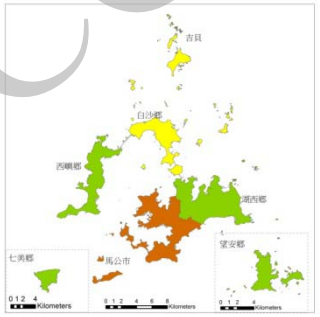
N/A: No industry/farmlands registered

Maps of vulnerability level: outlying islands

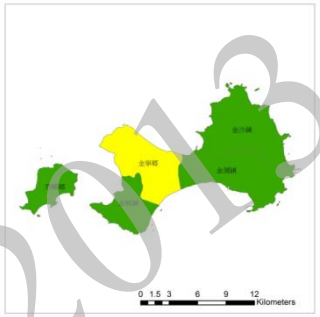
Domestic Use

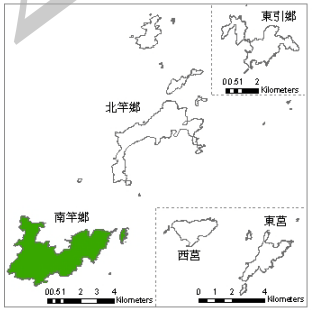


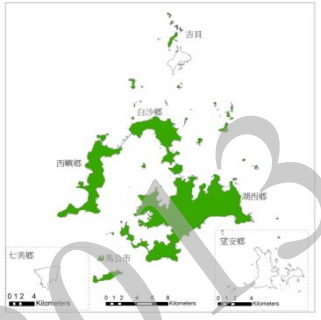




Industrial Use

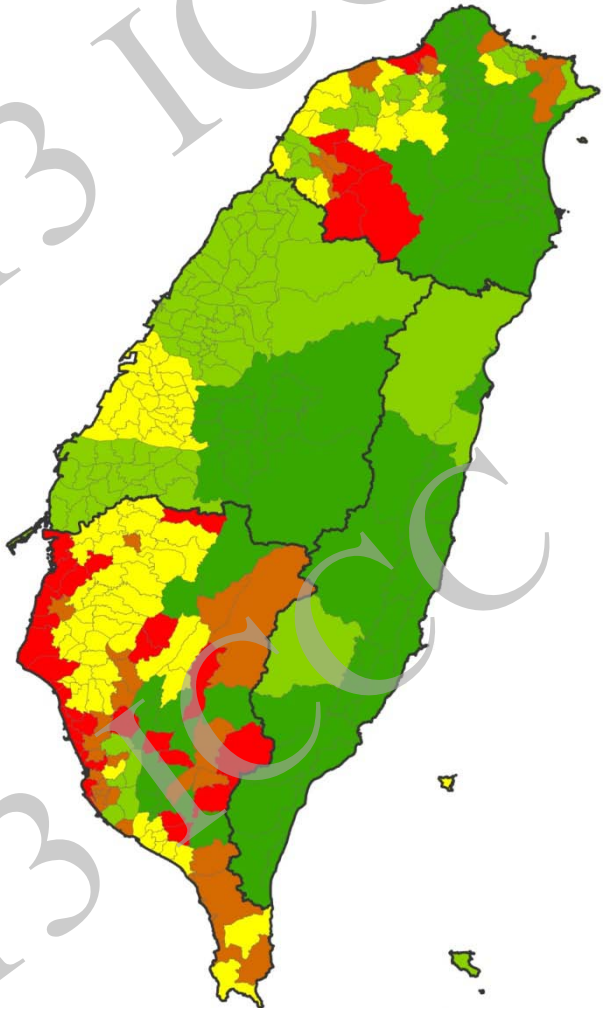




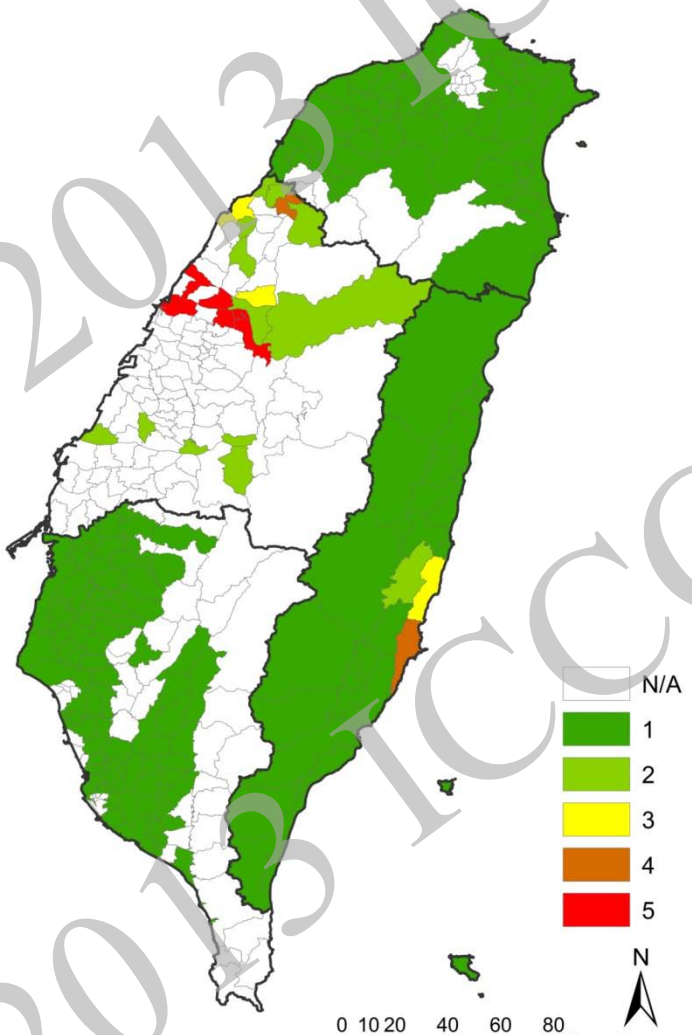


Maps of hazard level (target year, under A1B scenario and no-action plan)

Public Use (Domestic + Industrial)



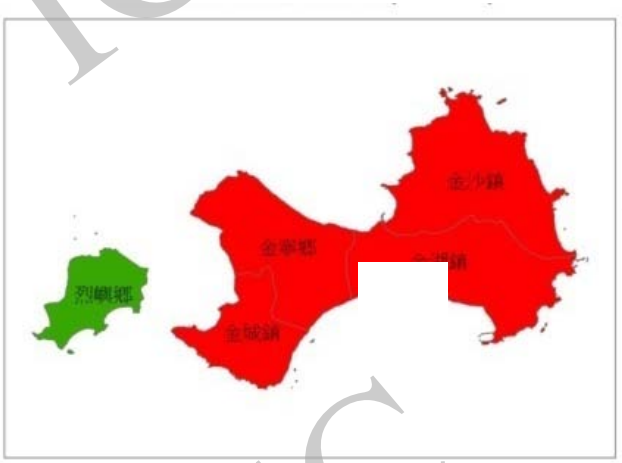
Agricultural Use

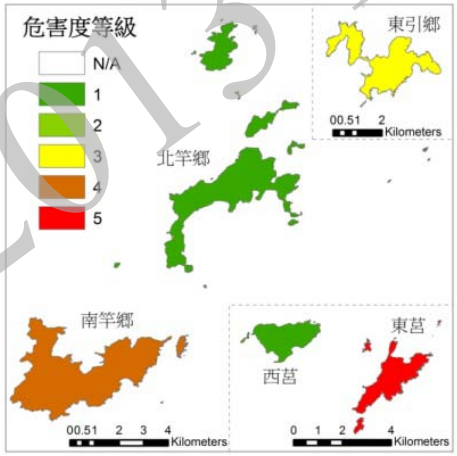


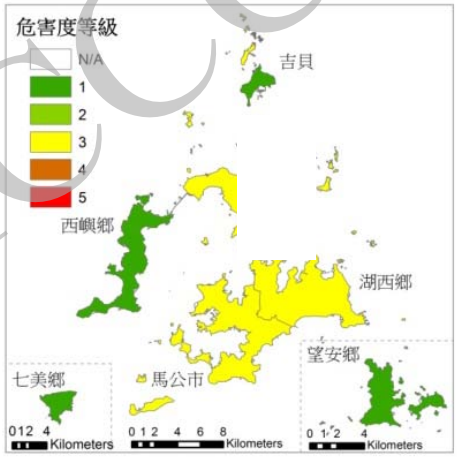
N/A: Farmlands by self-sustaining water sources. Water-use related data are not available.

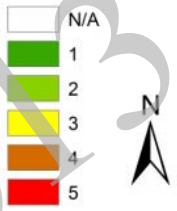
Maps of hazard level (outlying islands) (target year, under A1B scenario and no-action plan)

Public Use (Domestic + Industrial)

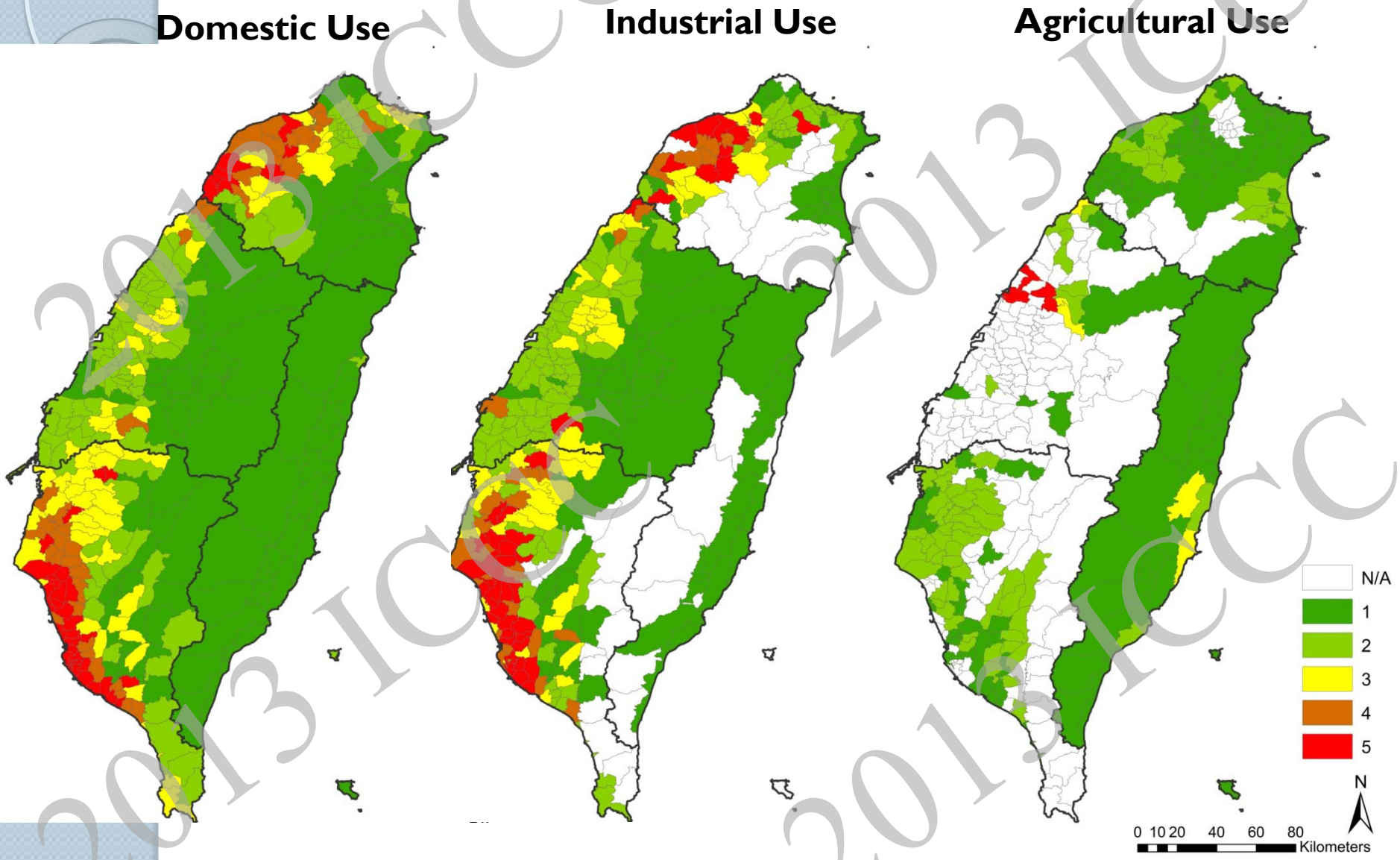






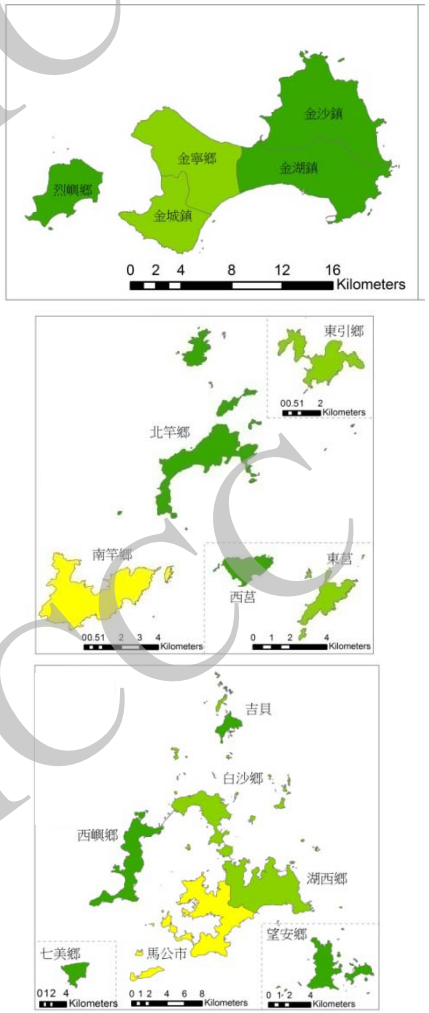


Maps of risk level
(target year, under A1B scenario and no-action plan)

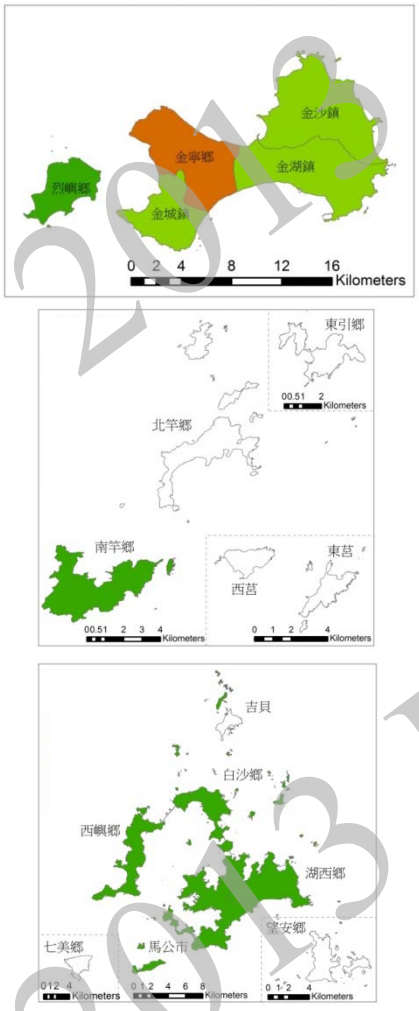


Maps of hazard level (target year, under A1B scenario and no-action plan)

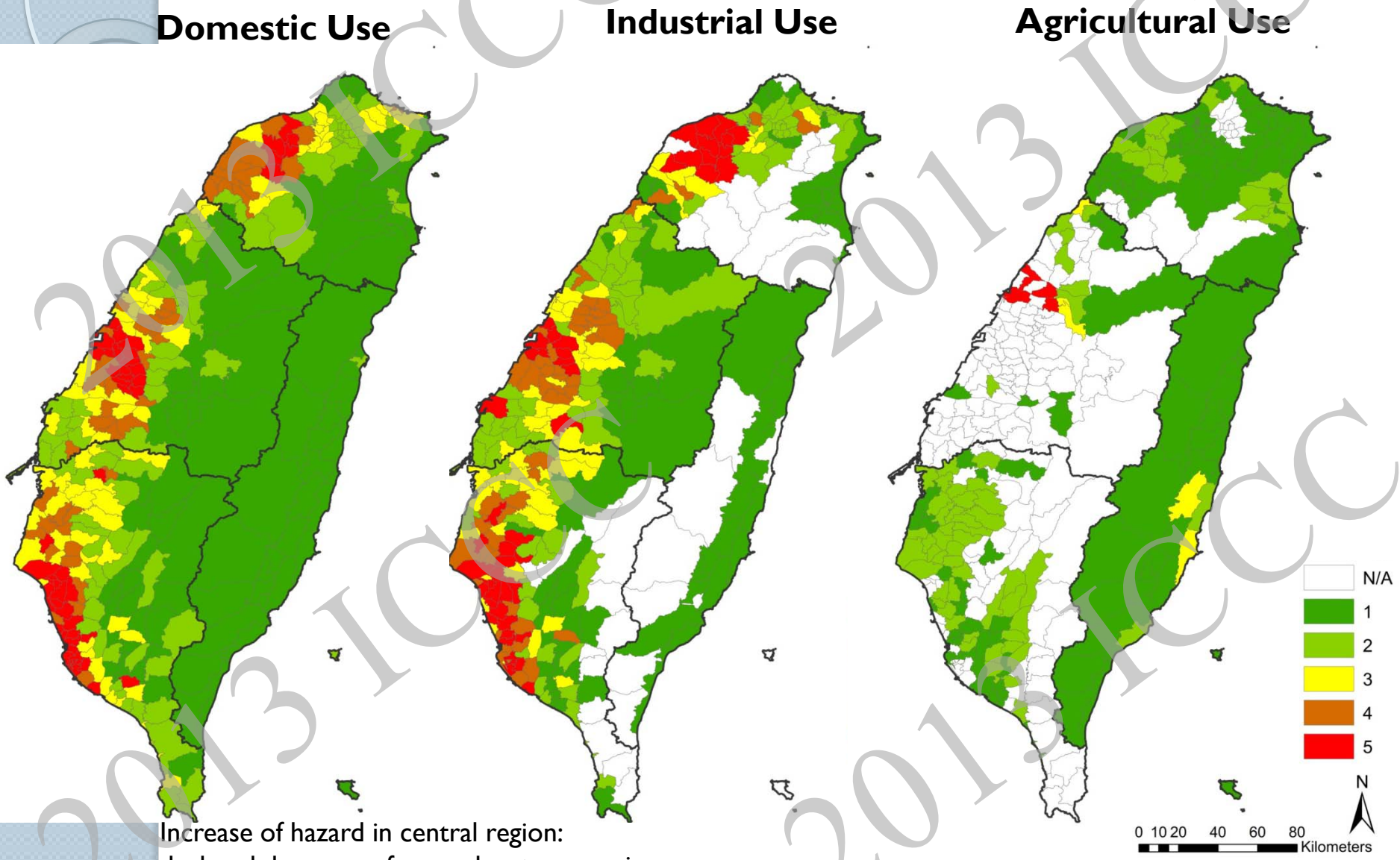
Domestic Use



Industrial Use



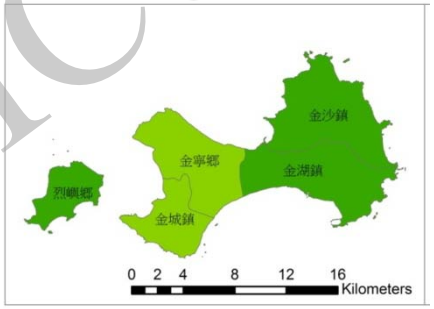
Maps of risk level (A1B scenario, under declared plan)

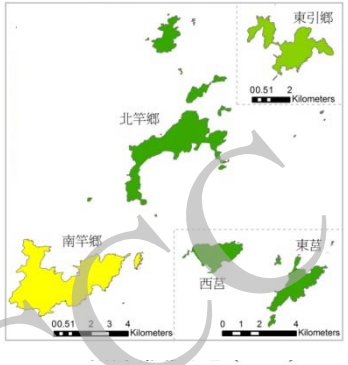


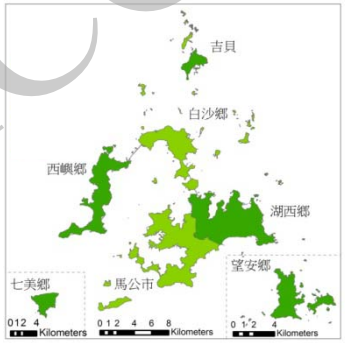
Increase of hazard in central region:
declared decrease of ground water pumping

Maps of hazard level (outlying islands) (target year, under A1B scenario and declared plan)

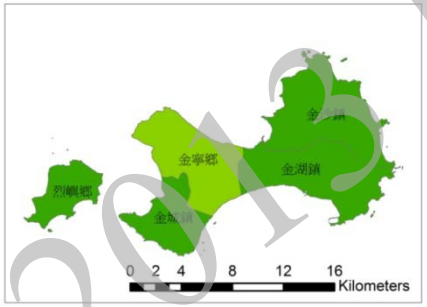
Domestic Use

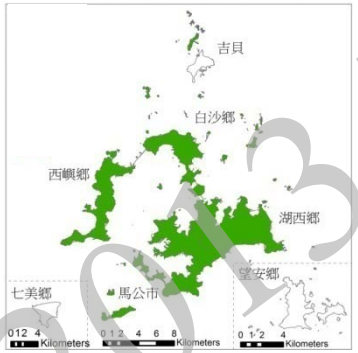


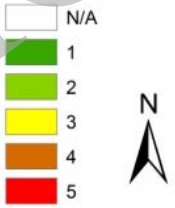




Industrial Use







Mainframe strategies

After referring to international and domestic adaption experiences and incorporating regional characteristics, the main-frame strategies are setup as follows:

- **Northern and Southern Regions:**

  Securing balance between supply and demand under the premise of water resource sustainable management and supply.

- **Central Region:**

  Diversified development and water conservation.

- **Eastern Region:**

  Maintaining sustainable low-risk usage of water resources.

- **Outlying Islands:**

  Risk reduction by water resource development and effective use.

Priority ranking of alternative action plans: Multicritera ordering method

Ex. Eastern Region

- Alternative plans are defined by regional characteristics (underground availability, distance to seashore, etc.)
- Shyoulin & Shoufong Townships of Hualien, Hairuei Township of Taitung:
  - Preferred action after ranking: set up water table well.

Criteria	Matrix of Comparison		Action # 1	2	3	Scores	Ranks
Effective-ness	Action #	1	0	1	0	1	1
		2	0	0	0	0	3
		3	0	1	0	1	1
Sustain-ability	Action #	1	0	0	0	0	2
		2	0	0	0	0	2
		3	1	1	0	2	1
Applic-ability	Action #	1	0	1	1	2	1
		2	0	0	0	0	3
		3	0	1	0	1	1
Urgency	Action #	1	0	1	1	2	1
		2	0	0	1	1	2
		3	0	0	0	0	3

Action #	Action Plan	Effect.	Sustain.	Applic.	Urgen.	∑score	Prior.
1	Water table wells	1	0	2	2	5	1
3	Desalination plants	0	0	0	1	1	3
4	Connect systems	1	2	1	0	4	2

Evaluation of action plans

-Evaluate the action plans by the deficit amended.

Region	Deficit under no-action plan (10^4CMD)	Type of action plan	Adaptation plan	Amendment amount (10^4CMD)	Percent amended
North	17	Declared action plan	G: declared water-resources management plan	8	47.1%
		Diversified development	D1: Dredging of reservoir in Taoyuan	9	52.9%
			D1: Construction of reservoir in Taoyuan		
Central	61.66	Declared action plan	G: declared water-resources management plan	13.03 (Miaoli) +10 (Taichuung)	37.3%
		Diversified development	D1:Desalination plant in Changhua	10.99	17.8%
			D2:Water recycling plant in Taichung	9.00	14.6%
		Efficient management	M1:Replacement of water pipes in Yunlin	1.86	3.0%
		Water conservation	S1:Domestic water conservation plan in Taichung	14.26	23.1%
			S5: Domestic water conservation plan in Yunlin	2.52	4.1%

Codes of adaptation plan
G: Declared water-resources action plan
S: Water conservation/saving
M: Efficient management
D: Diversified development

Evaluation of action plans

-Evaluate the action plans by the deficit amended.

Codes of adaptation plan
G: Declared water-resources action plan
S: Water conservation/saving
M: Efficient management
D: Diversified development

Region	Deficit under no-action plan (10^4CMD)	Type of action plan	Adaptation plan	Amendment amount (10^4CMD)	Percent amended
South	128.79	Declared action plan	G: declared water-resources management plan	7.73(Chiayi) +26.59(Tainan) +46.56(Kaohsiung) +8.80(Pingtun)	69.6%
		Diversified development	D1:Recycling plant in Anping treatment plant Tainan	3	2.3%
			D2:Desalination plant in Kaohsiung	10	7.8%
			D3: Construction of hydraulic facility downstreams of Ailiaoshi	5	3.9%
		Efficient management	M1:Deficit of Chiayi contributed by Yunlin	5.69	4.4%
			M2:Site planning and adjustment of industrial areas in Tainan	14.16	11%
			M3: Site planning and adjustment of industrial areas in Kaohsiung	0.5	0.4%
			M4: Site planning and adjustment of industrial areas in Pingtun	0.76	0.6%
East	0.1784	Declared action plan	G: declared water-resources management plan	0	0%
		Diversified development	D1: Add water-table well in Chinan system of Hualien	0.0845	47%
			D2: Add water-table well in Chinlun system of Taitung	0.0579	33%
			D3: Add water-table well in Shiadashi system of Taitung	0.0197	11%
			D4: Add water-table well in Lidao system of Taitung	0.0163	9%

Evaluation ofaction plans

-Evaluate the action plans by the deficit amended.

Codes of adaptation plan
G: Declared water-resources action plan
S: Water conservation/saving
M: Efficient management
D: Diversified development

Region	Deficit under no-action plan (10^4CMD)	Type of action plan	Adaptation plan	Amendment amount (10^4CMD)	Percent amended
Outlying Islands	1.1309	Declared action plan	G: declared water-resources management plan	1.1019	97.4%
		Diversified development	D1:Increase desalination capacity in Da-Kinmen system of Kinmen	0.0215	1.9%
			D2: Increase desalination capacity in Nankan and Dongyin system of Kinmen	0.0075	0.7%

Evaluation of action plans

-Deficit amended by combinations of action plans

Region	Adaptation plan	Combination	Amendment of deficit (10^4CMD)	Percent amended
North	Declared action plan	G	8.00	47.1%
	Combination 1	G+D1+D2	9.00	100.0%
Central	Declared action plan	G	23.03	37.7%
	Combination 1	G +D1	34.02	55.2 %
	Combination 2	G+D1+D2	43.02	69.8 %
	Combination 3	G+D1+D2+M1	44.88	72.8 %
	Combination 4	G+D1+D2+M1+S1	59.14	95.9 %
	Combination 5	G+D1+D2+M1+S1+S2	61.66	100.0 %
South	Declared action plan	G	89.68	69.6%
	Combination 1	G +D1	92.68	72.0%
	Combination 2	G+D1+D2	102.68	79.7%
	Combination 3	G+D1+D2+D3	107.68	83.6%
	Combination 4	G+D1+D2+D3+M1	113.37	88.0%
	Combination 5	G+D1+D2+D3+M1+M2	127.53	99.0%
	Combination 6	G+D1+D2+D3+M1+M2+M3	128.03	99.4%
	Combination 7	G+D1+D2+D3+M1+M2+M3+M4	128.79	100.0%
East	Declared action plan	G	0.00	0%
	Combination 1	G+D1	0.08	47.0%
	Combination 2	G+D1+D2	0.14	80.0%
	Combination 3	G+D1+D2+D3	0.16	91.0%
	Combination 4	G+D1+D2+D3+D4	0.18	100.0%
Outlying Islands	Declared action plan	G	1.10	97.4%
	Combination 1	G+D1	1.12	99.3%
	Combination 2	G+D1+D2	1.13	100.0%

Remarks on results in Eastern Region and Outlying Islands

- The map of risk level for the eastern region under declared water-resources management plan indicates risk levels of lower than 3 for domestic and industrial water use in all areas, indicating no large-scale adaptation actions are required.
- Under declared water-resources management plan, the risk level of public use of outlying islands are less than 3, indicating no large-scale adaptation actions are required.

Remarks on results in Eastern Region and Outlying Islands

- Because the amount of water use in Eastern Region is relatively low with respect to other regions, and the groundwater potential is abundant, sustainable use of the groundwater would be the optimal option in this region.
- In the Outlying Islands, the amount of water use is lower than other regions and there is a lack of natural water source, outsourcing possibilities (recycling water, sea water) would be the optimal option in this region.

Remarks on impacts by climate change in Taiwan

- In northern region, water supplies for Taoyuan area are always insufficient due to climate change.
- In central region, deficit remains under the impact of climate change in Miaoli, Taichung and Changhua.
- In eastern region, only small deficit exists due to climate change in small areas in Hualien and Taitung.
- In outlying islands only small deficit exists due to climate change in a few islands in Kinmen and Matsu.
- Risk of drought in Taiwan under current settings for the target year (2031) is impacted by climate change (under A1B scenario), but the impact is not dramatic.

Remarks on action plans for Taiwan

- The deficits in all water resource regions can be amended with the adaptation plans actualized.
- However, the action plans proposed are based on A1B scenario and a mid-to-low level of socio-economic growth.
- The scenario and socio-economic growth need to be re-examined periodically, and the action plans revised correspondently.
- Decision makes are recommended to review their strategy, if a climate factor has changed its impact significantly.
- Decision maker should improve the strategy if it does not deliver the benefits they were expected to.

Future works and suggestions

- Integration of concepts of ecosystem services into water resources management as water ecosystem services management under climate change
- Assessment of land use changes impacts on water ecosystem services under climate change
- Connections of ecosystem services, water and food as a cross-sector approach to maintain water and food security under climate change

Thank you for your attention!
Questions?