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Ministry of Environment

Regional Drought Risk Assessment Using a Gaussian Mixture Model

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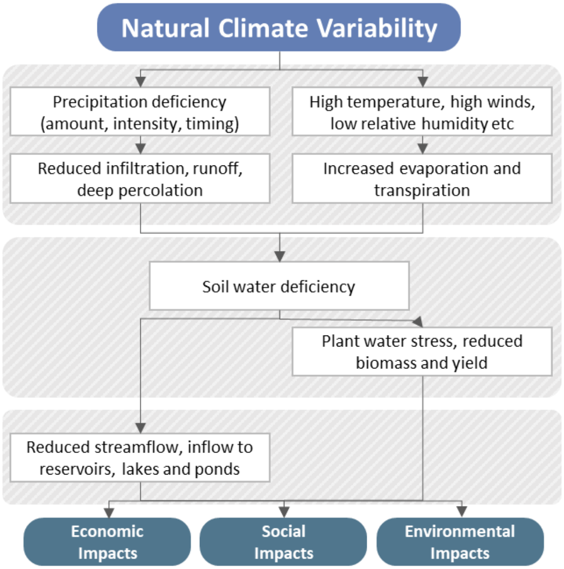
01 Introduction

● Background

- **Drought risk assessment is needed to reduce the risk of negative effects related to drought.**
  - Drought is a general term for an iterative phenomenon of persistent, long-term lack of precipitation, which can lead to water shortages.
  - Drought is a complex phenomenon, and can be categorized as meteorological, hydrological, agricultural, and socioeconomic, which are interrelated.
  - In addition, drought occurs more extensively over a long period than other natural disasters, resulting in significant damage.
  - Drought often wreaks havoc on the physical and socioeconomic environment and the human-natural system.



- **It is necessary to develop a conceptual drought risk assessment framework, which is the context of the combined role of hazard and vulnerability of a region.**
  - Drought risk is dependent largely on a region's vulnerability to natural hazards as well as the various meteorological characteristics of the area.
  - Similar meteorological droughts also cause different effects and damages from droughts depending on regional characteristics.

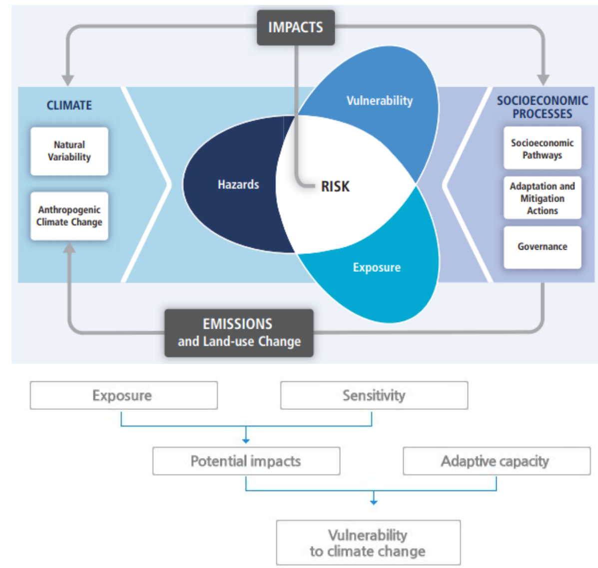
01 Introduction

Definition

- **Risk refers to the potential consequences of an uncertain outcome, and it results from the interaction of hazard and vulnerability.**
  - Risk is defined as the product of the probability of event occurrence and the negative result.

Drought Risk = **Drought Hazard** × **Drought Vulnerability**

< Definition of IPCC risk and vulnerability >



- **Definition of drought risk**
  - Drought is classified into drought as a hazard, which means the cause of physical harm, and drought as a disaster, which means an event that causes damage to society.
  - Drought Hazard : The climate-related physical impacts of drought.
  - Drought Vulnerability : The predisposition of factors to be adversely affected by a drought event.
- **In the disaster mitigation field, the risk focuses on vulnerability, where risk reduction is a major concern and is defined in cultural, political, and economic terms.**

01 Introduction

World Water Congress

● Case study and Purpose

- **Comprehensive understanding of drought implications for regional socioeconomics is needed in terms of hazard, vulnerability, and risk.**

  - Drought exposure, vulnerability, and risk are evaluated using various factors.

> ✓ Vargas and Paneque(2017) calculated the drought vulnerability of the river basin scale by arithmetically averaging the factors of exposure, sensitivity, and adaptive capacity.
> ✓ Ahmadalipour (2017) evaluated the risk of drought by multiplying hazard, exposure, and vulnerability.

- **Because precision in vulnerability assessments is a key factor in enhancing the accuracy of risk assessment, a major concern in quantifying vulnerability is selection of relevant weights.**

  - Probability and statistical methods are applied to exclude subjective factors in integrating various factors and reduce uncertainty in risk assessment.

> ✓ Moon et al.(2021) applied AHP and entropy method as a weighting method for evaluating the vulnerability of agricultural drought.
> ✓ Kim et al.(2019) used PCA and entropy methods to calculate the drought vulnerability index.
> ✓ Mihunov and Lam(2020) used the Bayesian Network to integrate agricultural, socioeconomic, water resources, and energy-related factors into the drought resilience index.

- **The aim of this study is to identify various levels of hazard due to drought vulnerability to identify regions most susceptible to drought.**
- **The performance of various weighting methods is investigated to characterize and quantify drought vulnerability and drought risk.**

02 Study area and Data

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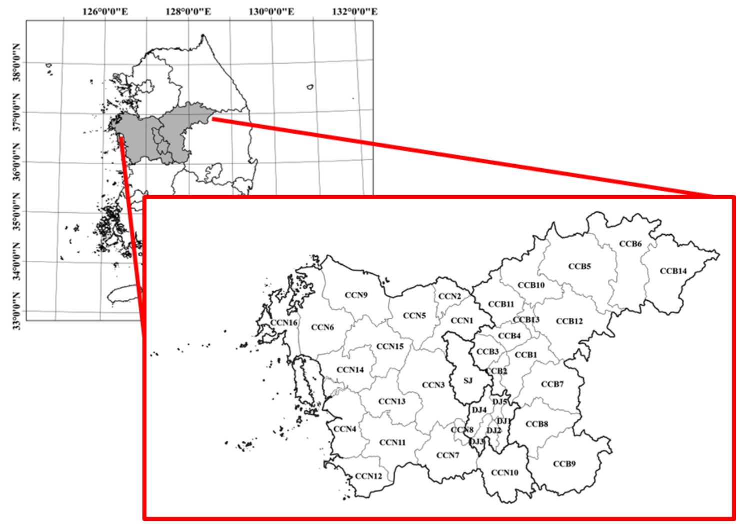
● Study area

- **The area of the Chungcheong-do(CC) was hit hard by the extreme drought in 2015, and the water reservoirs were critically low compared to their maxima.**
  - This province consists of 14 districts in Chungcheongbuk-do(CCB), 16 districts in Chungcheongnam-do(CCN), 5 districts in the Daejoen(DJ) metropolitan area, and Sejong City(SJ).
  - The province area about 16,641 km2 and its population is about 5,534,000.



● Research data

- **Two types of data were used to evaluate drought risk.**
- **Drought hazard index**
  - The station-based daily precipitation were collected by the KMA from 1973 to 2018.
- **Drought vulnerability index**
  - The data quantifying socioeconomic vulnerability to drought.

02 Study area and Data

● Selection of evaluation factors for vulnerability assessment

- **We investigated literature and case studies related to vulnerability and selected the evaluation factors that are consistent with the meaning of drought vulnerability.**
  - To calculate drought vulnerability, it is necessary to derive the socioeconomic influence factors related to drought vulnerabilities in the region.
  - We identified the influence factors based on various government reports and case studies, and selected evaluation factors considering frequency of use in other case studies and their degree of correlation with drought vulnerability.
  - Considering the ease of data collection and redundancy, we selected 8 indicators.

Reference	Population	Daily water supply per capita	Farm population	Number of recipient of basic living	Water fare gap indicator	Non-intake region from four large rivers	Area of industrial complex	Population density	Number of solitary senior citizen	Amount of underground water usage	Amount of water available per capita	Water supply ratio	Water usage equity	Financial soundness for water resources	Amount of water usage	Damage sensitivity	Agricultural land area	Area of planned industrial complex
A		√	√	√					√									
B			√							√							√	
C							√											
D			√	√				√	√									
E	√	√						√		√					√			
F				√		√		√	√								√	√
G	√																	
H					√						√	√	√	√	√			
I			√					√							√			
J																√		
Selec-tion			●					●							●			

▲ The frequency of use in case study

The degree of relation with the concept of vulnerability ▶

Factors	Meaning of factors	Relationship
Population	The number of population on resident registration	High
Daily water supply per capita	Water supply usage is divided into water supply population	High
Farm population	The number of people engaged in agriculture	High
Number of recipient of basic living	The number of basic living recipients	Low
Water fare gap indicator	The index which collects the charge about the water resources and compared by region	Low
Non-intake region from four large rivers	Region without a source of water for the four major rivers	Low
Area of industrial complex	Site area of industrial complex	High
Population density	The number of people per unit area	High
Number of solitary senior citizen	The number of solitary senior citizen	Low
Amount of underground water usage	Status of use of underground water development and utilization by purpose (life, industry, agriculture, etc.)	Normal
Amount of water available per capita	The annual precipitation by region is divided by the local population	High
Water supply ratio	A measure of the welfare level of the region utilizing water resources	High
Water usage equity	Equity of access to water use	Normal
Financial soundness for water resources	The rate of being covered with the water related contribution or the water cost among the water use cost	Normal
Amount of water usage	The value of water resources used in living, industrial, agricultural water by region	High
Damage sensitivity	The value of how sensitively the residents are to the water shortage	Normal
Agricultural land area	The value of agricultural land area	High
Area of planned industrial complex	The area of site of the site industrial complex	High

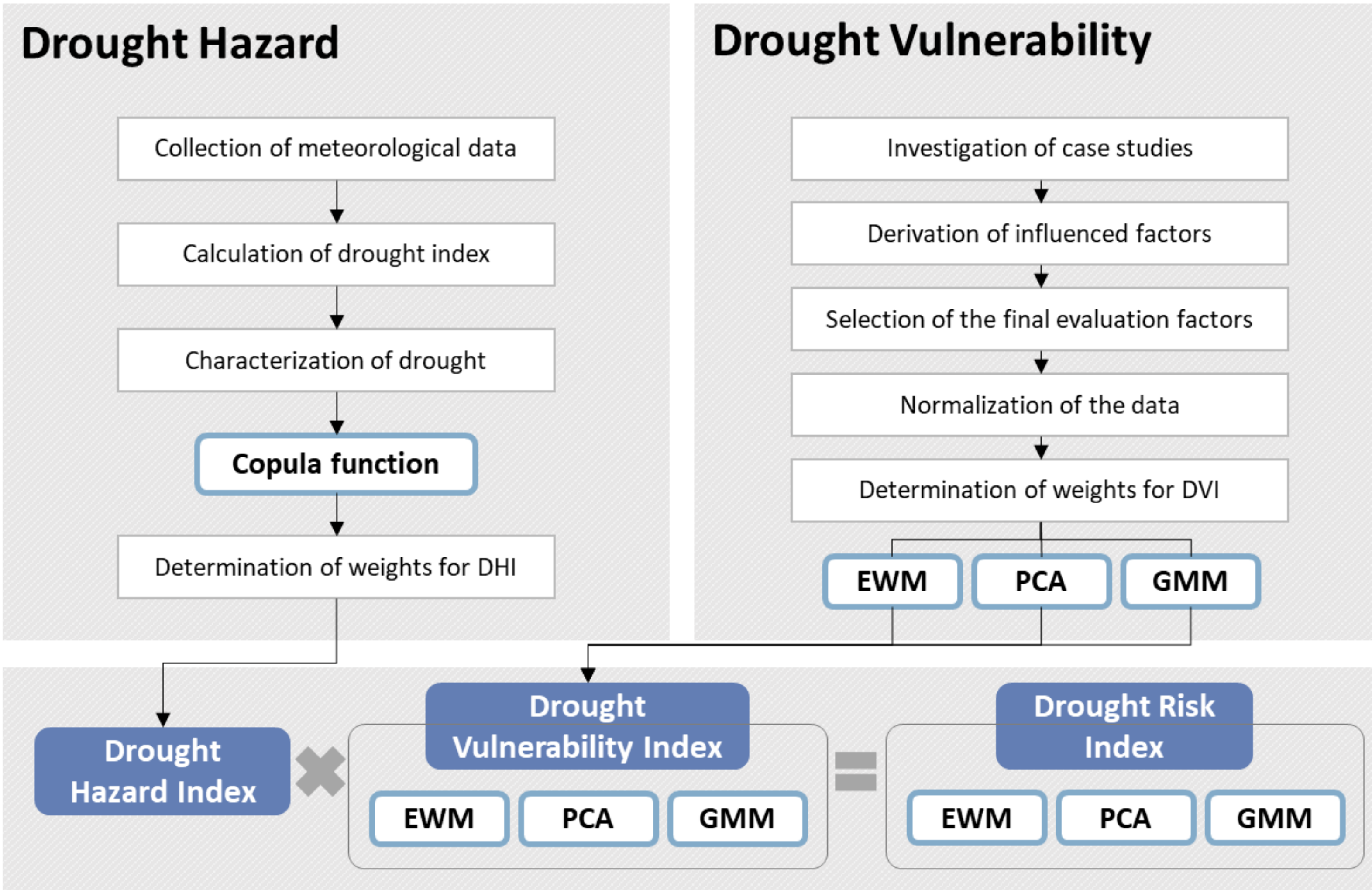
Selection of evaluation factors for vulnerability assessment

- **We investigated literature and case studies related to vulnerability and selected the evaluation factors that are consistent with the meaning of drought vulnerability.**
  - All the input data for these drought evaluation factors must have the same spatial and temporal resolution, so the temporal resolution for the drought vulnerability index was set to that of 2018.
  - These data were collected from water supply statistics, the National Statistical Office and the Water Resources Management Information System.

Factors		Unit
F1	Population	person
F2	Total area of district	km^2
F3	Farm population	person
F4	Total agricultural area	km^2
F5	Total area of industrial complexes	km^2
F6	Amount of domestic water usage	m^3/day
F7	Amount of industrial water usage	m^3/day
F8	Amount of industrial water usage	m^3/day
F9	Daily water supply per capita	L/person/day
F10	Water supply ratio	%

03 Method and Result

Procedure



STEP 1. Drought Hazard Assessment

- **Drought hazard typically refer to the climate factors that causes drought.**
  - In order to investigate the spatial and temporal extents and severity of drought occurrence, Standardized Precipitation Index(SPI) is used.
  - In this study, the six-month SPI(SPI-6) was calculated because it fit well with the dry and wet conditions in South Korea, and has been successfully applied to drought monitoring in South Korea.

Rank	Duration (d_k,)	Intensity (m_k)	Weight(r_k)
1	1	1.0 (moderate)	0.1
2	3		0.2
3	6		0.3
4	1	1.5 (severe)	0.4
5	3		0.5
6	6		0.6
7	1	2.0 (extreme)	0.7
8	3		0.8
9	6		0.9

<Description of drought classes and weights>

- **Drought hazard index (DHI) is calculated by applying a copula function with drought characteristics.**
  - We applied Archimedean copula functions to estimate the joint probability distribution for the marginal probability distribution function.

$$F(x, y) = C(u, v) = C(F_X(x), F_Y(y))$$

  - To demonstrate drought patterns, drought was categorized into nine classes corresponding to duration and intensity

$$DHI = \sum_{k=1}^{rank} r_k f(d_k, m_k)$$

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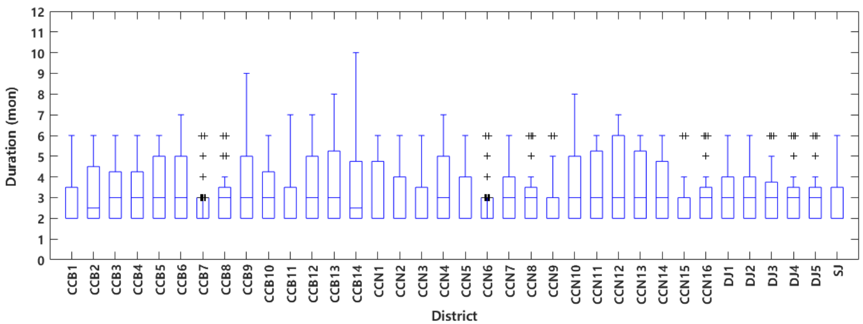
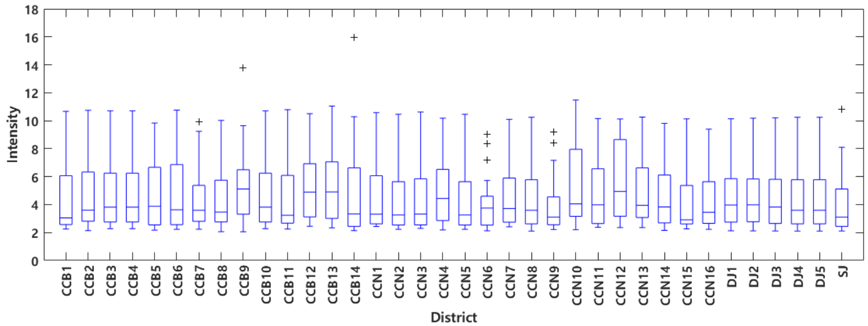
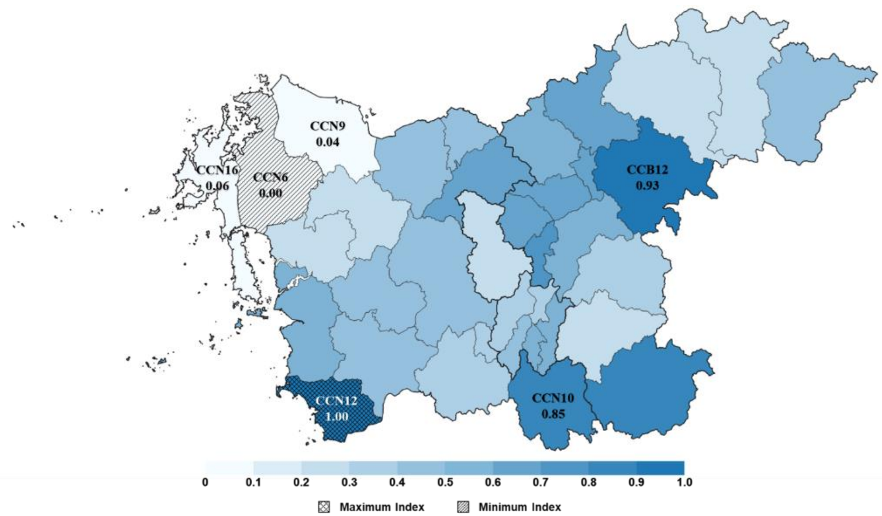
STEP 1. Drought Hazard Assessment







- The largest drought occurred in area CCB7, with duration and intensity of 6 and 9.90, respectively.
- CCB13 and CCN11 had a long average duration of about four months, and CCB9 had an average intensity of about 5.65.
- Considering the weights based on the drought characteristics, the areas with the highest drought hazard were CCN12, CCB12, and CCN10.

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STEP 2. Drought Vulnerability Assessment

- **Vulnerability assessment consists of various elements with different units and characteristics, which must be combined and integrated into a single index.**
  - "Standardization" refers to the transfer of criteria with different units to the same level so that they can be compared to each other.
  - We used re-scaling, which is also called the min–max normalization method because it is most appropriate when the bounds of the scores produced by the match are known.
  - All of the indicator values were set within the range of 0 to 1, and there were no negative values.

$$I = \frac{x - \min(x)}{\max(x) - \min(x)}$$

- **Applying statistics-based methods to assign objective weights to the factors in vulnerability assessment reduces the uncertainty associated with the "subjective nature," enhancing the reliability of the calculated results.**
  - The so-called equal weight method (EWM) is the most common approach to vulnerability assessment when there is a lack of information on the relative importance of the indicators, making it difficult to assign relative contributions by factors.

03 Method and Result

STEP 2. Drought Vulnerability Assessment

- **The PCA is a mainstay of modern data analysis tools for creating a composite index, which can be used to derive statistically the weights of individual variables and components.**

  - The PCA aims to combine various correlation indicators to include as much information as possible for each original dataset.
  - In particular, it efficiently recognizes data patterns to minimize information loss while reducing the high dimensionality of the dataset.

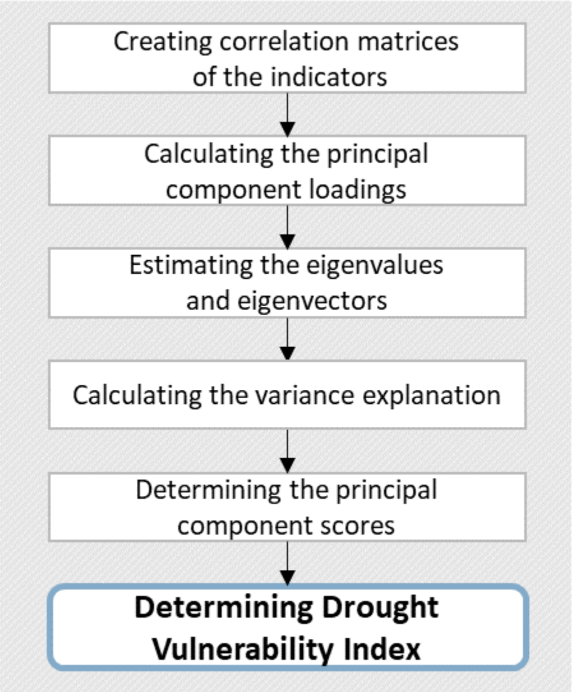
$$w_{i,j} = \frac{c_i v_j}{\sum_{i=1}^{n}\sum_{j=1}^{m} c_i v_j}$$

where n is the number of indicators selected from the PCs, and m is the number of PCs selected from the variance explanation. In addition, ci is the PC loadings of the ith indicators, and vj is the variance explanation of the jth PC.

  - The DVI is calculated as the sum of the factor scores.

$$DVI = \sum_{j=1}^{m}\sum_{i=1}^{n} x_i w_{i,j}$$

where xi is the vulnerability indicator and wi,j is the weight determined by the PCA.



< Procedure of PCA >

03 Method and Result

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STEP 2. Drought Vulnerability Assessment

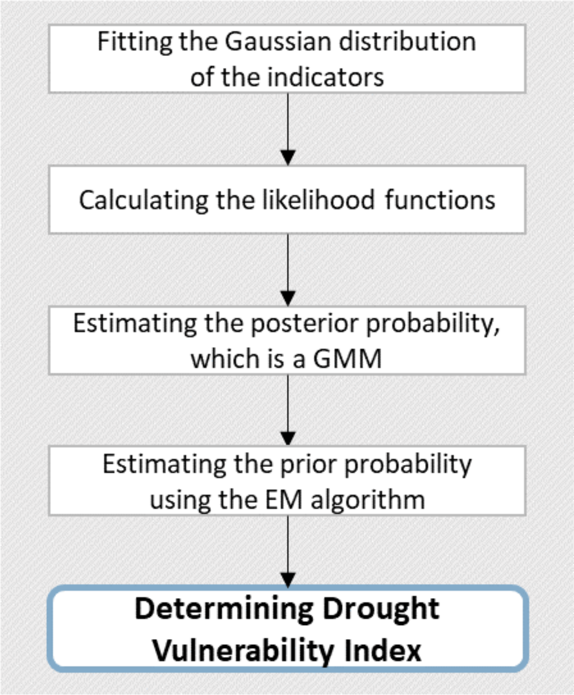
- **Another way to calculate the DVI is to use a GMM based on Bayes' theorem, and calculate the weights by estimating the model parameters corresponding to the weight of each factor.**
  - The GMM is a probabilistic model that assumes all the data points are generated from a mixture of a finite number of Gaussian distributions with unknown parameters.
  - It is the parametric statistical model that assumes that the data originate from a weighted sum of several Gaussian sources.

$$P(\theta|x) = \sum_{i=1}^{M} \alpha_i P(x|\theta_i)$$

where $P(x|\theta_i)$ denotes the probability density function of the basic component of a mixed model, αi is the weight of each Gaussian source, θi is its respective parameter, and M denotes the number of Gaussian sources in the GMM.

  - The DVI is determined by multiplying the calculated weights by standardized indicators and adding them all together.

$$DVI = \sum_{i=1}^{M} x_i w_i$$



< Procedure of GMM >

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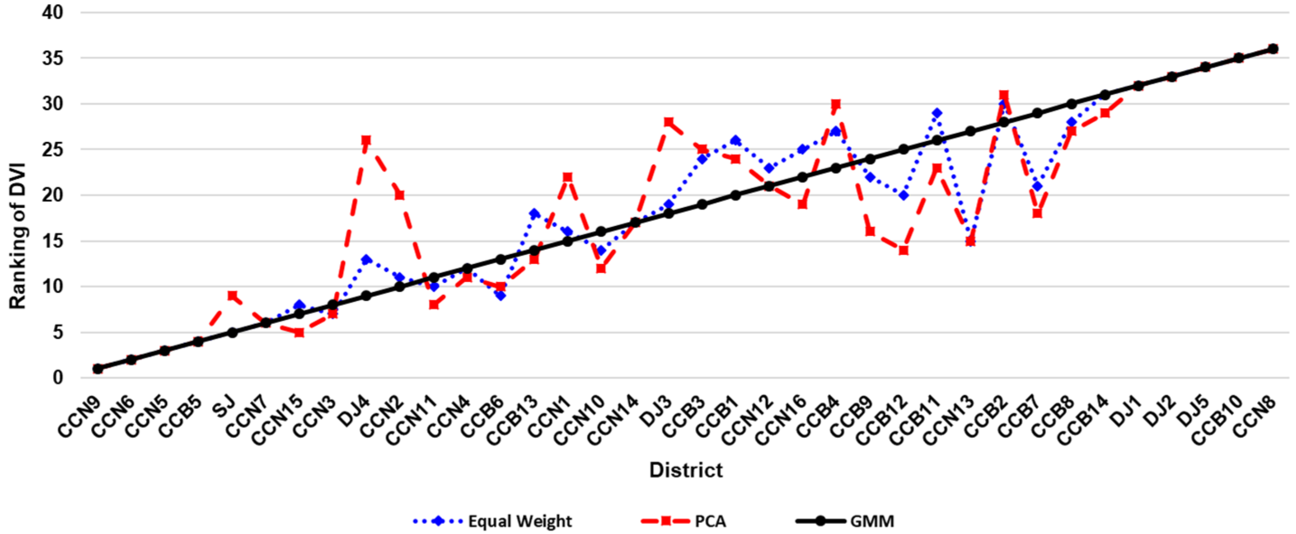
STEP 2. Drought Vulnerability Assessment

Factors		Weights of PCA		Weights of GMM	Weights of EWM
		PC1	PC2		
F1	Population		0.15	0.09	0.1
F2	Total area of district	0.07		0.15	0.1
F3	Farm population	0.11		0.12	0.1
F4	Total agricultural area	0.16		0.13	0.1
F5	Total area of industrial complexes		0.14	0.06	0.1
F6	Amount of domestic water usage		0.05	0.10	0.1
F7	Amount of agricultural water usage	0.11		0.14	0.1
F8	Amount of industrial water usage		0.13	0.08	0.1
F9	Daily water supply per capita		0.06	0.03	0.1
F10	Water supply ratio	0.01		0.10	0.1

- **The agricultural area was determined to have the largest weight in PCA, and agricultural and industrial factors were highly weighted.**
- **The agricultural-related factors had significant weights in GMM.**
- **However, unlike in the PCA, the influence of agricultural factors had more weights than did the domestic or industrial water-related factors.**
- **We believe this result was due to the area being agricultural, with several industrial complexes.**

03 Method and Result

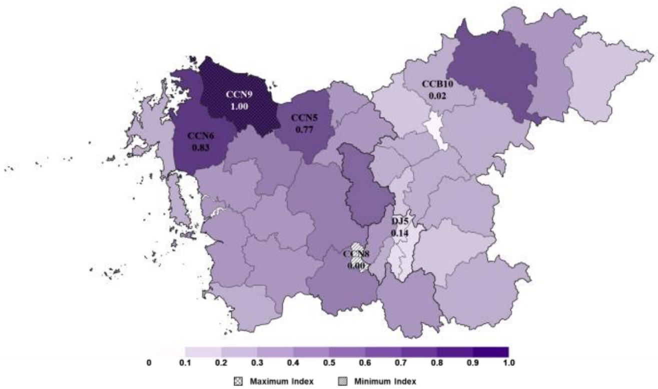
STEP 2. Drought Vulnerability Assessment



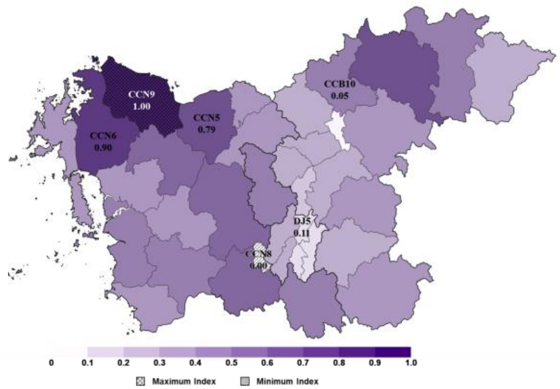
- Figure shows a graph comparing the ranks of each region based on the ascending results of the GMM method.
- Area CCN9 was calculated as the most vulnerable area in all three methods because its agricultural and industrial component values were significantly larger than in the other regions, as are its other indicators.
- High- and low-ranking values had similar results, while those of middle ranks showed deviation from the others.

03 Method and Result

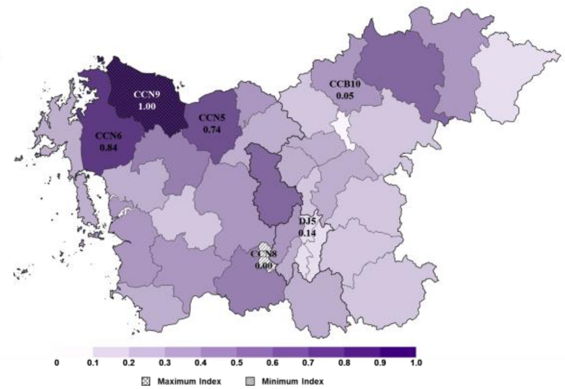
STEP 2. Drought Vulnerability Assessment



< DVI of EWM >



< DVI of PCA >



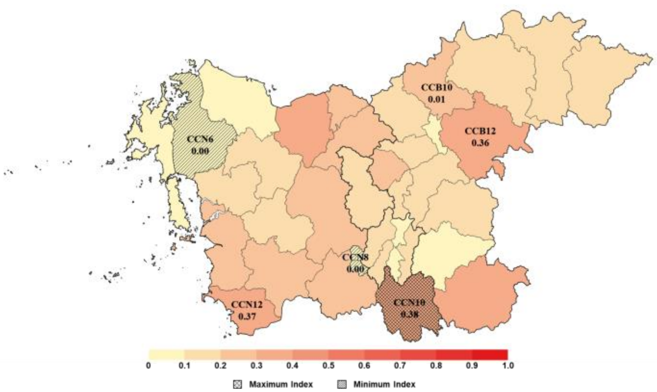
< DVI of GMM >

- Figure shows a graph comparing the ranks of each region based on the ascending results of the GMM method.
- Area CCN9 was calculated as the most vulnerable area in all three methods because its agricultural and industrial component values were significantly larger than in the other regions, as are its other indicators.
- High- and low-ranking values had similar results, while those of middle ranks showed deviation from the others.

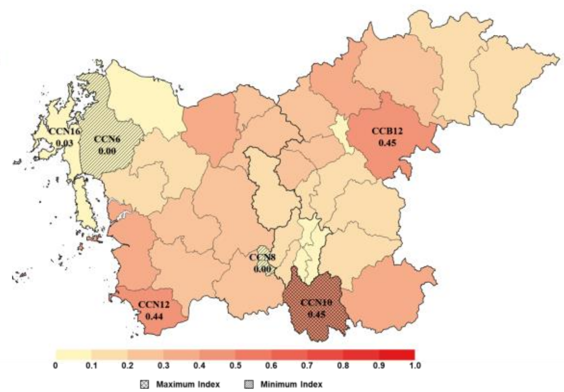
03 Method and Result

STEP 3. Drought Risk Assessment

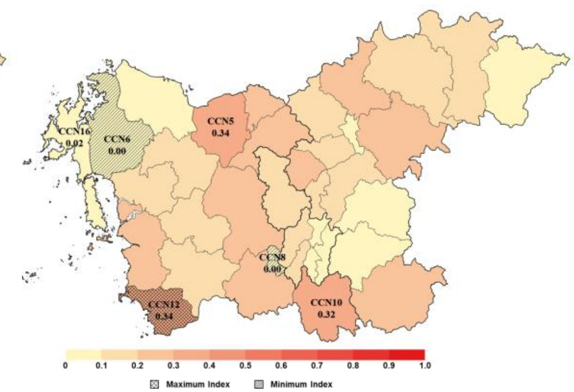
- **Drought risk assessment should be considered in terms of the two factors, since the characteristics of both drought vulnerability and drought hazard result in drought risk.**



< DRI of EWM >



< DRI of PCA >



< DRI of GMM >

- **The high-risk areas were CCN12, CCN10, and CCN10 as calculated by PCA, GMM, and EWM, respectively. These results reflect a very high calculated DHI.**
- **However, in CCN9, where the DVI was the highest, the DRI was small because that area had the lowest DHI.**
- **CCN6 and CCN8 were identified to have zero DVI and DHI, respectively, and the DRI was also zero.**

Conclusion

- This study evaluated drought vulnerability based on probabilistic statistics-based objective weighting considering the contribution of indicators to several indices
- The use of statistical methods helped reduce the subjectivity of indices, of which PCA and GMM proved to be useful tools to determine the contribution of indicators affect regional drought.
- In addition, the DHI based on the SPI calculated through the copula function was integrated with three DVIs to quantify the regional DRI.
- The application of 3-methods showed that area CCN9 was the most vulnerable to drought.
  - **The results for vulnerable areas in this study were the same, but different results may be obtained for other areas.**
  - **In this case, the impact of factors cannot be considered when evaluating only with EWM, and vulnerability assessments using PCA and GMM can ensure validity and improve reliability of the results.**
  - **Among them, GMM is judged to have higher accuracy than other research methods, as factors with similar characteristics have similar weights.**

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Conclusion

- The hazard and vulnerability assessments showed that CCN12 had the greatest probability of drought occurrence, while that in CCN9, which was highly vulnerable to drought, was very small.
- This means that the drought risk of CCN9 was very low, but any drought in CCN12 and CCN10 would be very dangerous.
  - ➢ **Risk assessments that consider both the hazard and the vulnerability should be carried out, since evaluating drought with only one type of factor can produce distorted results.**

❖ **Therefore, if we perform drought risk considering hazard, which is a hydro-meteorological factor, and vulnerability, which is a socioeconomic factor applied with GMM, we will be possible to obtain reliable results that are comprehensive, objective, and take into account the impact of various factors.**

Thank You

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