Drought Risk Assessment in Changing Climate using Hydro-Meteorological and Socio-Economic Indicators

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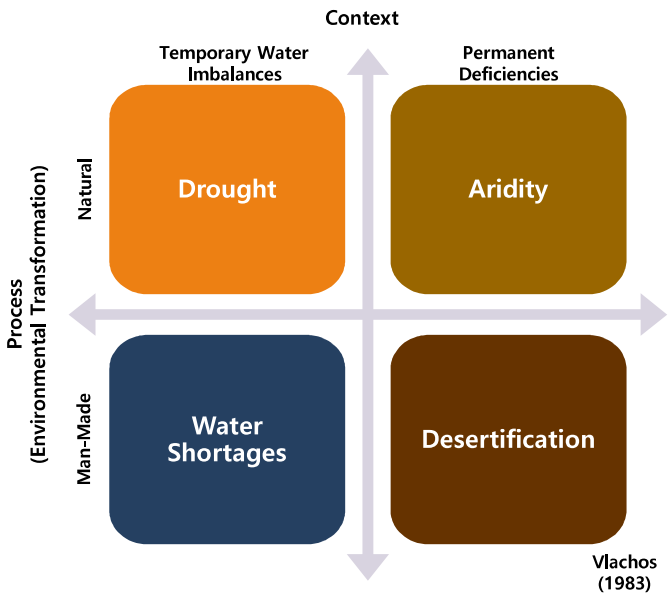
Contents

Background

What is Drought?

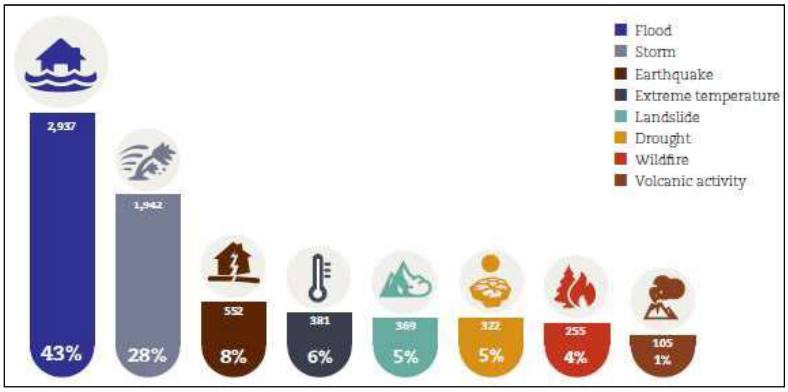


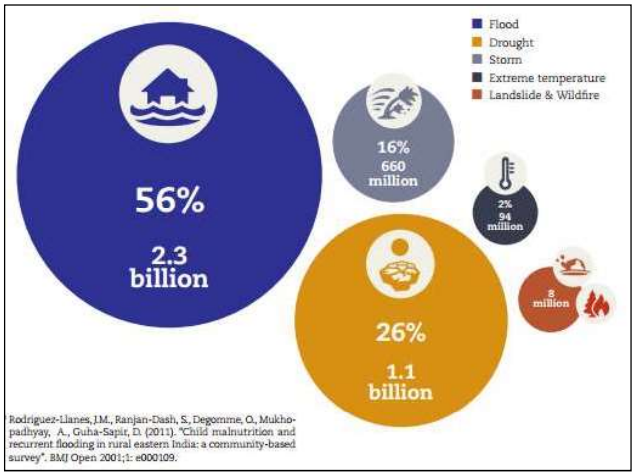
- **Drought refers to the occurrence of an unusual water shortage.**
- **Drought should be assessed based on the shortfall of the climatic averages in the region**
- **If there is no disaster caused by water shortage, it is not necessary to define it as drought.**

Natural Disasters in the World

Ref : The Human cost of weather related disasters(1995-2015)

✓ **Share of occurrence of natural disasters by disaster type (1994-2015)**





✓ **Number of people affected by disasters by disaster type (1994-2015)**

(NB : deaths are excluded from the total affected)

Mega Drought Signals from Google

California May Suffer A 35-Year-Long Megadrought If Planet Continues To Warm

The 2010–2015 megadrought in central Chile: impacts on regional hydroclimate and vegetation

NEWS / THAILAND

Thailand hit by its worst drought in decades

Thai dams run low as an El Nino-induced water shortage reduces reservoirs to critical levels.

30 provinces of Thailand declared drought disaster zones and will receive aid

California's current drought ranks as "exceptionally severe" by historical standards —perhaps the worst such event in 1,200 years.

Why Vietnam Is Running Dry, Worst Drought In Nearly 100 Years

The unusual 2013–2015 drought in South Korea in the context of a multicentury precipitation record: Inferences from a nonstationary, multivariate, Bayesian copula model

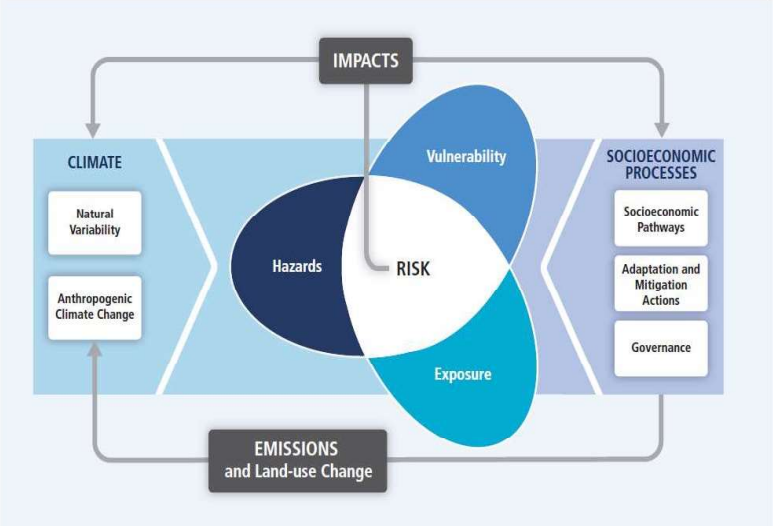
The Millennium Drought in southeast Australia (2001–2009): Natural and human causes and implications for water resources, ecosystems, economy, and society

Drought Risk

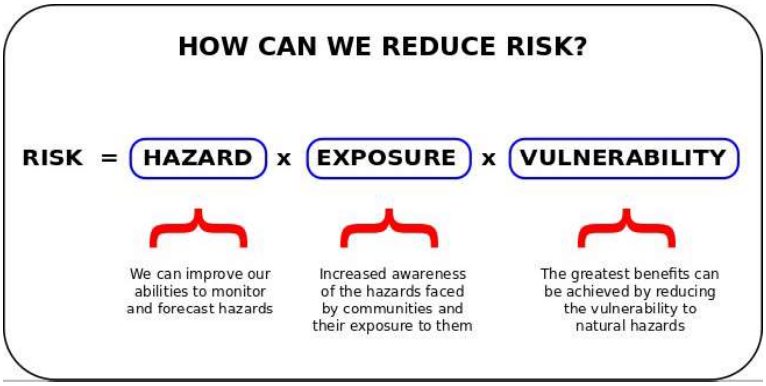
What is Risk ?

"Risk" is defined as the expectation value of losses (deaths, injuries, property, etc.) that would be caused by a hazard.

Disaster Risk = function (Hazard, Exposure, Vulnerability)



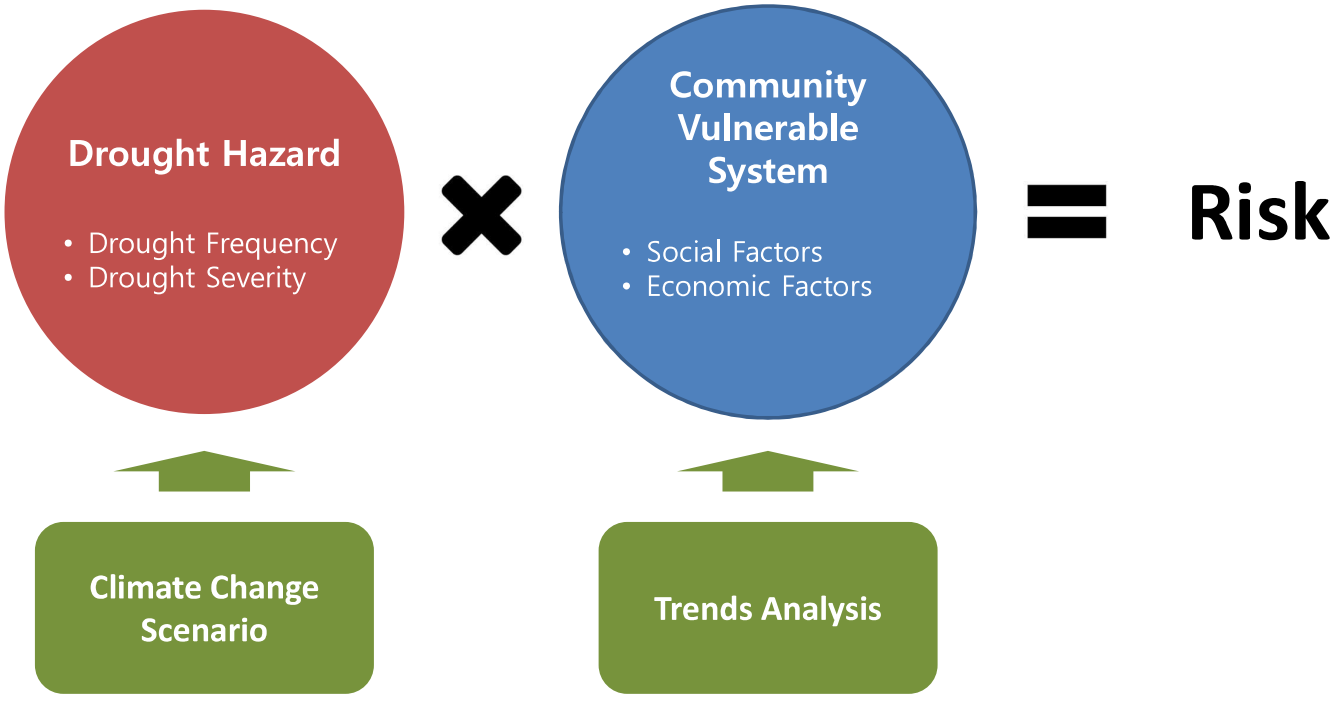
How to Assess Risk ?



USGS

FEMA

How to Assess Future Drought Risk ?

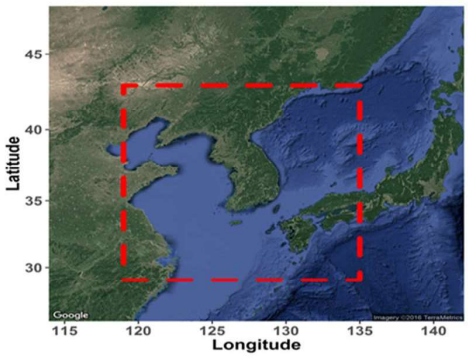


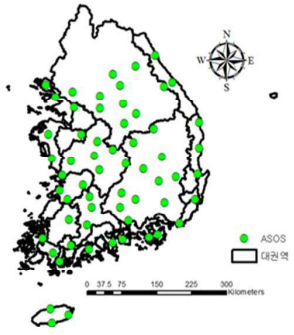
Climate Change

Climate Change Scenario

- **CIMP5 GCMs**

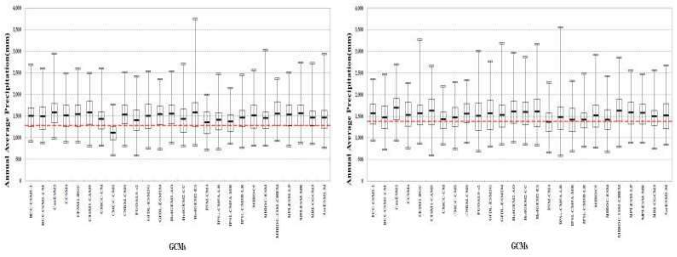
GCMs	Resolution	Institution
CMCC-CM	0.750 x 0.748	Centro Euro-Mediterraneo per I Cambiamenti Climatici
CCSM4	1.250 x 0.942	National Center for Atmospheric Research
CESM1-BGC	1.250 x 0.942	
CESM1-CAM5	1.250 x 0.942	
BCC-CSM1-1-M	1.125 x 1.122	Beijing Climate Center, China Meteorological Administration
MRI-CGCM3	1.125 x 1.122	Meteorological Research Institute
CNRM-CM5	1.406 x 1.401	Centre National de Recherches Meteorologiques
MIROC5	1.406 x 1.401	Atmosphere and Ocean Research Institute (The University of Tokyo)
HadGEM2-AO	1.875 x 1.250	Met Office Hadley Centre
HadGEM2-CC	1.875 x 1.250	
HadGEM2-ES	1.875 x 1.250	
INM-CM4	2.000 x 1.500	Institute for Numerical Mathematics
IPSL-CM5A-MR	2.500 x 1.268	Institut Pierre-Simon Laplace
MPI-ESM-LR	1.875 x 1.865	Max Planck Institute for Meteorology (MPI-M)
MPI-ESM-MR	1.875 x 1.865	
FGOALS-s2	2.813 x 1.659	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences
NorESM1-M	2.500 x 1.895	Norwegian Climate Centre
GFDL-ESM2G	2.500 x 2.023	Geophysical Fluid Dynamics Laboratory
GFDL-ESM2M	2.500 x 2.023	Geophysical Fluid Dynamics Laboratory
IPSL-CM5A-LR	3.750 x 1.895	Institut Pierre Simon Laplace
IPSL-CM5B-LR	3.750 x 1.895	
BCC-CSM1-1	2.813 x 2.791	Beijing Climate Center, China Meteorological Administration
CanESM2	2.813 x 2.791	Canadian Centre for Climate Modelling and Analysis
MIROC-ESM-CHEM	2.813 x 2.791	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MIROC-ESM	2.813 x 2.791	





GCMs Assessment

Annual Precipitation



- Annual precipitation from 2011 to 2099

No. of dry days

Scenario / GCM	RCP 4.5	RCP 8.5	Scenario / GCM	RCP 4.5	RCP 8.5
BCC-CSM1-1	30,160	35,371	HadGEM2-CC	43,272	38,727
BCC-CSM1-1-M	37,119	33,614	HadGEM2-ES	40,381	45,097
CanESM2	27,865	31,468	INM-CM4	41,504	36,828
CCSM4	30,936	38,028	IPSL-CM5A-LR	51,046	56,013
CESM1-BGC	34,263	37,991	IPSL-CM5A-MR	41,119	46,405
CESM1-CAM5	37,166	38,398	IPSL-CM5B-LR	43,993	48,978
CMCC-CM	27,074	28,678	MIROC5	39,849	35,449
CMCC-CMS	33,116	50,449	MIROC-ESM	32,524	32,067
CNRM-CM5	31,497	33,951	MIROC-ESM-CHEM	27,569	34,126
FGOALS-s2	42,289	52,112	MPI-ESM-LR	48,919	44,575
GFDL-ESM2G	57,017	60,170	MPI-ESM-MR	42,053	40,634
GFDL-ESM2M	48,381	50,113	MRI-CGCM3	27,436	32,158
HadGEM2-AO	44,636	41,201	NorESM1-M	47,602	56,333

Drought Occurrence Frequency

Drought Spell / GCMs	SPI < -1 RCP4.5	SPI < -1 RCP8.5	Drought Spell / GCMs	SPI < -1 RCP4.5	SPI < -1 RCP8.5
BCC-CSM1-1	804	833	HadGEM2-CC	1,239	809
BCC-CSM1-1-M	1,146	1,194	HadGEM2-ES	973	930
CanESM2	793	682	INM-CM4	1,521	1,405
CCSM4	951	948	IPSL-CM5A-LR	1,352	1,317
CESM1-BGC	948	838	IPSL-CM5A-MR	1,425	1,685
CESM1-CAM5	722	809	IPSL-CM5B-LR	843	1,055
CMCC-CM	1,083	1,083	MIROC5	1,057	1,068
CMCC-CMS	2,425	951	MIROC-ESM	996	1,212
CNRM-CM5	932	841	MIROC-ESM-CHEM	802	772
FGOALS-s2	1,211	1,356	MPI-ESM-LR	736	724
GFDL-ESM2G	1,191	1,138	MPI-ESM-MR	768	651
GFDL-ESM2M	941	1,035	MRI-CGCM3	880	886
HadGEM2-AO	888	836	NorESM1-M	1,139	1,106

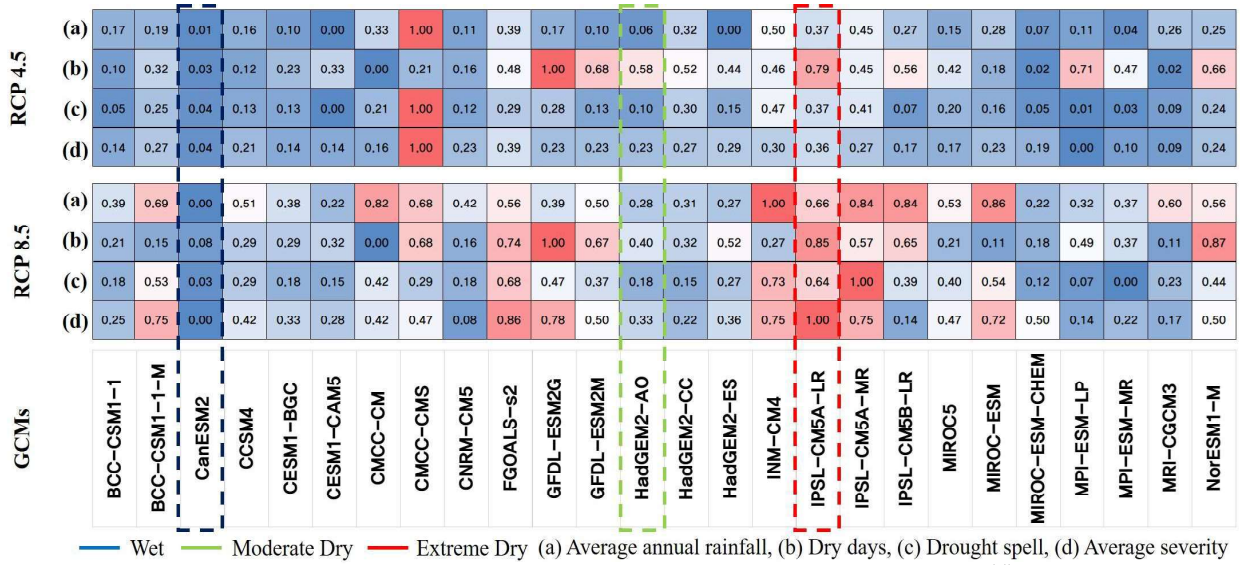
- Using SPI(6) using monthly precipitation
- Count the frequency of SPI < -1

Average Drought Severity

SPI / GCMs	SPI < -1 RCP4.5	SPI < -1 RCP8.5	SPI / GCMs	SPI < -1 RCP4.5	SPI < -1 RCP8.5
BCC-CSM1-1	-1.63	-1.63	HadGEM2-CC	-1.72	-1.62
BCC-CSM1-1-M	-1.72	-1.81	HadGEM2-ES	-1.73	-1.67
CanESM2	-1.56	-1.54	INM-CM4	-1.74	-1.81
CCSM4	-1.68	-1.69	IPSL-CM5A-LR	-1.78	-1.90
CESM1-BGC	-1.63	-1.66	IPSL-CM5A-MR	-1.72	-1.81
CESM1-CAM5	-1.63	-1.64	IPSL-CM5B-LR	-1.65	-1.59
CMCC-CM	-1.64	-1.69	MIROC5	-1.65	-1.71
CMCC-CMS	-2.23	-1.71	MIROC-ESM	-1.69	-1.80
CNRM-CM5	-1.69	-1.57	MIROC-ESM-CHEM	-1.66	-1.72
FGOALS-s2	-1.80	-1.85	MPI-ESM-LR	-1.53	-1.59
GFDL-ESM2G	-1.69	-1.82	MPI-ESM-MR	-1.60	-1.62
GFDL-ESM2M	-1.69	-1.72	MRI-CGCM3	-1.59	-1.60
HadGEM2-AO	-1.69	-1.66	NorESM1-M	-1.70	-1.72

- Using SPI(6) sing monthly precipitation
- Calculate Average Severity SPI < -1

GCM Selection for Drought Projection



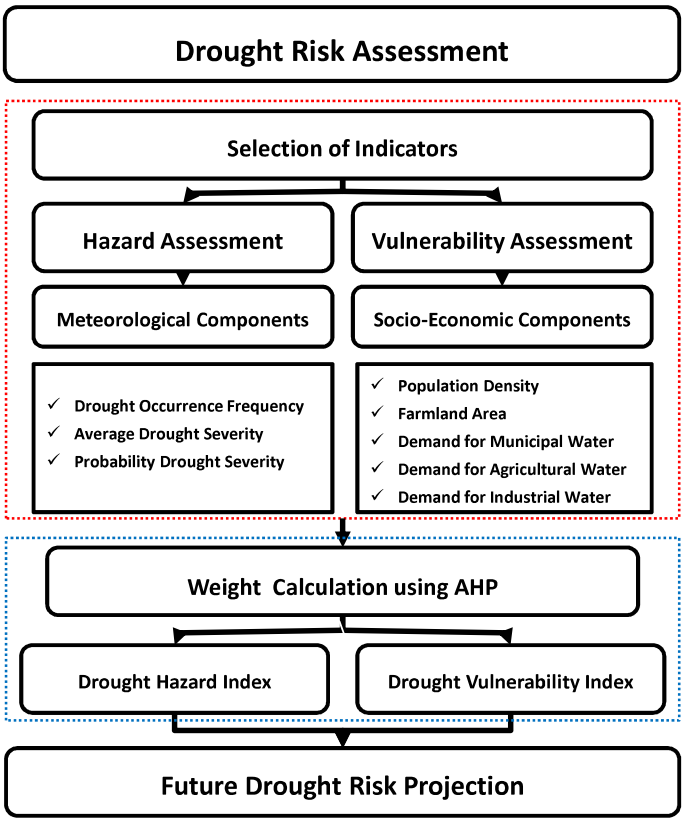
출 처 : Assessment of CMIP5 GCMs for future extreme drought analysis (Hong et al. 2018)

- Selected GCMs

IPSL-CM5A-LR(Extremely Dry), HadGEM2-AO(Moderate Dry), CanESM2(Wet)

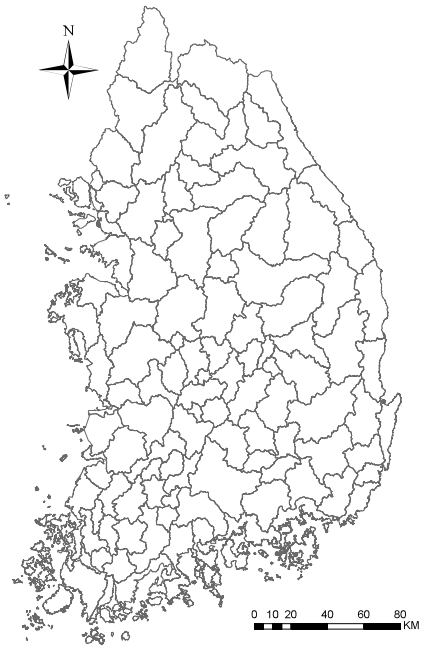
Assessment of Drought Risk

Methodology



Study Area

Korean 117 River Basin



Data

⇒ Assessment Period

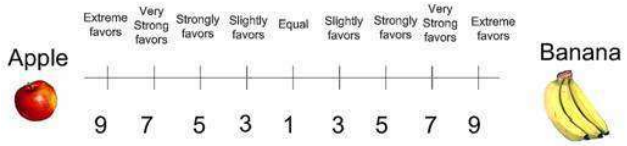
Period	Year	Class	Information
Past	1976-2005	S0	Past
Future	2011-2040	S1	Near-future
	2041-2070	S2	Mid-future
	2071-2099	S3	Far-future

⇒ Indicators for Drought Risk Assessment

Period	Hazard	Vulnerability
Past	✓ SPI	✓ Population Density
Future	✓ Drought Frequency ✓ Average Drought Severity ✓ Probability Drought Severity	✓ Farmland Area ✓ Demand of Municipal Water ✓ Demand of Industrial Water ✓ Demand of Agricultural Water
Source	✓ KMA ✓ APCC	✓ WAMIS ✓ Statistics of Korea

AHP (Analysis Hierarchy Process)

- A Multi Criteria decision making method to derive ratio scales from pair-wise comparisons.
- AHP allow some small inconsistency in judgment because human is not always consistent.



Ⅰ. Meteorological factor (Hazard)

The following is an assessment of the importance of meteorological factor in the vulnerability priority rank assessment criteria. Please check(✓) the score box by assessing the relative importance of the two evaluation indexes.

Assessment Indicator	left more than Important ←								→ right more than Important							Assessment Indicator
	AI		VI		Im		SI		Sa		SI		Im		VI		AI	
	9/1	8/1	7/1	6/1	5/1	4/1	3/1	2/1	1/1	1/2	1/3	1/4	1/5	1/6	1/7	1/8	1/9	
Drought Occurrence Frequency									✓									Average Drought Severity
					✓													Probability Drought Severity
Average Drought Severity					✓													Probability Drought Severity

Ⅱ. Socio-Economic factor (Vulnerability)

The following is an assessment of the importance of socio-economic factors in the vulnerability priority rank assessment criteria. Please check(✓) the score box by assessing the relative importance of the two evaluation indexes.

Assessment Indicator	left more than Important ←								→ right more than Important							Assessment Indicator
	AI		VI		Im		SI		Sa		SI		Im		VI		AI	
	9/1	8/1	7/1	6/1	5/1	4/1	3/1	2/1	1/1	1/2	1/3	1/4	1/5	1/6	1/7	1/8	1/9	
Population Density									✓					✓				Farmland Area
									✓									Demand of Municipal Water
									✓					✓				Demand of Agricultural Water
									✓									Demand of Industrial Water
Farmland Area									✓				✓					Demand of Municipal Water
									✓									Demand of Agricultural Water
									✓				✓					Demand of Industrial Water
Demand of Municipal Water									✓					✓				Demand of Agricultural Water
									✓									Demand of Industrial Water
Demand of Agricultural Water									✓				✓					Demand of Industrial Water

Weighting Factors

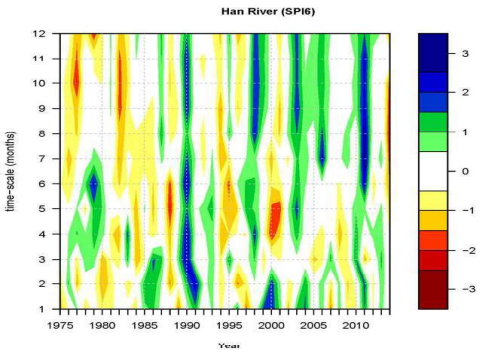
위해성	Drought Occurrence Frequency (DOF)	Average Drought Severity (ADS)	Probability Drought Severity (PDS)	Consistency Index
Weight	0.458	0.286	0.256	0.0013

취약성	Population Density (PD)	Farmland Area (FA)	Demand for Municipal Water (DMW)	Demand for Agricultural Water (DAW)	Demand for industrial Water (DIW)	Consistency Index
Weight	0.236	0.166	0.322	0.186	0.089	0.095

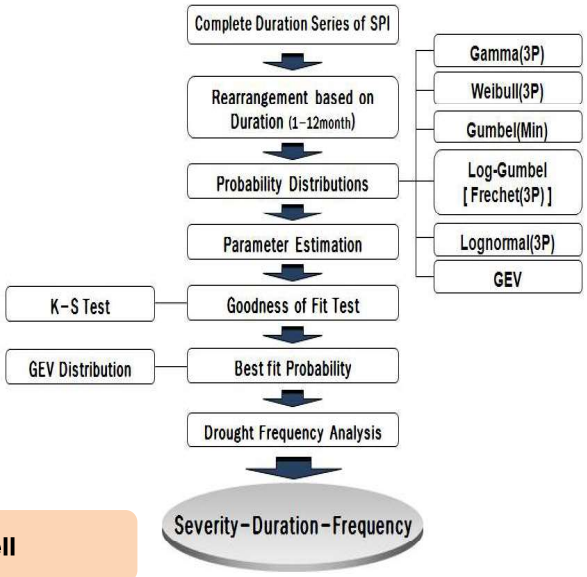
- **Hazard** = 0.458ⅩDOF + 0.286ⅩADS + 0.256ⅩPDS
- **Vulnerability** = 0.236ⅩPD + 0.166ⅩFA + 0.322ⅩDMW + 0.186ⅩDAW + 0.089ⅩDIW
- **Risk** = Hazard Ⅹ Vulnerability

Data for Hazard Assessment

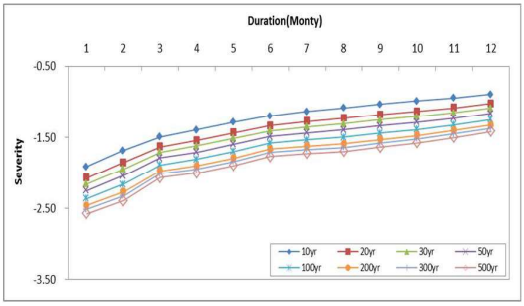
SPI



Drought Frequency Analysis



SDF (severity-duration-frequency)

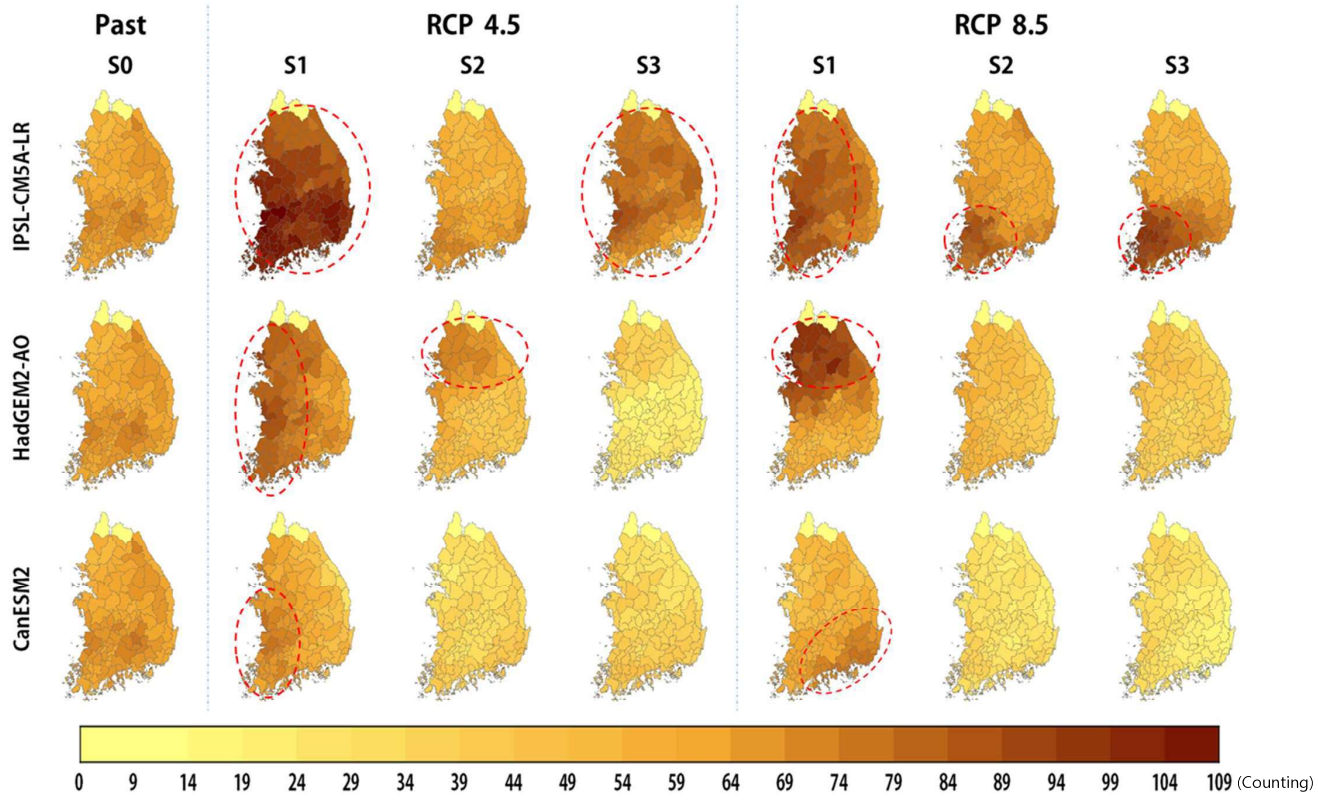


Dry Spell

No	Year	Magnitude	Severity	Duration (Months)	Return Period (Year)
1	2014	-16.3	-1.4	12	300
2	1982	-12.8	-1.3	10	50
3	1988	-12.8	-1.2	11	30

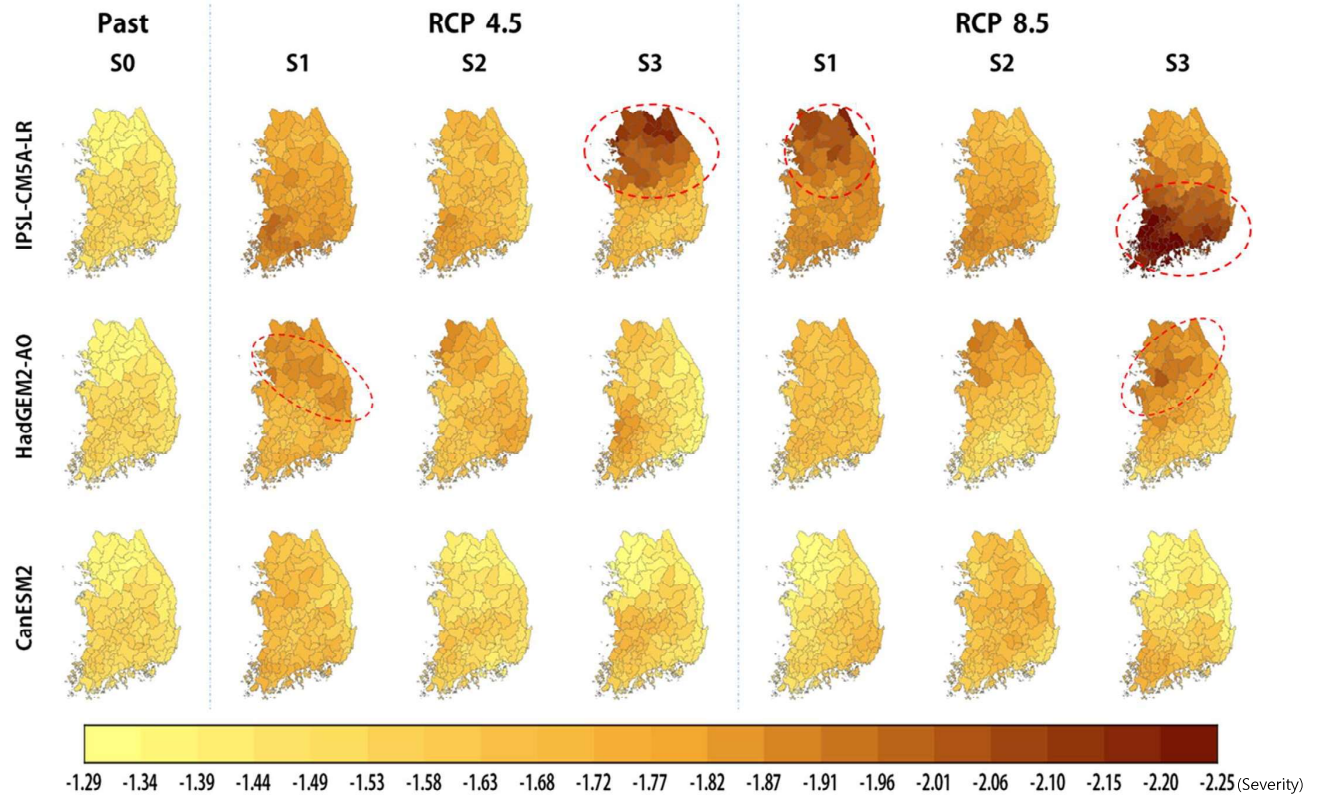
Hazard Indicators

- **Drought Occurrence Frequency (DOF) – Dry Spell with SPI**



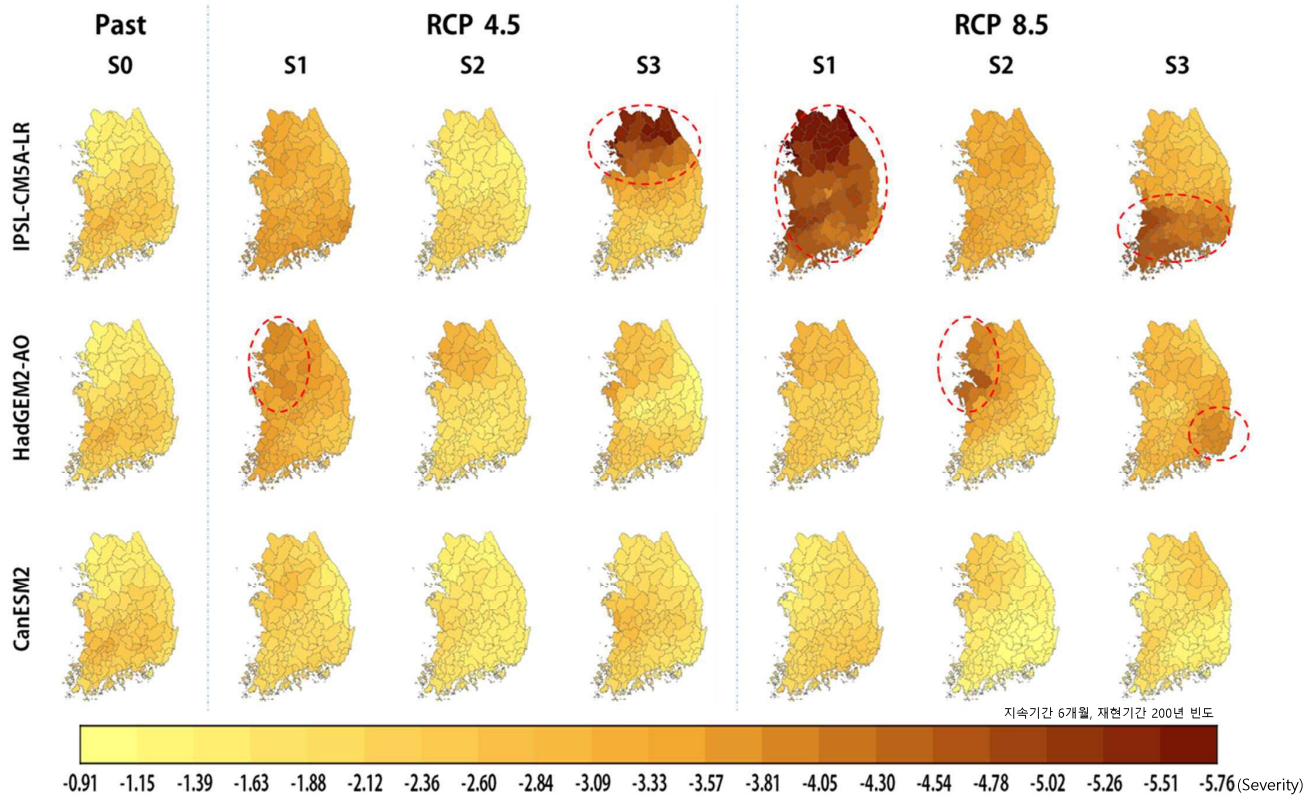
Hazard Indicators

- **Average Drought Severity (ADS) – Dry Spell with SPI**



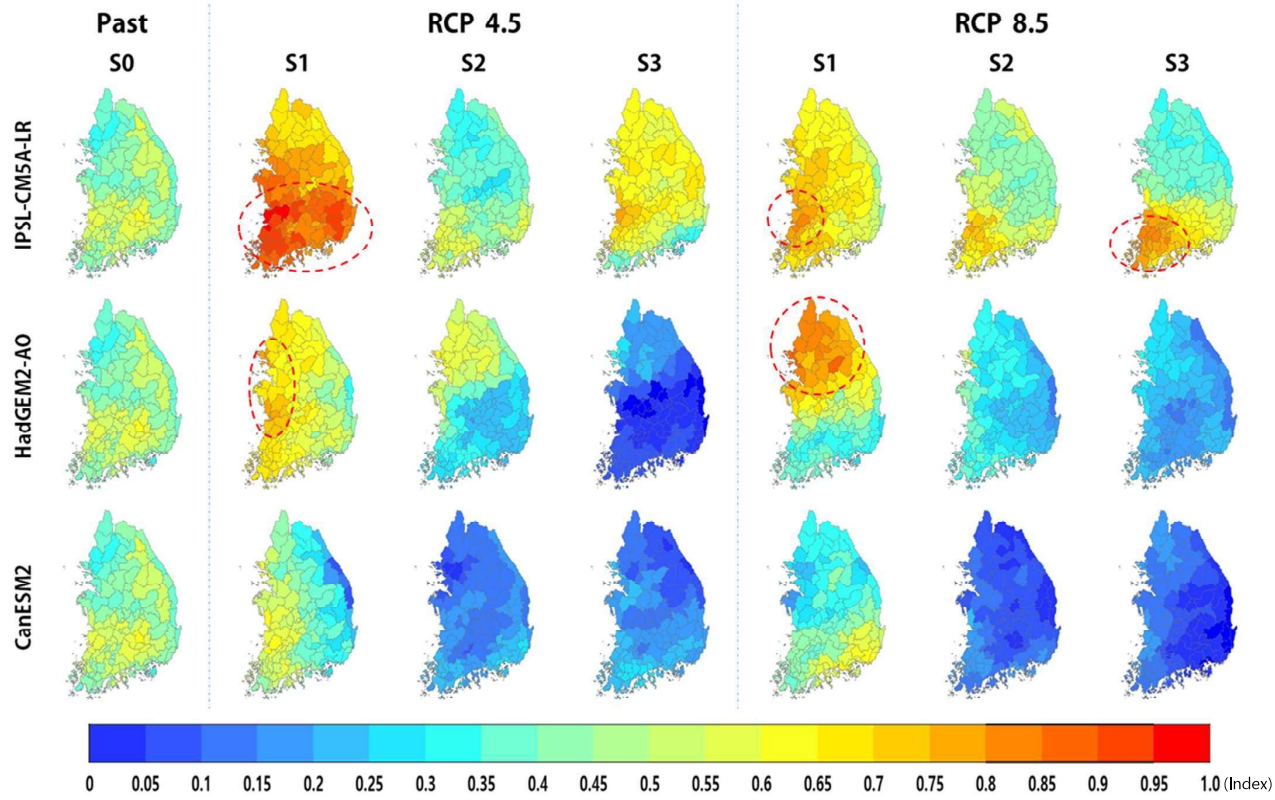
Hazard Indicators

- **Probability Drought Severity (PDS) – Drought Frequency Analysis**



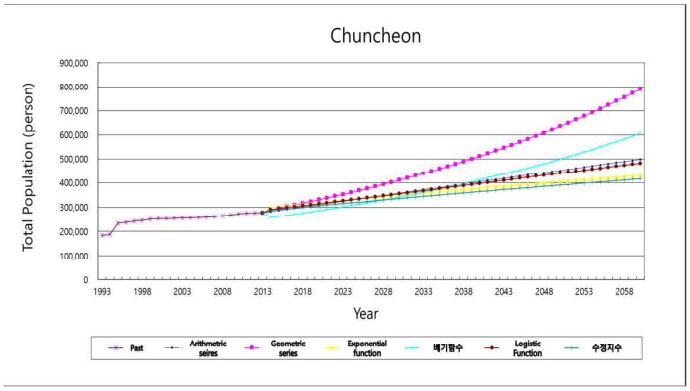
Drought Hazard Index (DHI)

- **DHI = 0.458 X DOF + 0.286 X ADS + 0.256 X PDS**



Data for Vulnerability Assessment

Population



- Population data of National Statistical Office
- Forecast future population by five univariate time series prediction models(arithmetic, logistic function..)

Farmland Area Forecast

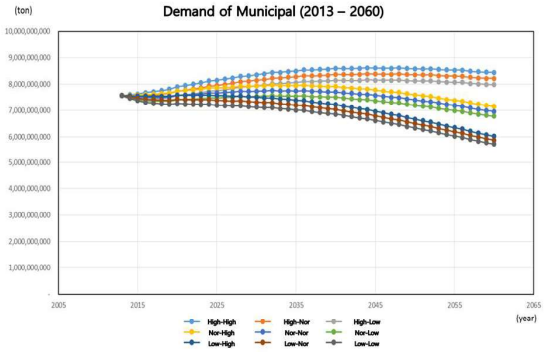
Class	Content of key indicators by scenario
High Demand	Maintain the Farmland of 1,656,000ha in 2025
Average Demand	Maintain the Farmland of 1,631,000ha in 2025
Low Demand	Maintain the Farmland of 1,607,000ha in 2025

Source : Agricultural Outlook 2016, Korea Rural Economic Institute

- Farmland area of WAMIS Korea
- Forecast the future farmland area based on average demand in KREI's Agricultural Outlook (2016)

Data for Vulnerability Assessment

Demand of Municipal Water



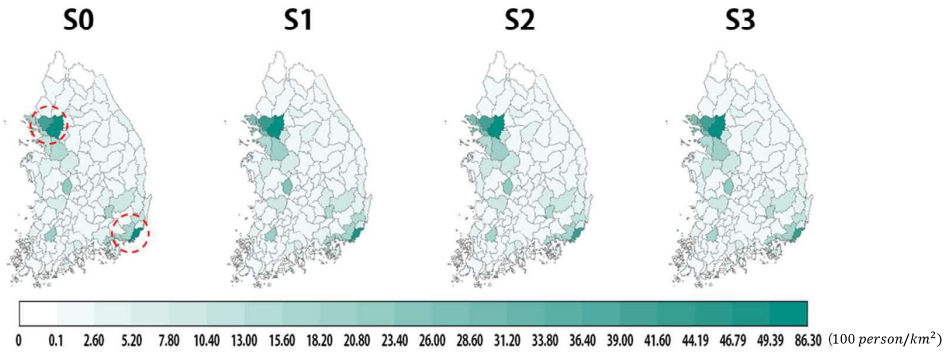
Demand of Industrial Water

Demand of Agricultural Water

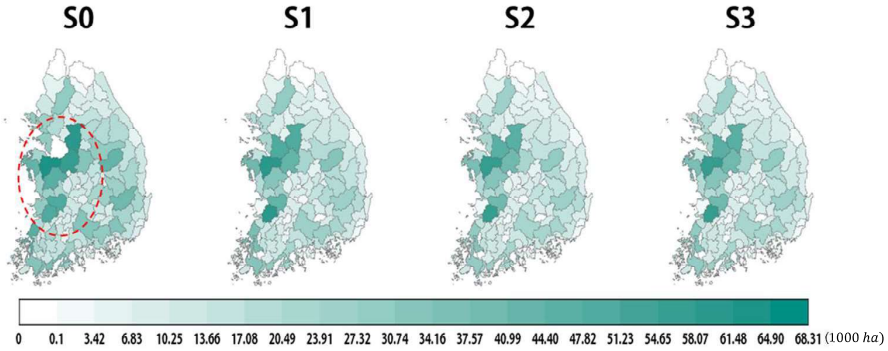
- Population, lpcd, Industrial Area, Farmland Area ….
- National Master Plans for Water Resources Management of Korea (Water Vision2020)

Vulnerability Indicators

- **Population Density (PD)**

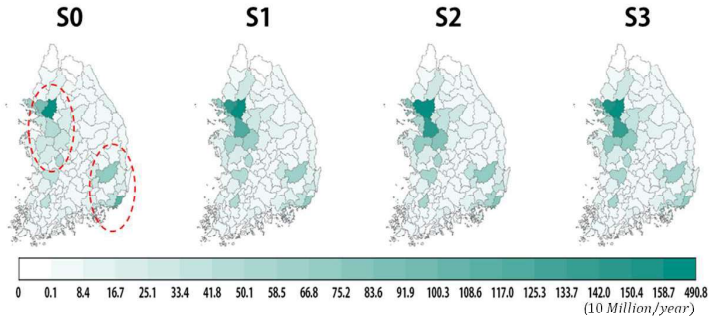


- **Farmland Area (FA)**

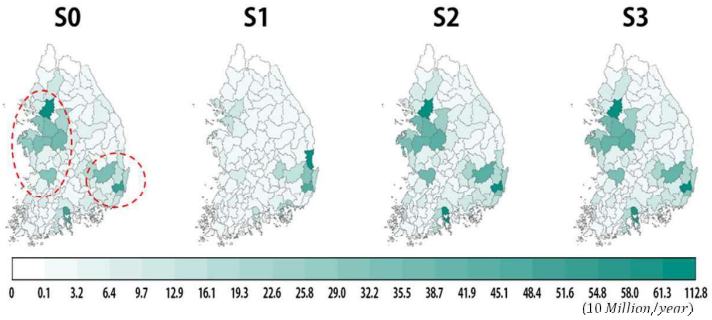


Vulnerability Indicator

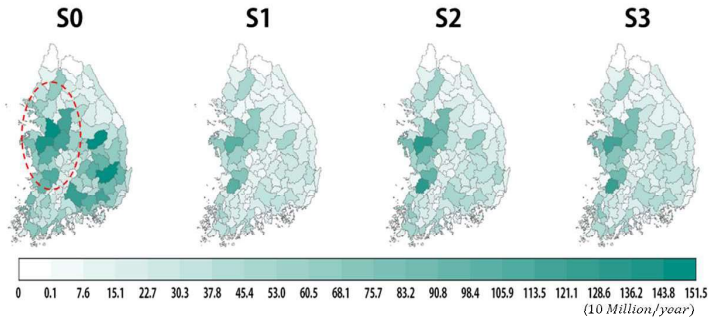
- **Demand of Municipal Water (DMW)**



- **Demand of Industrial Water (DIW)**

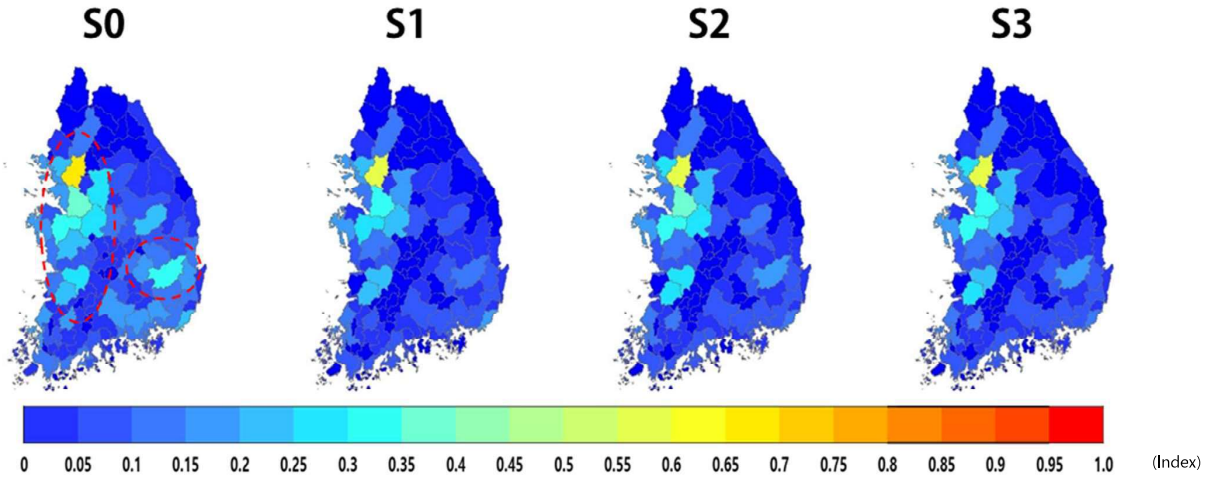


- **Demand of Agricultural Water (DAW)**



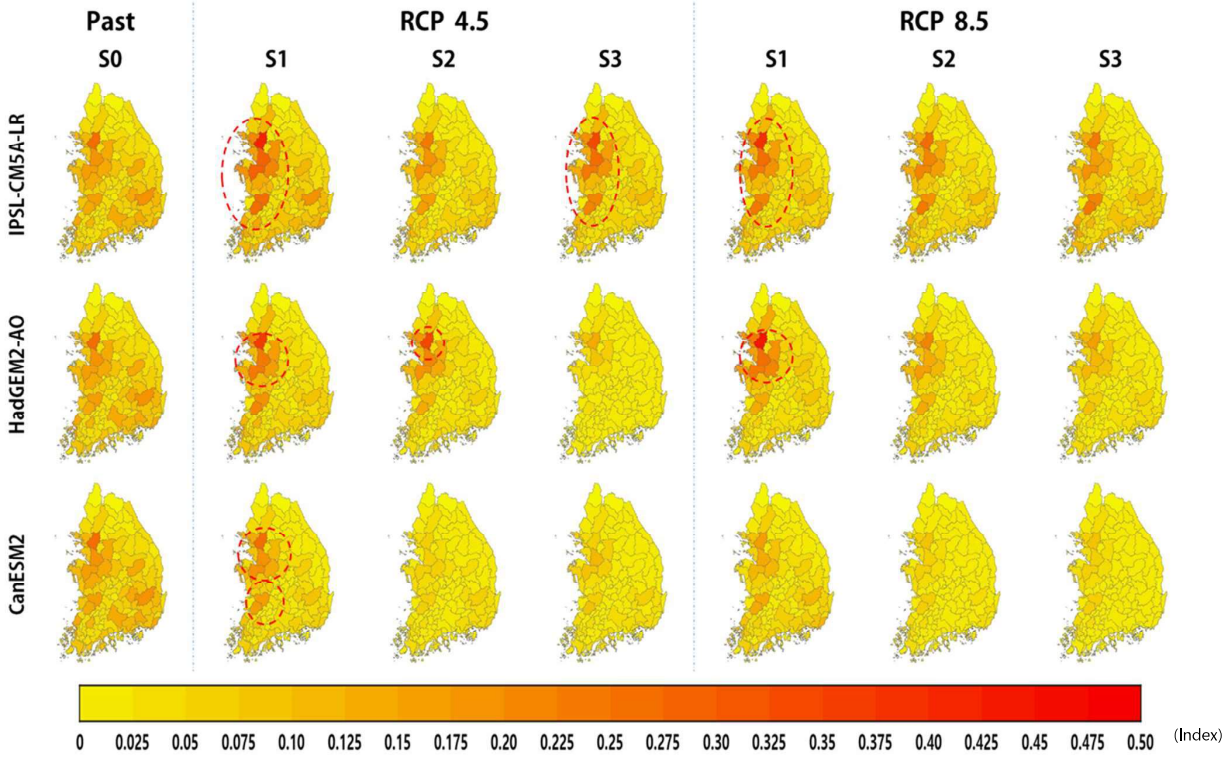
Drought Vulnerability Index (DVI)

- DVI = 0.236ⅩPD + 0.166ⅩFA + 0.322ⅩDMW + 0.186ⅩDAW + 0.089ⅩDIW

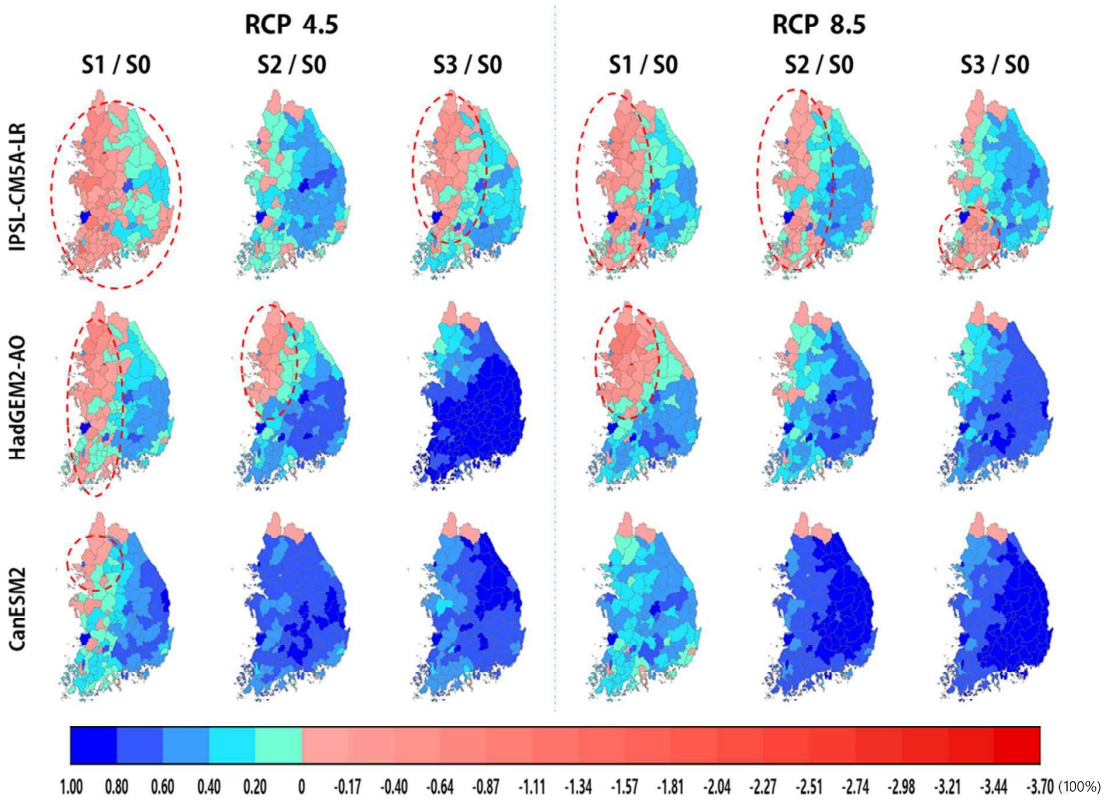


Drought Risk Index (DRI)

- DRI = DHI Ⅹ DVI



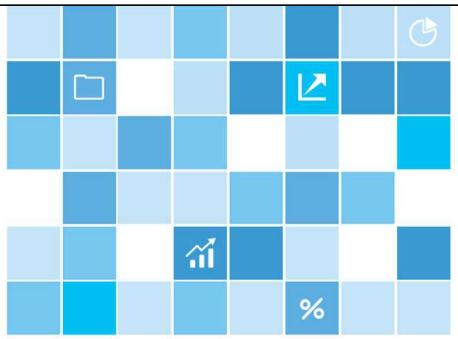
Change of Future Drought Risk



Conclusions

Conclusions

- The future drought risk of the Korean peninsula varies according to climate change scenarios.
- According to the projected drought risk, the risk of drought in the Han River and Yeongsan River basins increased compared to the past.
- According to future period analysis, the drought risk in S1 (near future) period is increased most severely.
- The results the future drought risk projection are expected to be used as basic data for drought management and preparedness.



Thank You

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