Developing geo-statistical indicators and adaptive pathways for disaster risk reduction

: cases of flood, drought, sand and dust storms, and air pollution in Central Asian countries (with Pilot case study of South Korea and Kazakhstan)

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Content

1. Introduction

1. Introduction

A. Objective of the research

- The research objective is to develop a set of geo-statistical indicators to assess disaster risk (vulnerability) and prepare adaptive pathways for Disaster Risk Reduction (DRR).
- These indicators aim to support policymakers and technical officials in member states to prepare more effective policies and actions to reduce disaster risk and prevent or mitigate human suffering and economic and environmental damages.

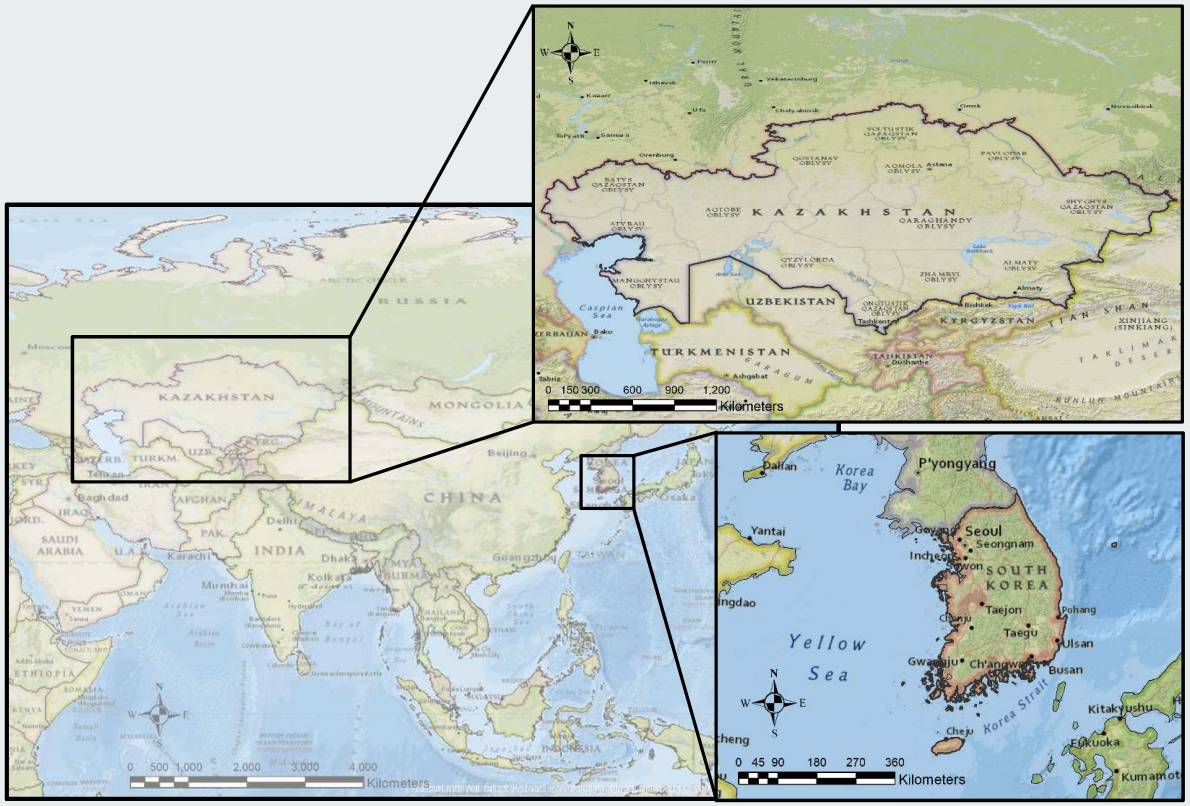
1. Introduction

B. Research Scope and Area

- Disasters:
  - Drought / Flood / Sand and dust storm / Air pollution

C. Research Area

- Kazakhstan
- South Korea



2. Method

2. Method

A. Definitions

- We assessed "disaster risk" using the concept of vulnerability, as outlined by the Intergovernmental Panel on Climate Change.

Term	Definition from IPCC
Vulnerability	"The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes"
Exposure	"The nature and degree to which a system is exposed to significant climatic variations"
Sensitivity	"The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli"
Adaptive capacity	"The ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities, or to cope with the consequences"

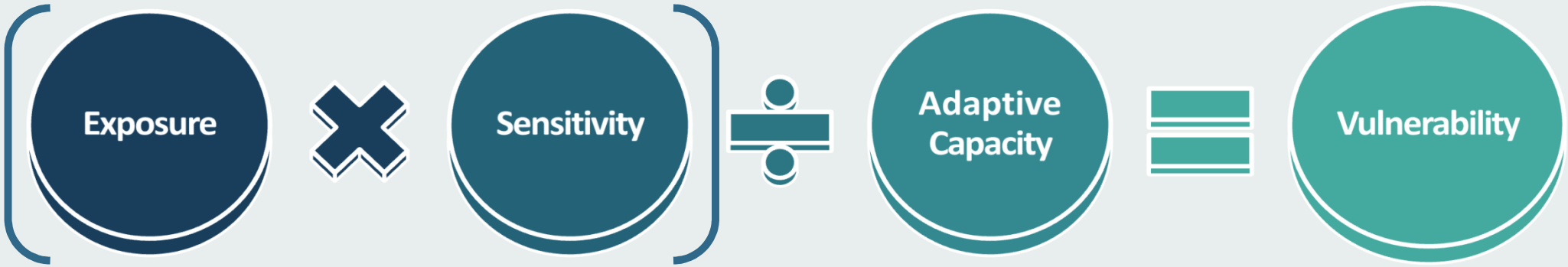
2. Method

B. Method

- To develop geo-statistical indicators for assessing vulnerability, we first selected indicators related to exposure, sensitivity and adaptive capacity through literature reviews.
- Then we prepared vulnerability indices and maps by computing the exposure, sensitivity and adaptive capacity indicators.
- These methods are based on Geographic Information System (GIS) technology which prepares data into spatial forms and analyzes them statistically.

2. Method

B. Method



Extreme climate	Environmental	Infra / Inst. & policies
Non-controllable	Hard to control	Controllable
	Geospatial	Statistical

2. Method

B. Method

Step 1

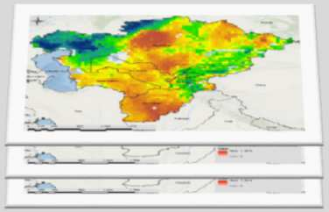
Exposure, Sensitivity
(Geo-spatial) Indicators

Category	Indicator	Availability		Reference
		South Korea	Kazakhstan	
Exposure	Annual precipitation (mm)	0	0	Choi et al. (2009) Jung et al. (2010)
Sensitivity				

Adaptive Capacity
(Statistical) Indicators

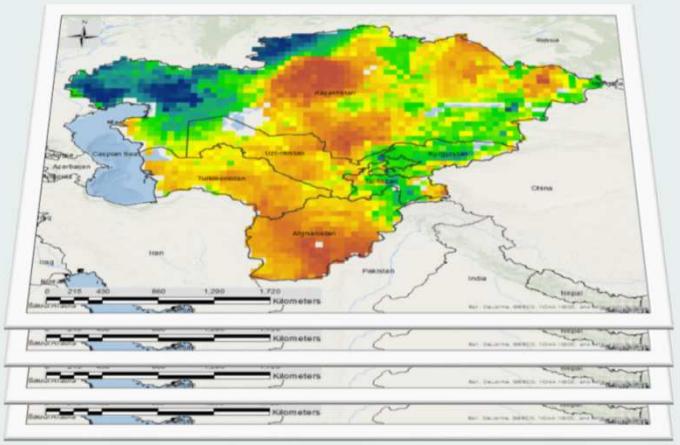
Category	Indicator	Availability		Reference
		South Korea	Kazakhstan	
Adaptive Capacity				

Step 2



Exposure, Sensitivity Map

Adaptive Capacity Map
(Infrastructure / Institutions and Policies)



Vulnerability Map

3. Result

3. Result

A. Literature review and available indicators

Drought

Category	Indicator	Availability		Reference
		South Korea	Kazakhstan	
Exposure	Annual precipitation (mm)	O	O	Choi et al. (2009) Jung et al. (2010)
	Palmer Drought Severity Index (PDSI)	O	O	Sivakumar et al. (2010)
	Standardized Precipitation Index (SPI)	O	O	Łabędzki and Bąk (2014)
Sensitivity	Population density	O	O	Oh et al. (2012) Swain and Swain (2011)
	Cultivated area	O	O	Kim et al. (2013) Jang (2006)
	Topographic Wetness Index (TWI)	O	O	Muukkonen et al. (2015) Zhang et al. (2011)
	Drainage class	O	X	Quiring and Ganesh (2010)
	Agricultural value added/GDP (%)	O	O	Iglesias et al. (2009)

3. Result

A. Literature review and available indicators

Drought

Category	Indicator	Availability		Reference
		South Korea	Kazakhstan	
Adaptive Capacity	GDP per capita	O	O	Cheng and Tao (2010) Wu et al. (2013)
	Population with access to improved water (% of total)	△	O	Iglesias et al. (2009)
	Available reservoir storage of farm dams	O	△	Oh et al. (2012)
	Number of reservoirs	O	O	Cancelliere et al. (1998).
	Agricultural water location	O	△	Yi et al. (2004)
	Disaster management fund	O	X	Kim (2010) Park (2008) Lee et al. (2017)
	Land designated for agricultural promotion	O	X	Park (2006)
	Annual budget per capita	O	O	This study

3. Result

B. Indices

Drought

$$\boldsymbol{Agricultural\ Drought\ Vulnerabilty\ Index}$$
$$= [(1 - PDSI) \times (1 - TWI) \times (Agriculture\ value\ added) \times (Drainage\ class\ (high))]$$
$$\div [(Dam\ storage\ capacity) \times (Improved\ water\ source)$$
$$\times (Land\ designated\ for\ agricultural\ promotion) \times (Agricultural\ water\ location)$$
$$\times (Budget\ per\ capita) \times (Disaster\ management\ fund)]$$

Description

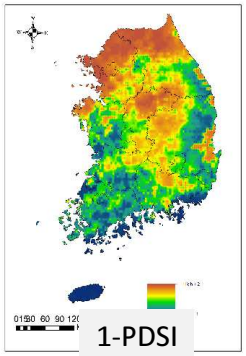
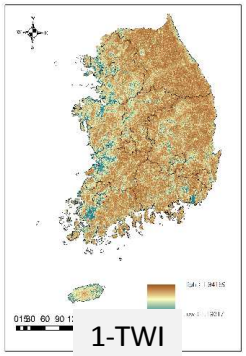
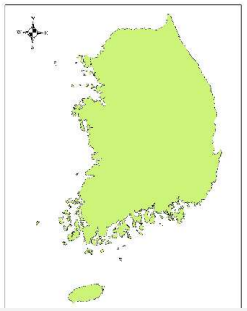
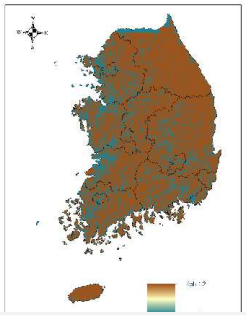
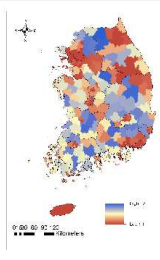
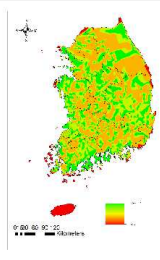
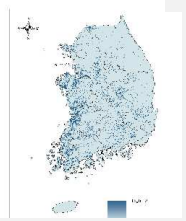
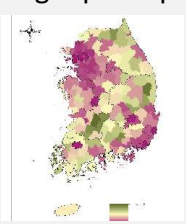
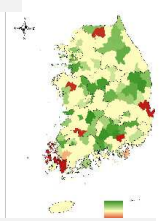
This index is developed to see the potential impact of drought on agriculture by its value, water source, local governments' financial commitment to disaster management, including the meaning of meteorological drought.

3. Result

B. Indices

2015 – Observation

Drought

Exposure	Sensitivity	Adaptive Capacity
 1-PDSI	 1-TWI  Agriculture value added  Drainage class (high)	Improved water source   N/A  Dam storage capacity Agricultural water location Budget per capita    Land designated for agricultural promotion Disaster management fund

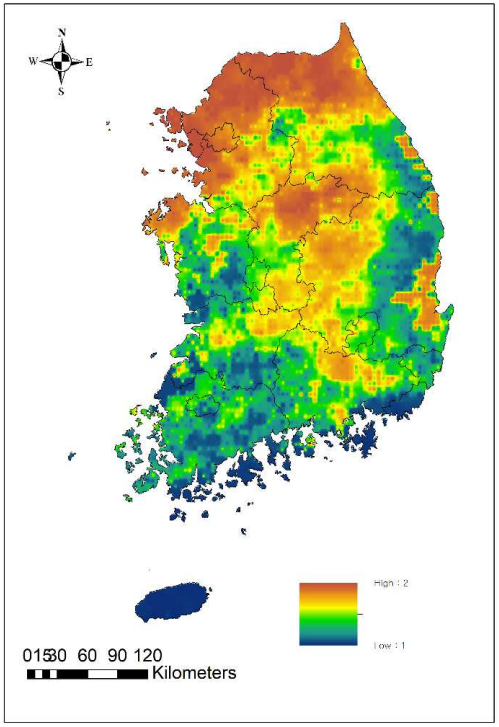
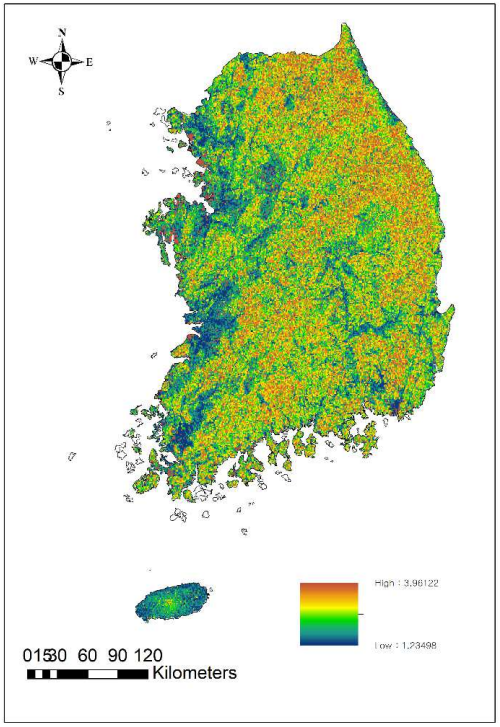
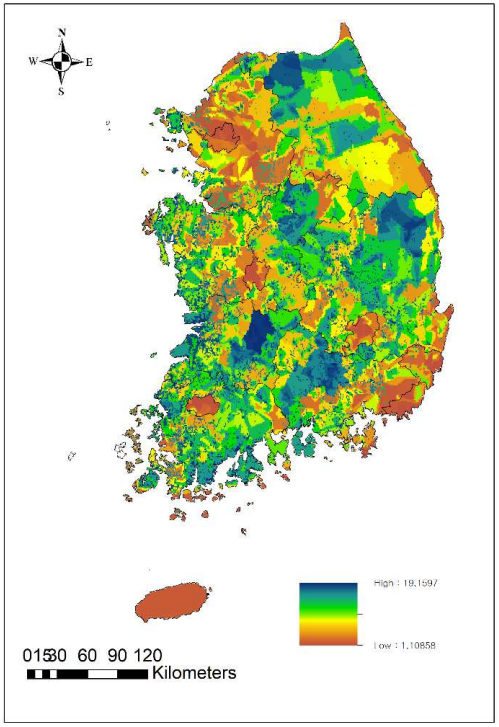
→ Infra

→ Inst. & Policies

3. Result

B. Indices

2015 – Observation | Drought

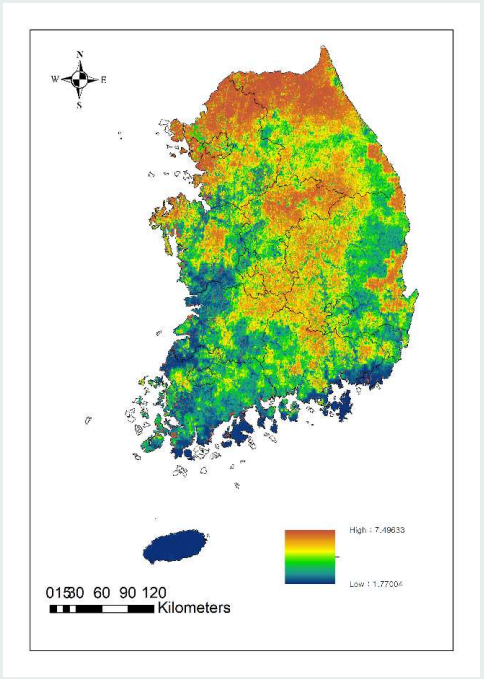
Exposure	Sensitivity	Adaptive Capacity
		

3. Result

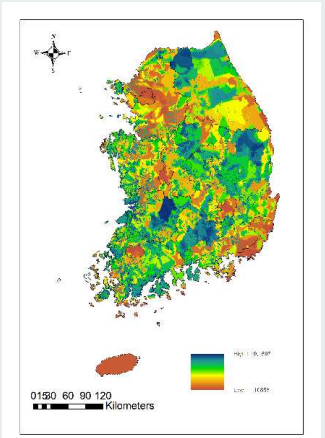
B. Indices

2015 – Observation
1km*1km

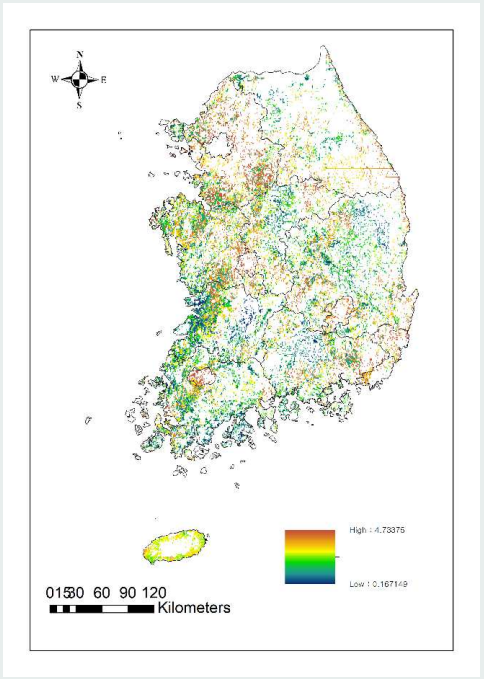
Drought



Exposure*Sensitivity



Adaptive Capacity



Vulnerability

3. Result

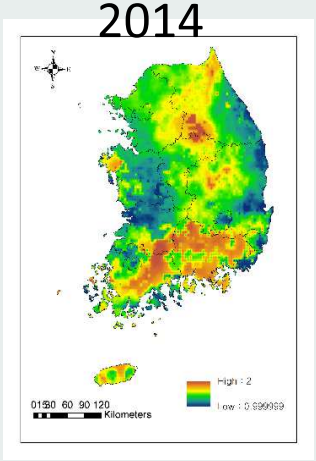
B. Indices

2014-2018 – Observation

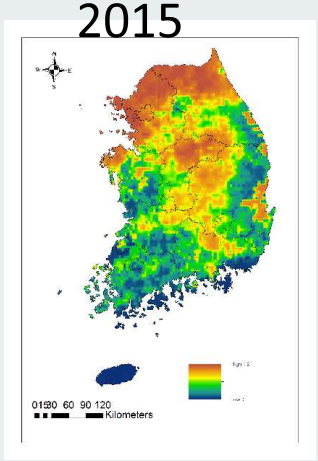
Drought

1-PDSI

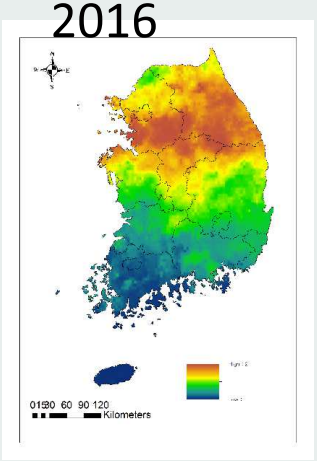
2014



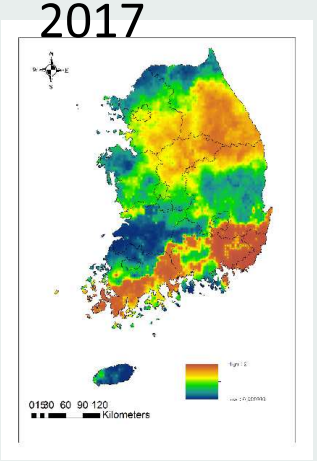
2015



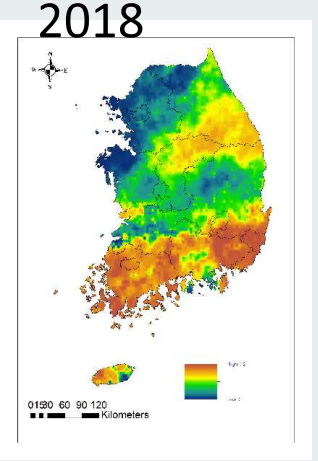
2016



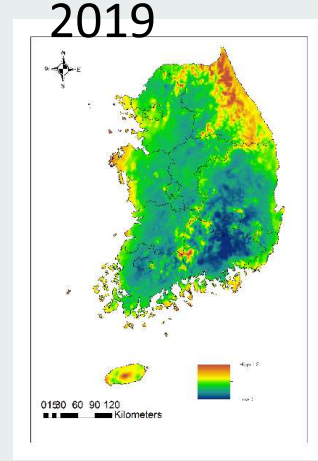
2017



2018



2019

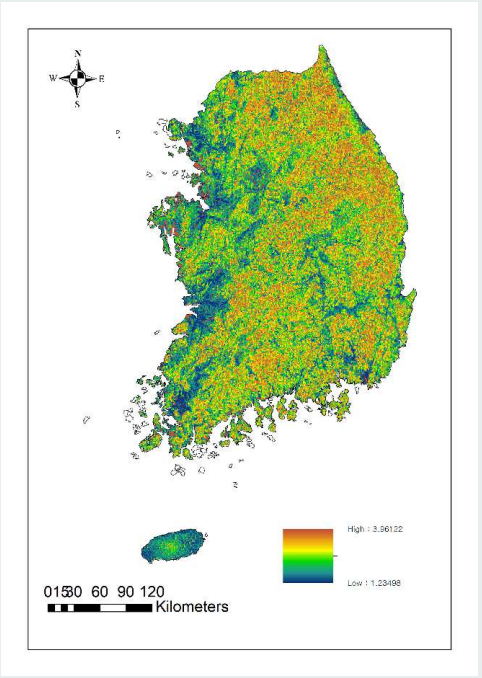


3. Result

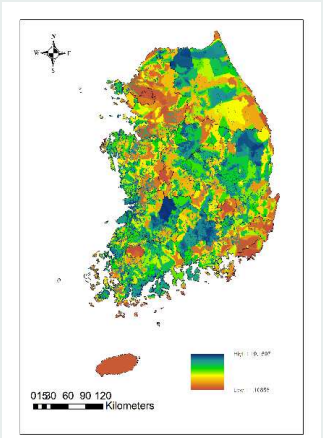
B. Indices

2015 – Observation
1km*1km

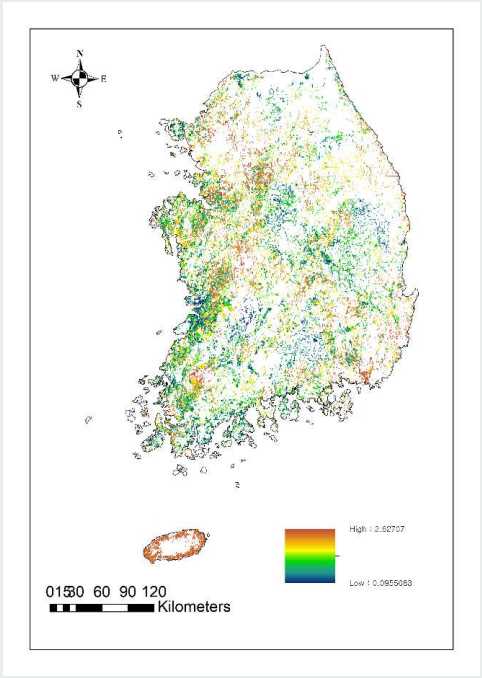
Drought



Sensitivity



Adaptive Capacity

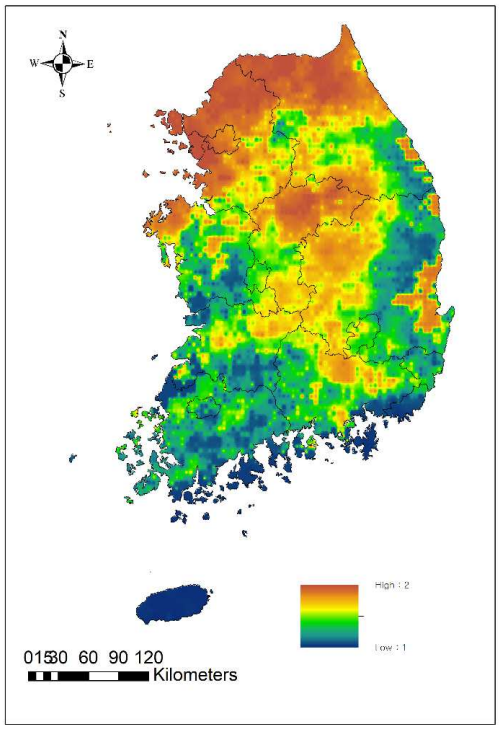


Vulnerability

3. Result

B. Indices

(1-PDSI) of 2015



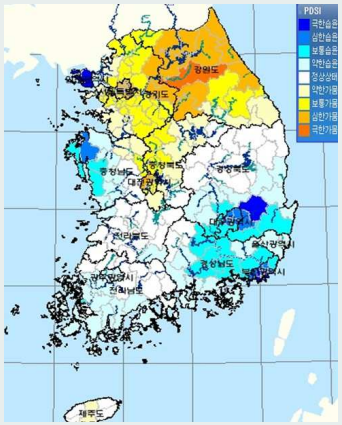
2015 – Observation

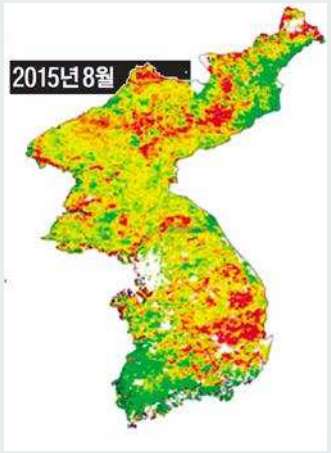
Drought

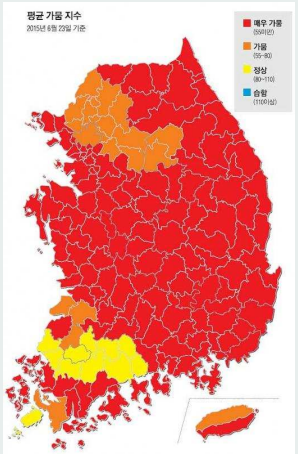
← 2014 accumulated precipitation

↓Average drought index of June 23, 2015 from Ministry of Public Safety and Security

Drought of Aug, 2015 from RS (Choi et al.) →





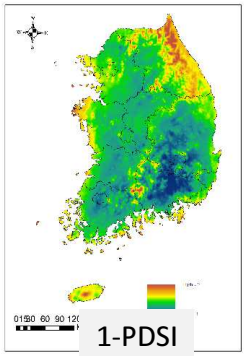
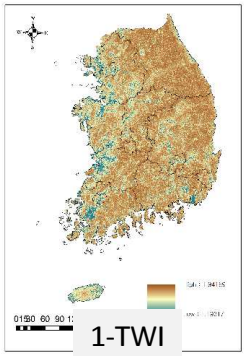
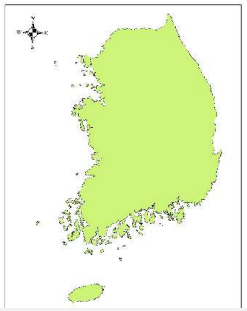
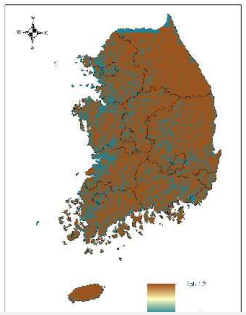
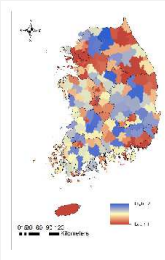
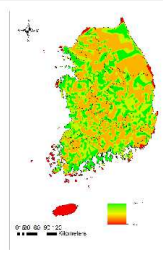
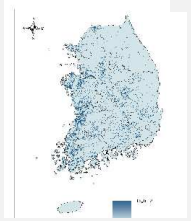
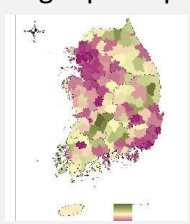
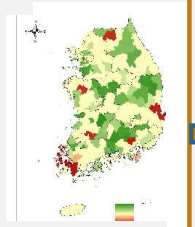


←PDSI of Feb 9, 2015 from K-water

3. Result

B. Indices

2019 – Prediction **Drought**

Exposure	Sensitivity	Adaptive Capacity
 1-PDSI	 1-TWI  Agriculture value added  Drainage class (high)	Improved water source   N/A  Dam storage capacity Agricultural water location Budget per capita    Land designated for agricultural promotion Disaster management fund

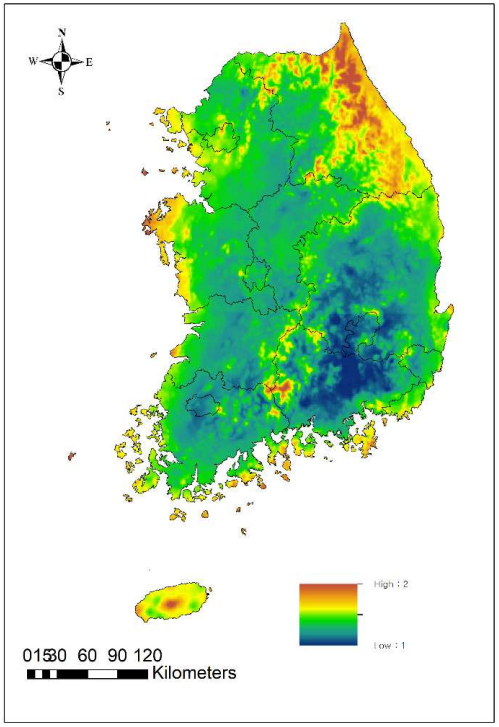
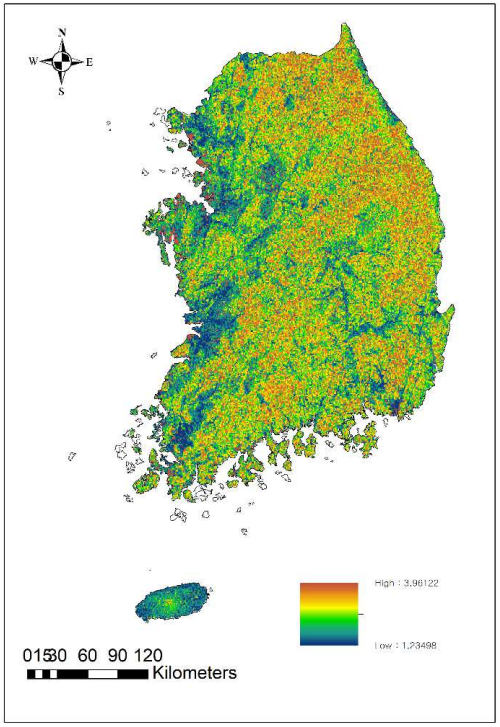
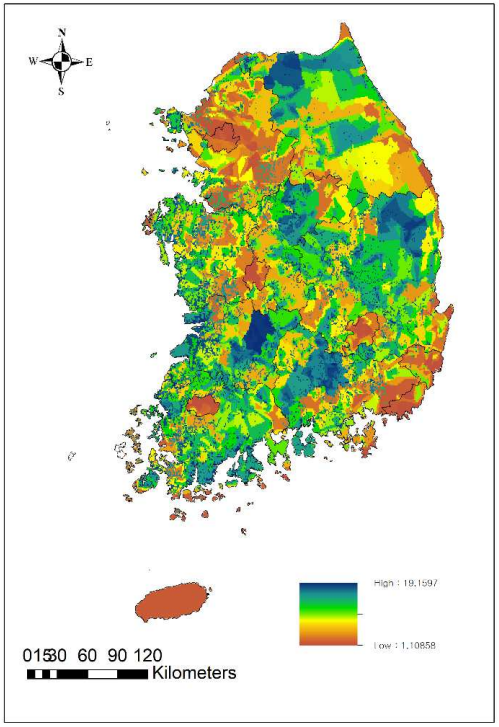
→ Infra

→ Inst. & Policies

3. Result

B. Indices

2019 – Prediction | **Drought**

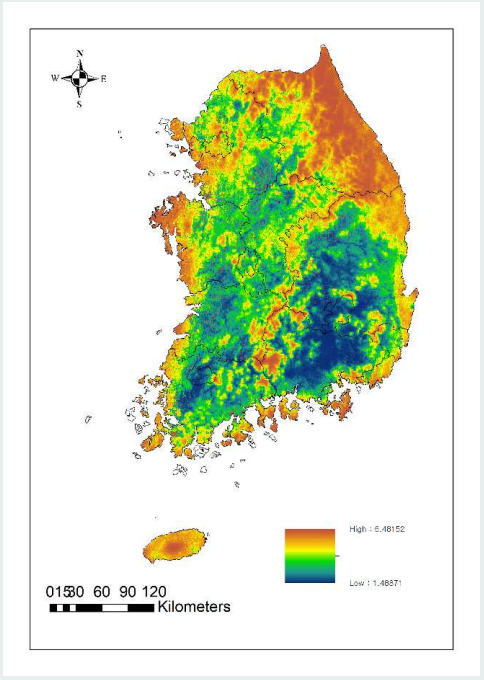
Exposure	Sensitivity	Adaptive Capacity
		

3. Result

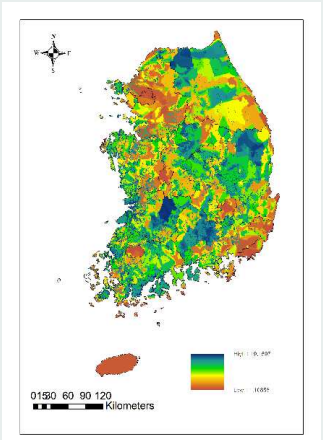
B. Indices

2019 – Prediction
1km*1km

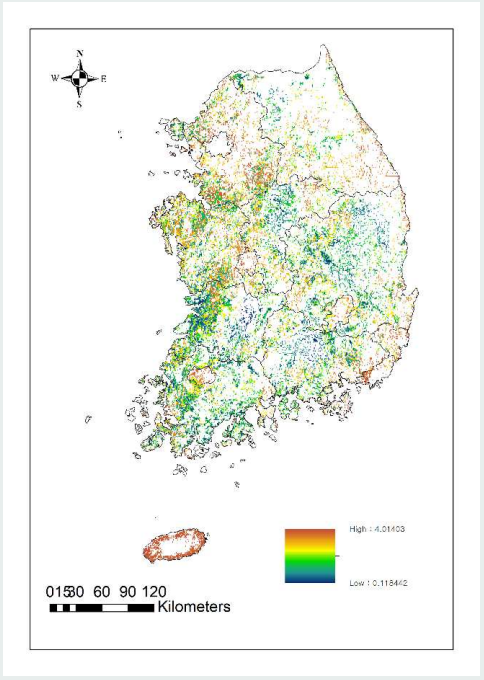
Drought



Exposure*Sensitivity



Adaptive Capacity



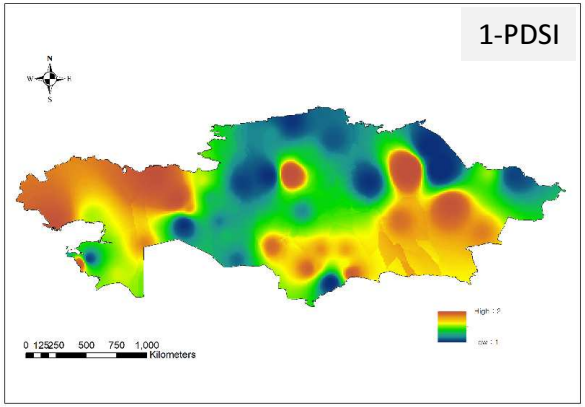
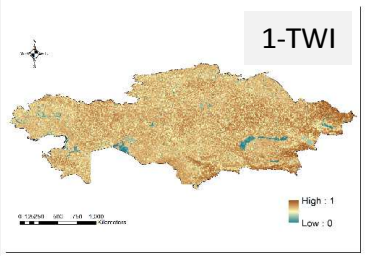
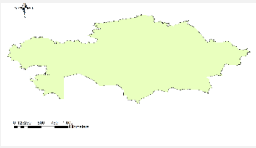
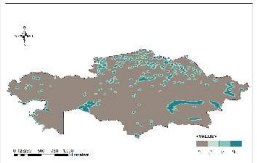
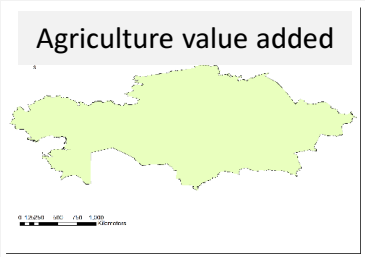
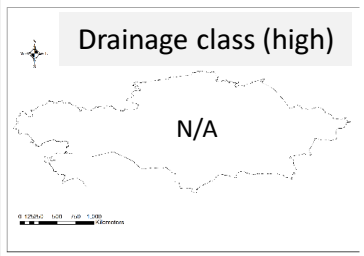
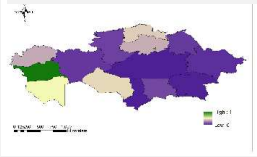
Vulnerability

3. Result

B. Indices

2015 – Observation

Drought

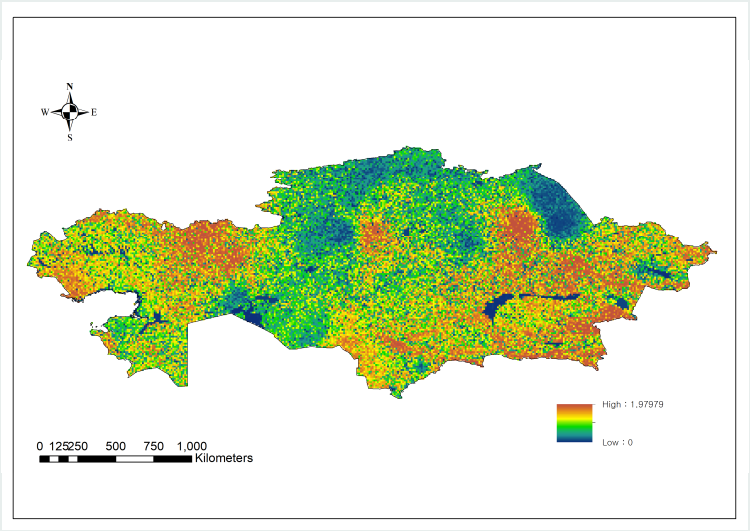
Exposure	Sensitivity	Adaptive Capacity	
1-PDSI 	1-TWI 	← Dam storage capacity N/A  Improved water source  N/A  ← Agricultural water location (all lakes and reservoirs)	→ Infra
	Agriculture value added 		
	Drainage class (high) N/A 	← Land designated for agricultural promotion N/A  Budget per capita  N/A  ← Disaster management fund	→ Inst. & Policies

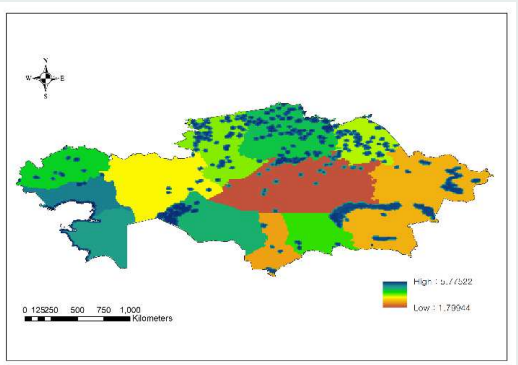
3. Result

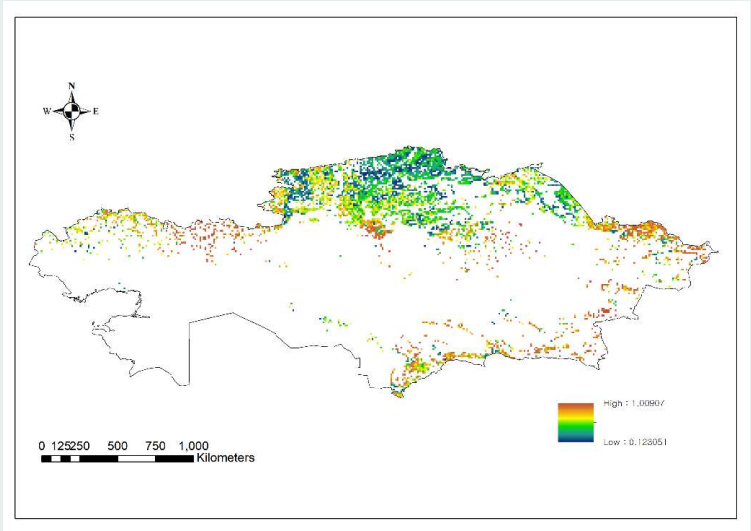
B. Indices

2015 – Observation
10km*10km

Drought







Exposure*Sensitivity

Adaptive Capacity

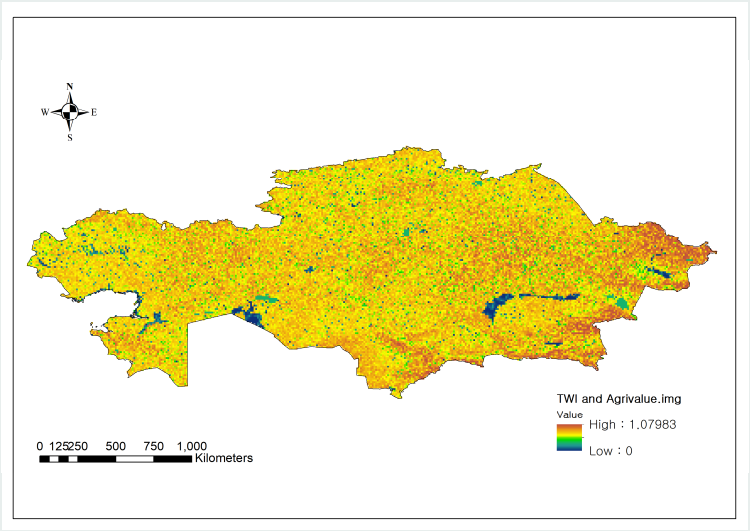
Vulnerability

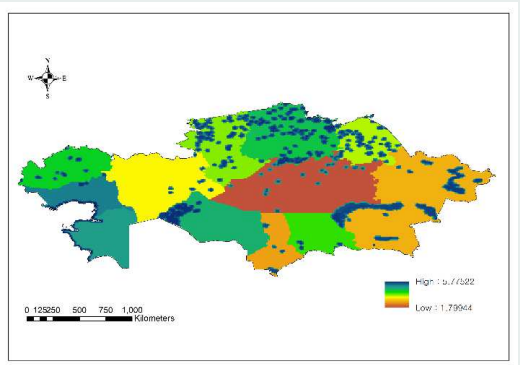
3. Result

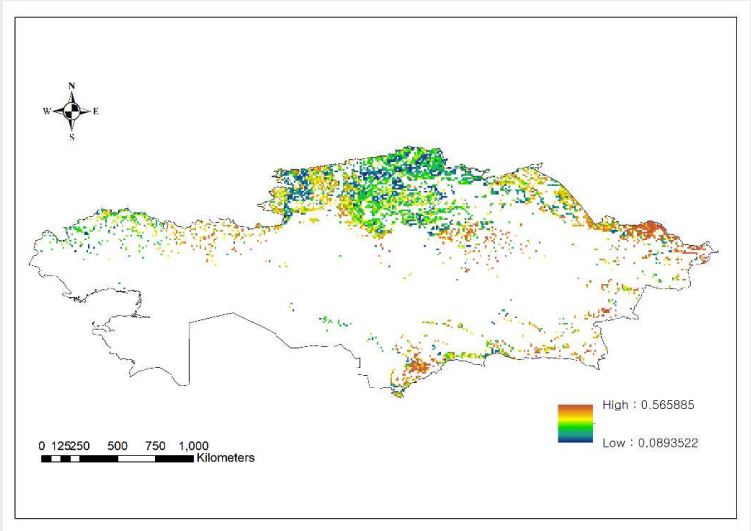
B. Indices

2015 – Observation
10km*10km

Drought







Sensitivity

Adaptive Capacity

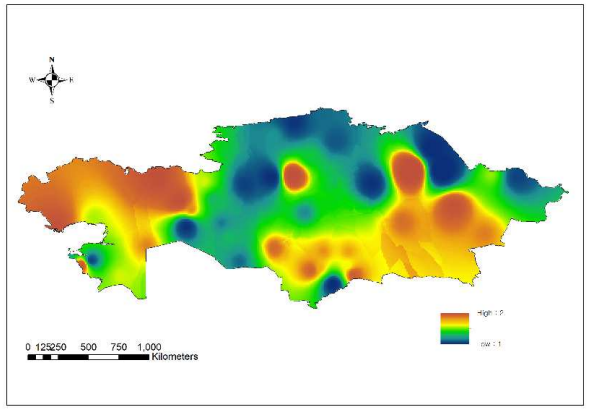
Vulnerability

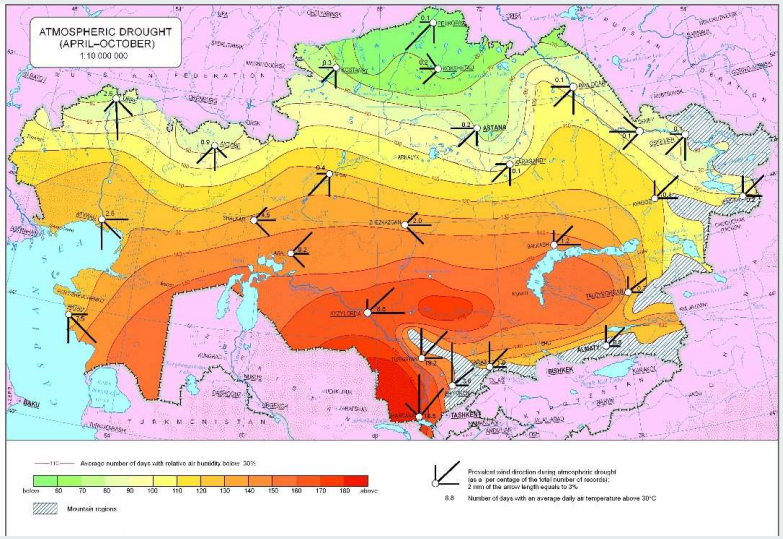
3. Result

B. Indices

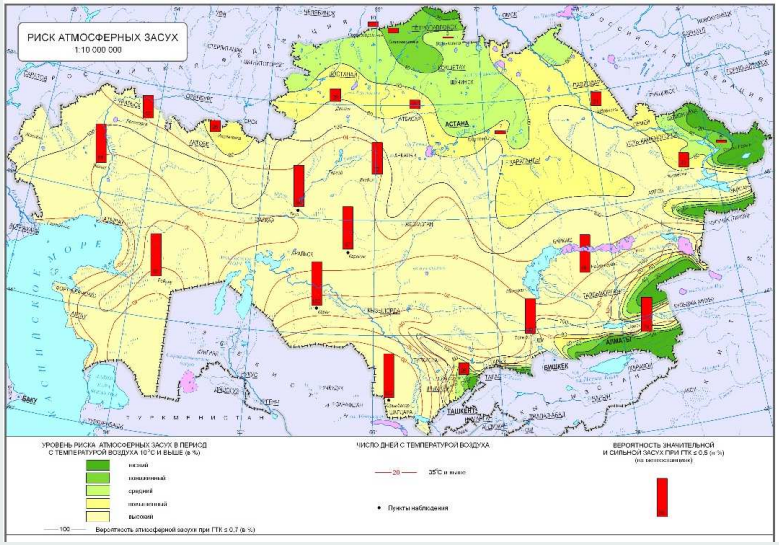
Drought

(1-PDSI) of 2015





Atmospheric drought
- Mainly from air humidity below 30%
- Average year



The risk of atmospheric drought from hydrothermal index
- (red bar) Probability of drought from hydrothermal index
- Average year

3. Result

A. Literature review and available indicators

Flood

Category	Indicator	Availability		Reference
		South Korea	Kazakhstan	
Exposure	Annual rainfall (mm)	O	O	Kim and Kim (2018)
	Daily maximum rainfall (mm)	O	O	Nasiri et al. (2013), Kang and Lee (2012)
	Days over 80(30)mm rainfall (days)	O	O	Park (2006), Kang and Lee (2012)
	Snow depth (mm)	?	O	Arkhipkin et al. (2010)
	Days over 0 degree Celsius (days)	?	O	Arkhipkin et al. (2010)
Sensitivity	TWI (Topographic Wetness Index)	O	O	Khosravi et al. (2016), Pavrai et al. (2014)
	SPI (Stream Power Index)	O	O	Khosravi et al. (2016)
	Soil depth	O	X	This study
	Forest ratio	O	O	This study

3. Result

A. Literature review and available indicators

Flood

Category	Indicator	Availability		Reference
		South Korea	Kazakhstan	
Adaptive Capacity	River improvement rate	O	X	Nasiri et al. (2013), Park (2006), Lee and Choi (2018), Kim and Kim (2018)
	Warning system	O	X	Nasiri et al. (2013)
	Capacity of pumping station	O	X	Park (2006), Lee and Choi (2018), Kim and Kim (2018)
	Retarding basin capacity	O	X	Kim and Kim (2018)
	Flood control capacity	O	X	Park (2006)
	Annual budget per capita	O	O	This study
	Disaster management fund	O	X	This study

3. Result

B. Indices

Flood

$$\boldsymbol{Flood\ Vulnerability\ Index}$$
$$= [(Annual\ rainfall) \times (Daily\ maximum\ rainfall) \times (Days\ over\ 80mm\ rainfall) \times (Snow\ depth)$$
$$\times (Days\ over\ 0\ degree\ celsius)] \times [(TWI) \times (SPI) \times (Soil\ depth) \times (1 - Forest\ rate)]$$
$$\div [(Flood\ regulation\ capacity) \times (River\ improvement\ rate) \times (Retarding\ basin\ capacity)$$
$$\times (Capacity\ of\ pumping\ station) \times (Disaster\ management\ fund) \times (per\ capita\ budget)]$$

Description

This index is developed to figure out the potential vulnerability of flood with the estimated risk by meteorological, topographic data, and environmental data and risk managed by government's financial commitment and capacity to disaster prevention and preparedness.

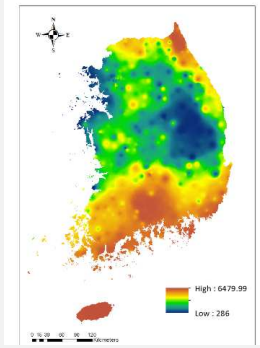
3. Result

B. Indices

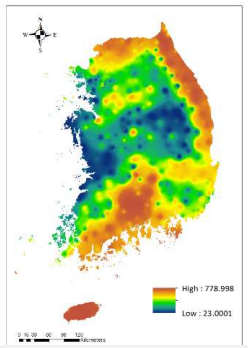
2015 – Observation

Flood

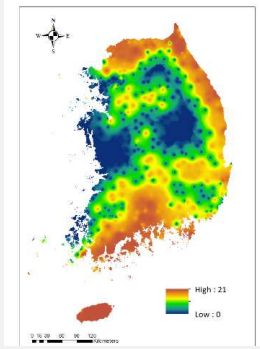
Exposure



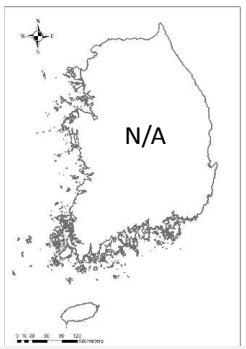
Annual Rainfall



Daily maximum rainfall

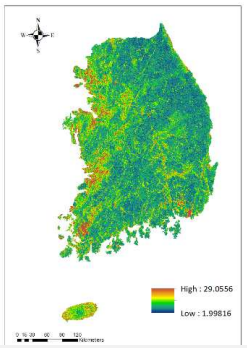


Days over 80mm rainfall

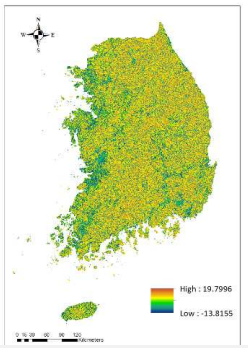


Snow melt

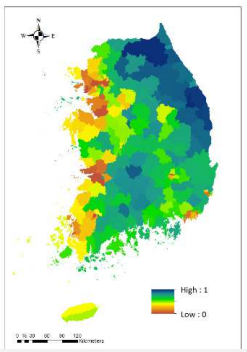
Sensitivity



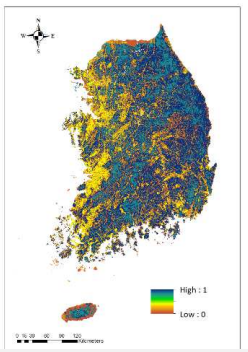
TWI



SPI

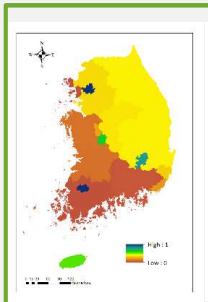


Forest ratio

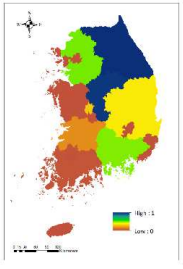


Soil depth

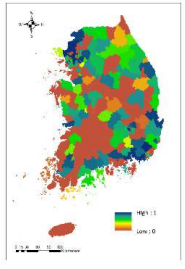
Adaptive Capacity



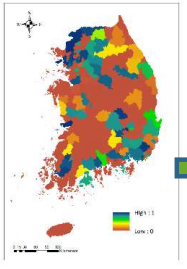
River improvement rate



Flood regulation capacity

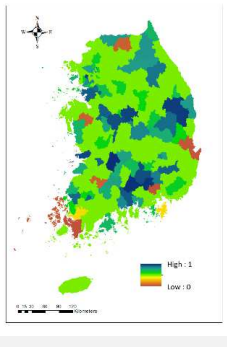


Capacity of pumping station

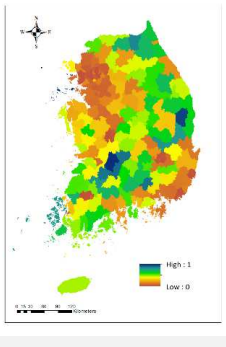


Retarding basin capacity

→ Infra



Disaster management fund



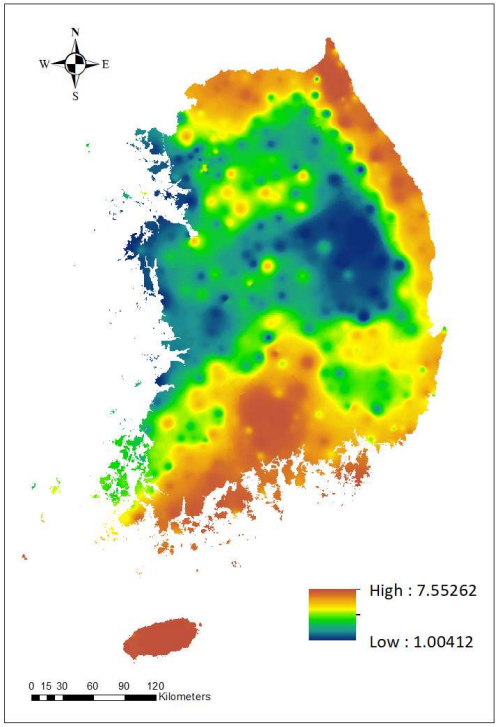
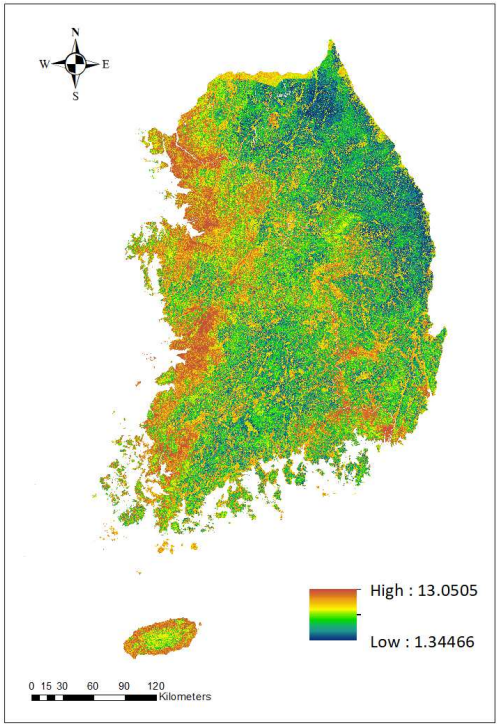
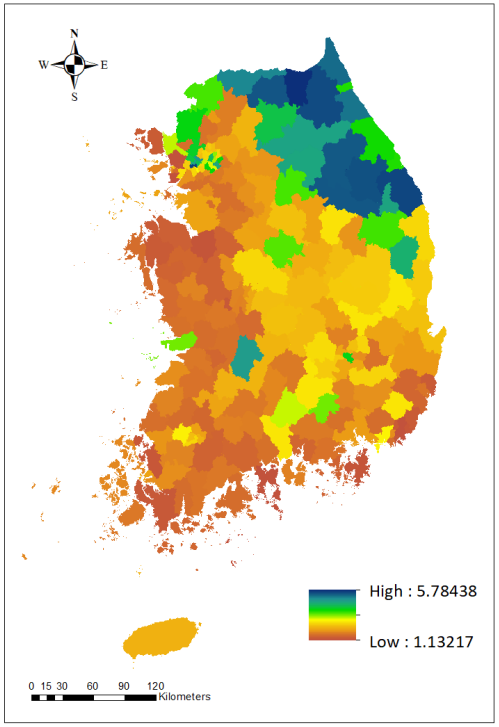
Budget per capita

→ Inst. & Policies

3. Result

B. Indices

2015 – Observation | Flood

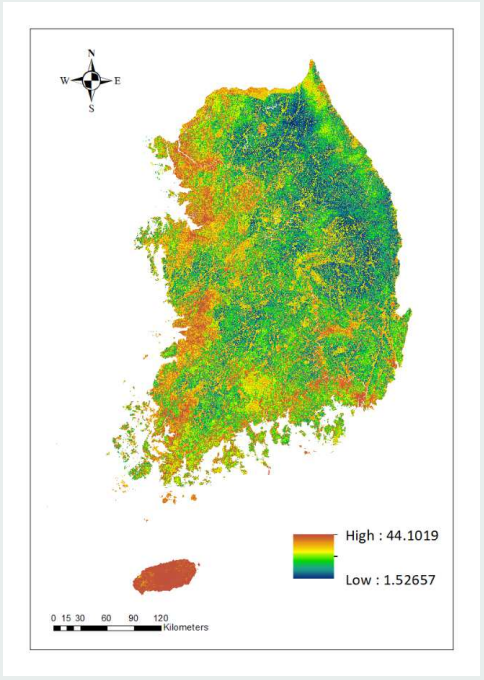
Exposure	Sensitivity	Adaptive Capacity
		

3. Result

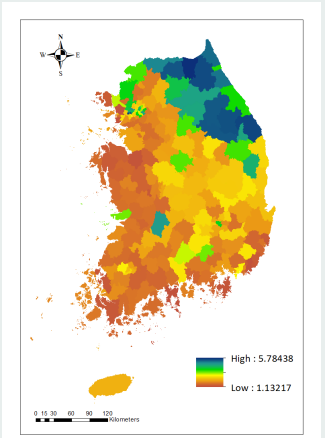
B. Indices

2015 – Observation

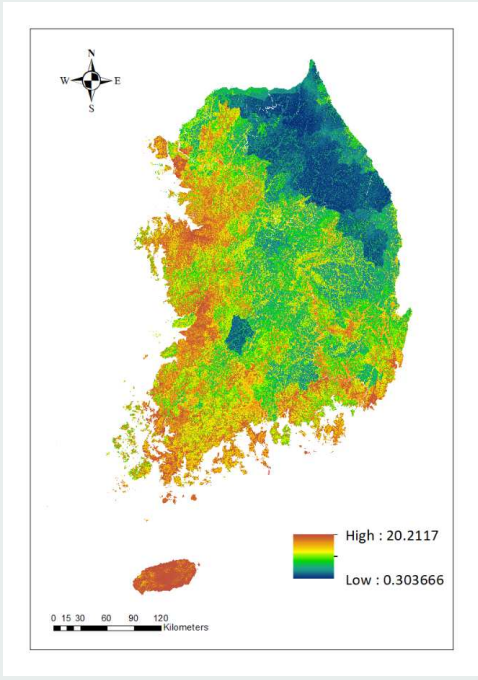
Flood



Exposure*Sensitivity



Adaptive Capacity



Vulnerability

3. Result

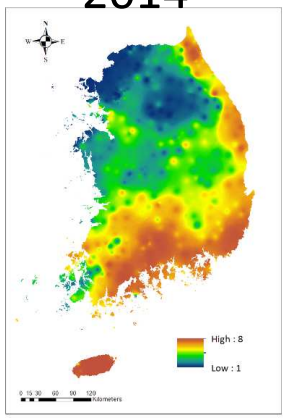
B. Indices

2014-2018 – Observation

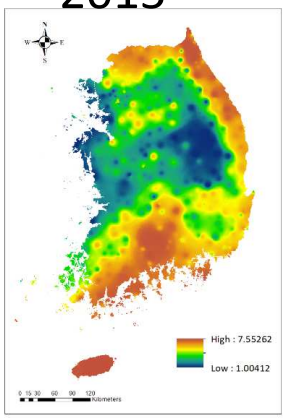
Flood

Exposure

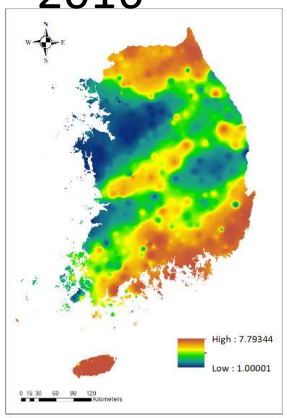
2014



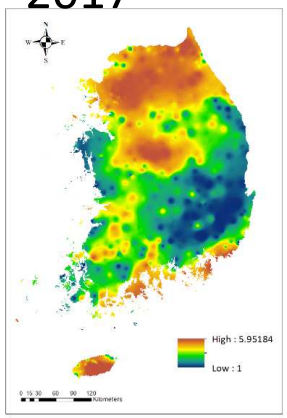
2015



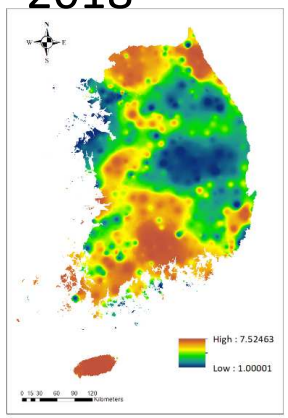
2016



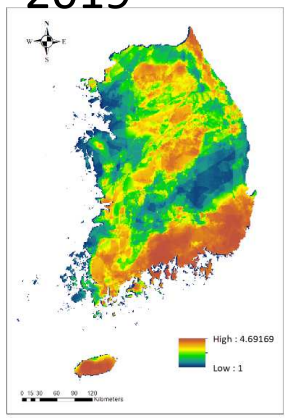
2017



2018



2019

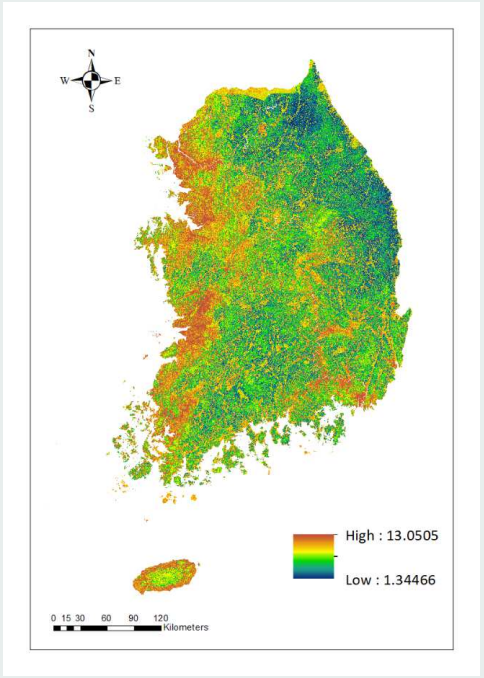


3. Result

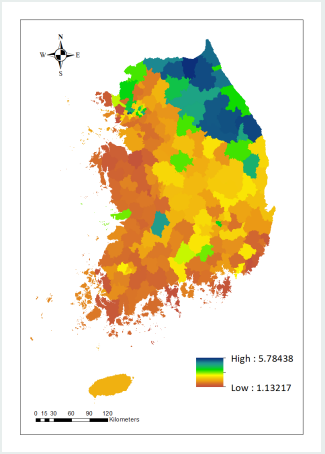
B. Indices

2015 – Observation

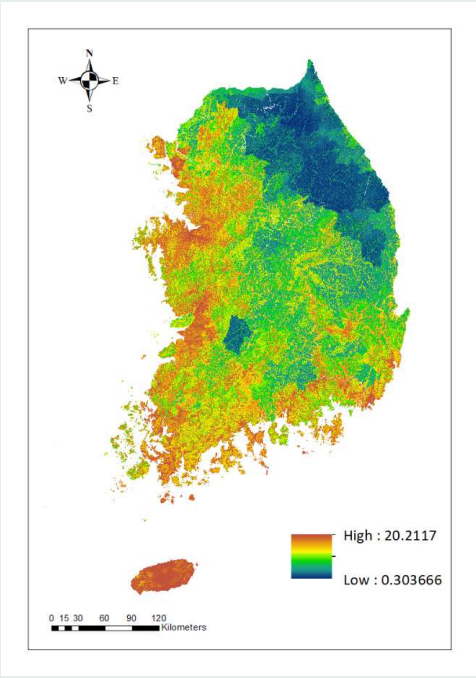
Flood



Sensitivity



Adaptive Capacity



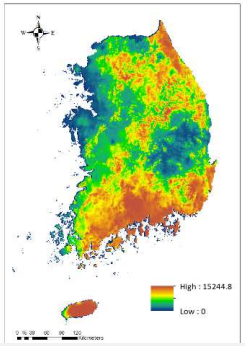
Vulnerability

3. Result

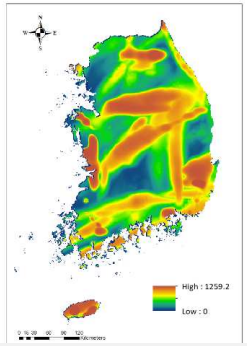
B. Indices

2019 – Prediction **Flood**

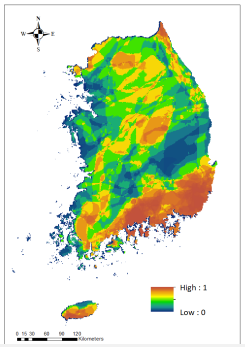
Exposure



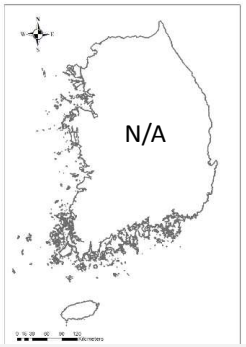
Annual Rainfall



Daily maximum rainfall

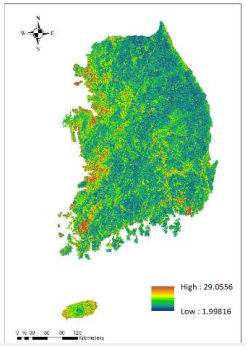


Days over 80mm rainfall

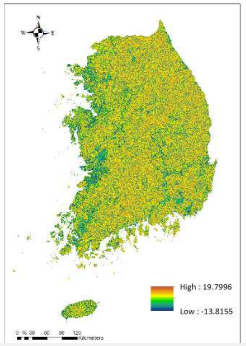


Snow melt

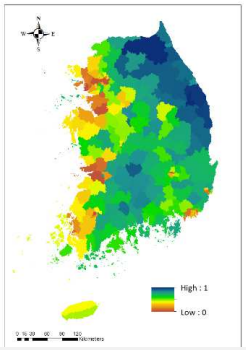
Sensitivity



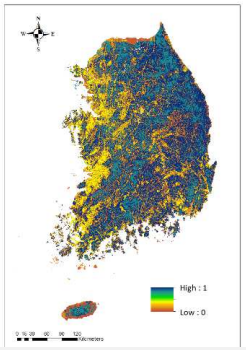
TWI



SPI

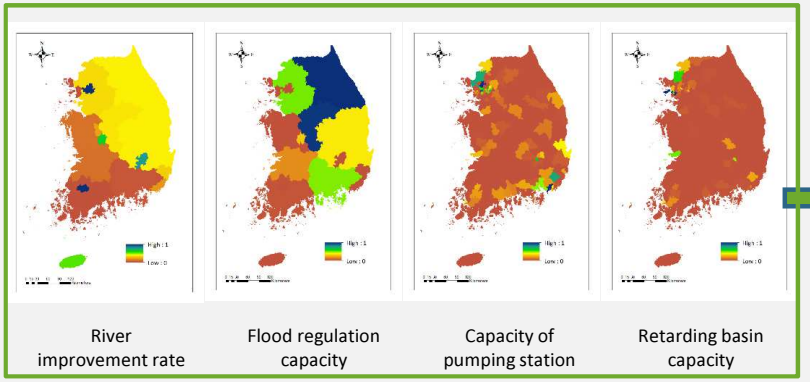


Forest ratio



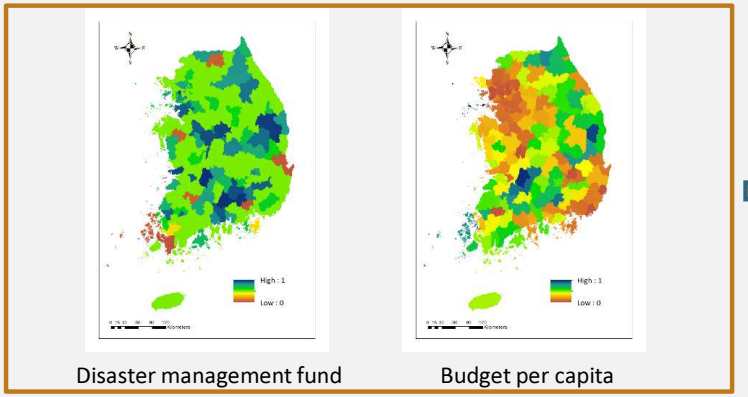
Soil depth

Adaptive Capacity



River improvement rate | Flood regulation capacity | Capacity of pumping station | Retarding basin capacity

→ Infra



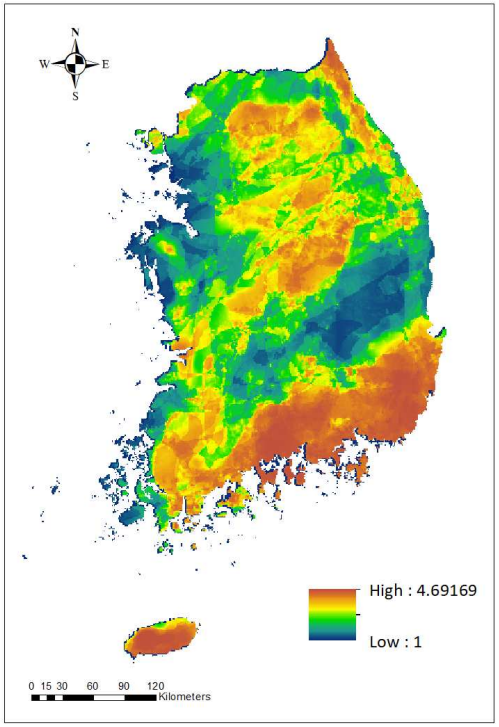
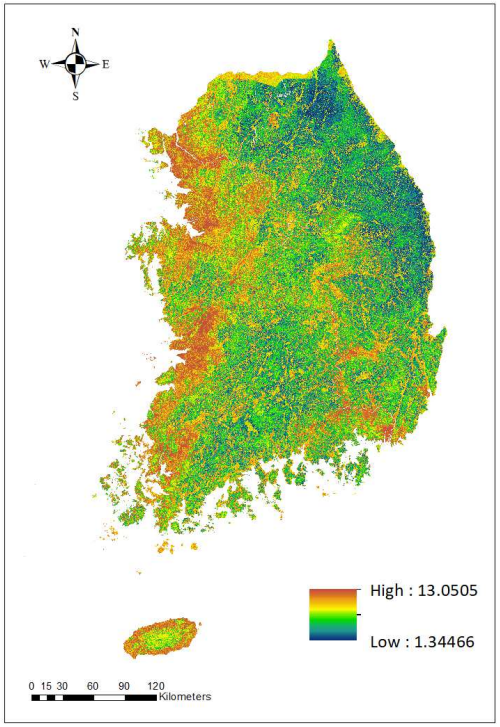
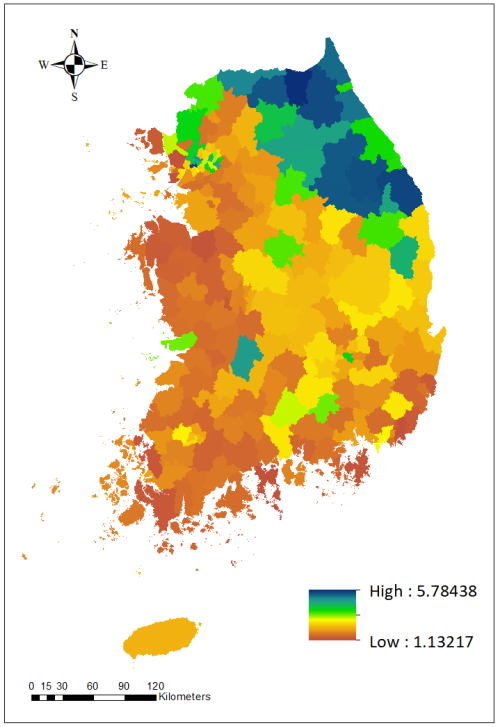
Disaster management fund | Budget per capita

→ Inst. & Policies

3. Result

B. Indices

2019 – Prediction **Flood**

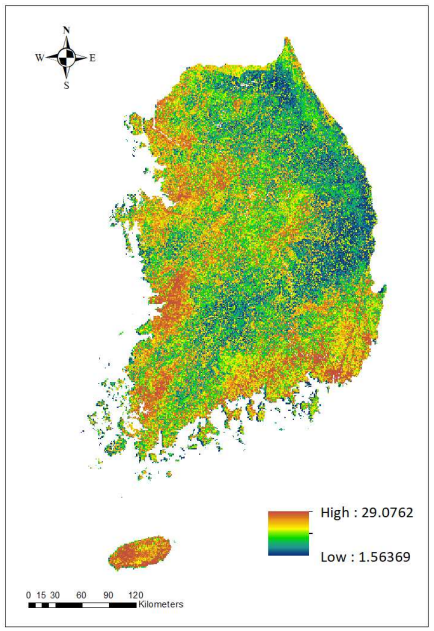
Exposure	Sensitivity	Adaptive Capacity
		

3. Result

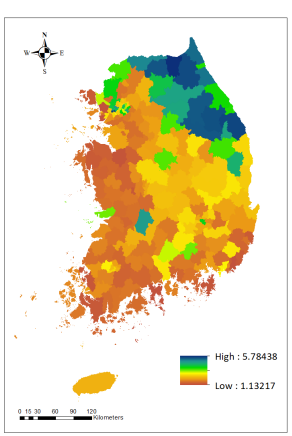
B. Indices

2019 – Prediction

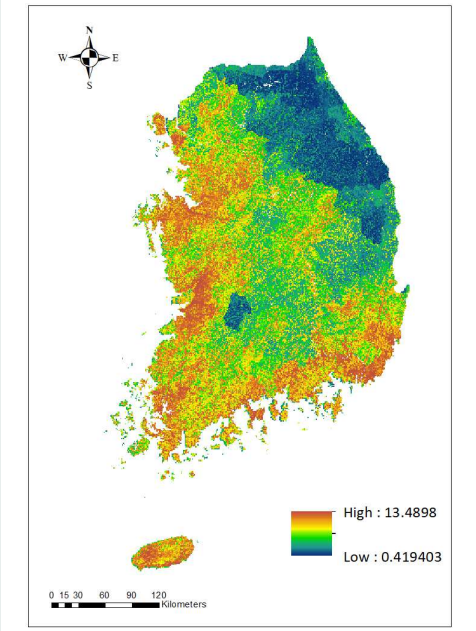
Flood



Exposure*Sensitivity



Adaptive Capacity

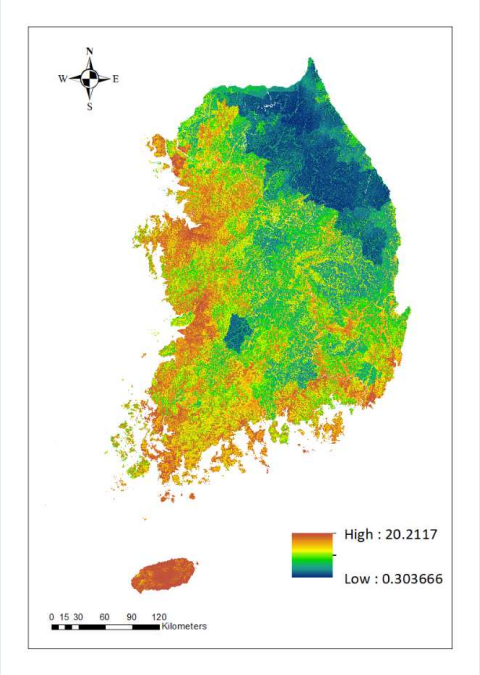


Vulnerability

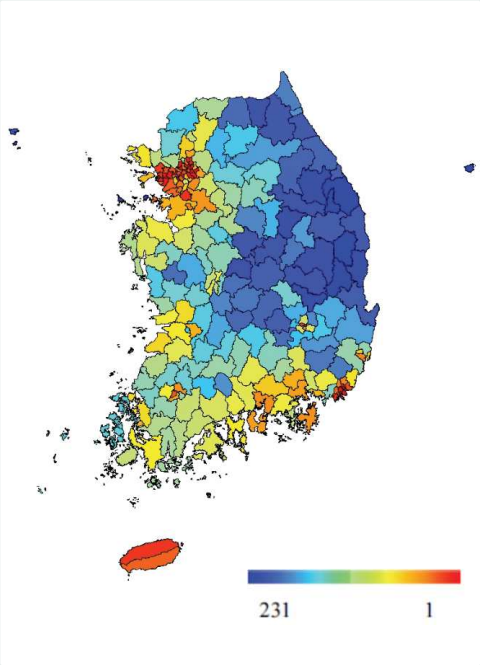
3. Result

B. Indices

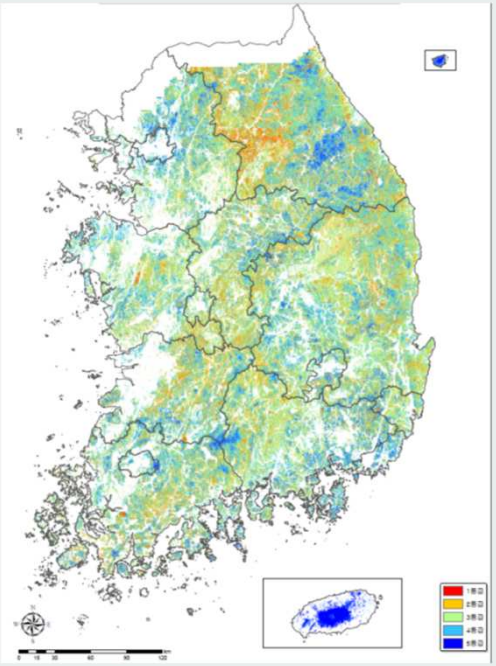
2019 – Prediction | **Flood**



Flood Vulnerability in ROK
(From this study)



Flood Vulnerability Index
(Lee and Choi, 2018)



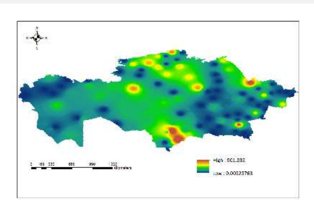
Landslide Risk Map
(KFS, 2012)

3. Result

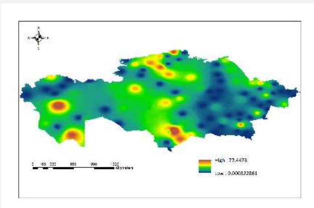
B. Indices

2015 – Observation **Flood**

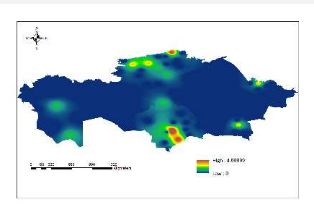
Exposure



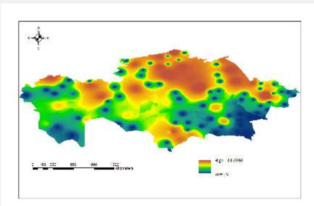
Annual Rainfall



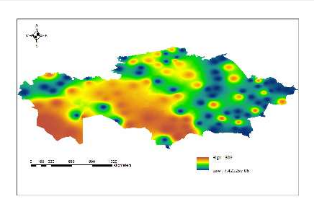
Daily maximum rainfall



Days over 30mm rainfall

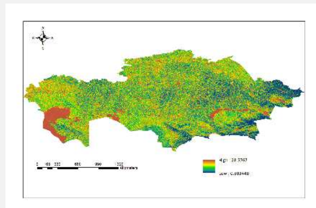


Snow depth

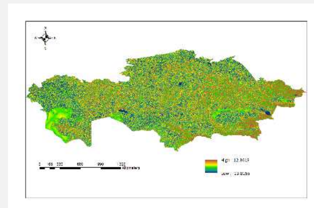


Days over 0 degree celsius

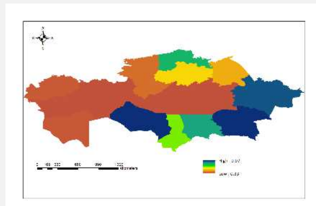
Sensitivity



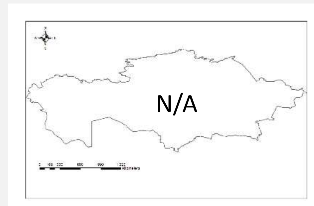
TWI



SPI

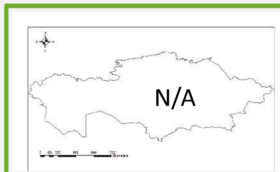


Forest rate

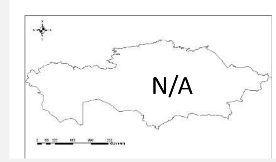


Soil depth

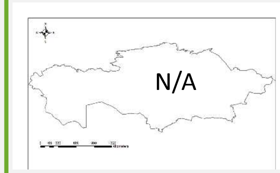
Adaptive Capacity



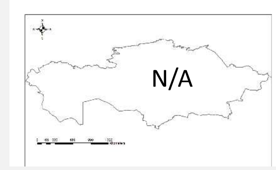
River improvement rate



Flood regulation capacity

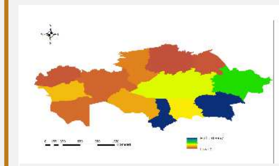


Capacity of pumping station

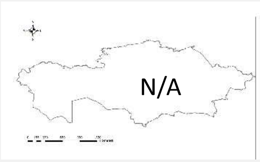


Retarding basin capacity

→ Infra



Budget per capita



Disaster management fund

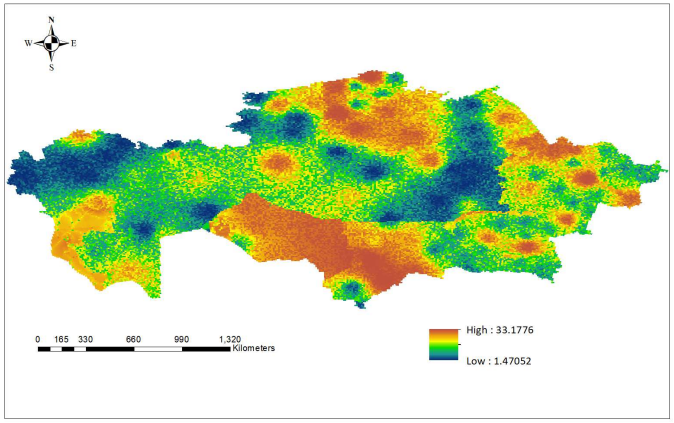
→ Inst. & Policies

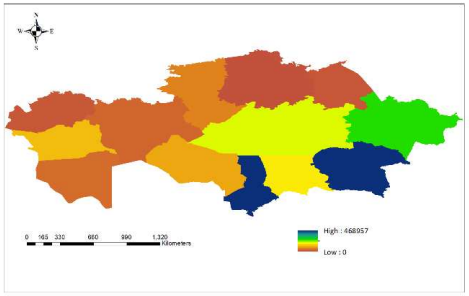
3. Result

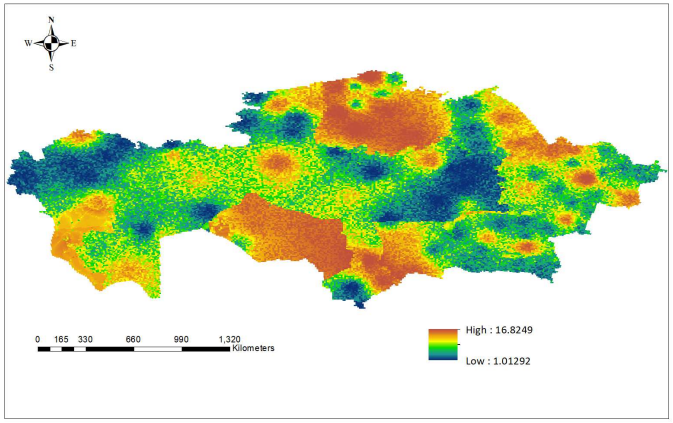
B. Indices

2015 – Observation

Flood







Exposure*Sensitivity

Adaptive Capacity

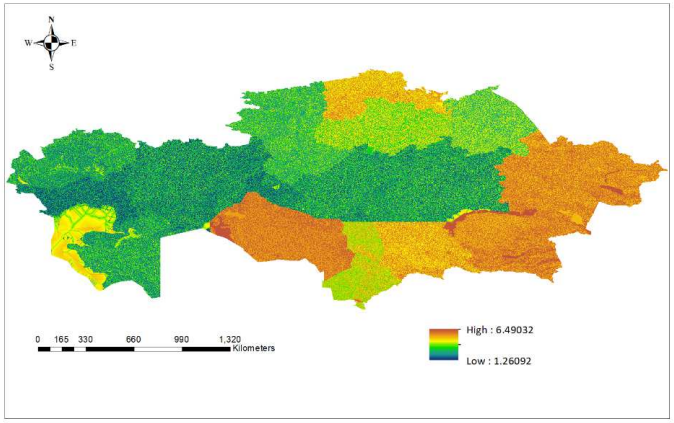
Vulnerability

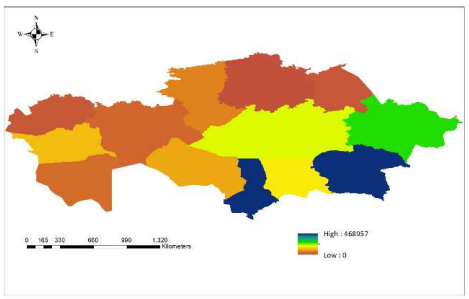
3. Result

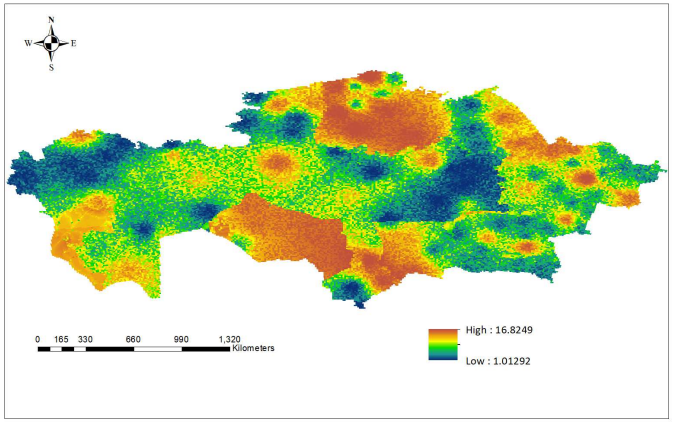
B. Indices

2015 – Observation

Flood







Sensitivity

Adaptive Capacity

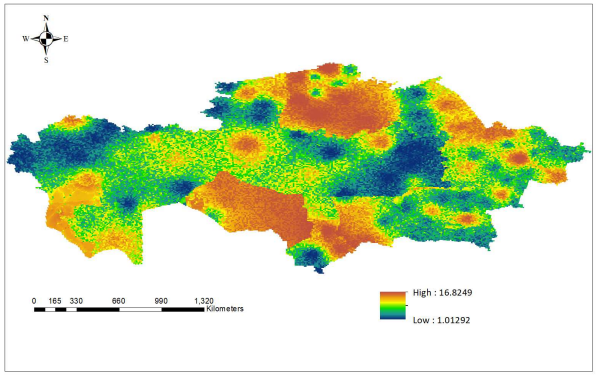
Vulnerability

3. Result

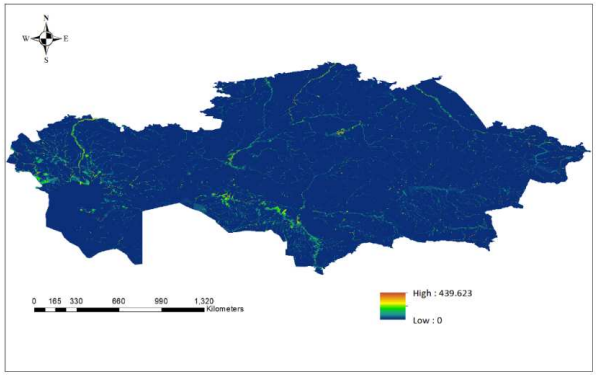
B. Indices

2015 – Observation

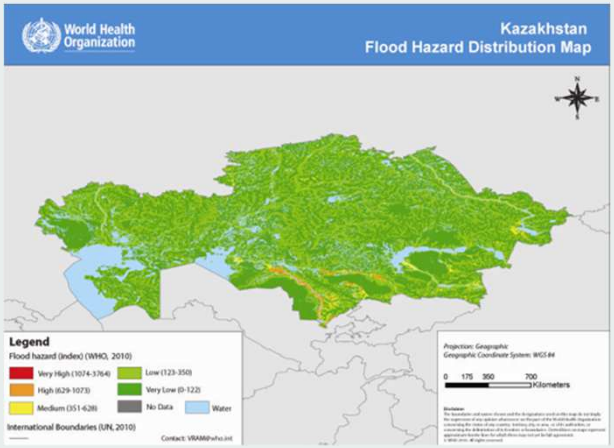
Flood



Flood vulnerability in Kazakhstan
(From this study)



Flood Hazard Map
(UNISDR, 2015)



Flood Hazard Distribution Map
(WHO, 2011)

3. Result

A. Literature review and available indicators

Sand and Dust Storm

Category	Indicator	South Korea	Kazakhstan	Reference
Exposure	Distance from SDS Source area	O	O	
	Aspect	O	O	
	Road concentration	O	O	
	City grade	O	O	
Sensitivity	The number of grazing livestock	?	X	Lee (2015)
	Human-induced Soil Degradation (HISD)	O	O	Oldeman et al. (1991)
	1 - NDVI	O	O	Lamchin et al. (2016)
	1 - Green area ratio	O	X	

3. Result

A. Literature review and available indicators

Sand and Dust Storm

Category	Indicator			Reference
		South Korea	Kazakhstan	
Adaptive Capacity	Local budget for SDS	O	O	
	Budget per capita	O	O	
	Afforestation ratio	O	X	
	Forest protection area	O	X	

3. Result

B. Indices

Sand and Dust Storm

$$\boldsymbol{SDS\ Vulnerabilty\ Index}$$
$$= [\{(Distance\ from\ SDS\ Source\ area\ ) \times (Aspect\ ) \times (Road\ concentration\ ) \times (City\ grade)\} \times \{(HISD) \times (1\ -\ NDVI\ ) \times (1 - Green\ area\ ratio\ )\}] \div [(Local\ budget\ for\ SDS\ ) \times (Budget\ per\ capita\ ) \times (Forest\ protection\ area) \times (Afforestation\ ratio)]$$

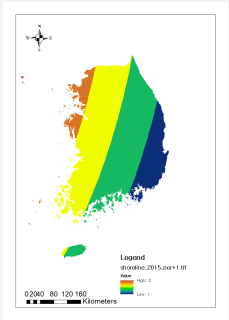
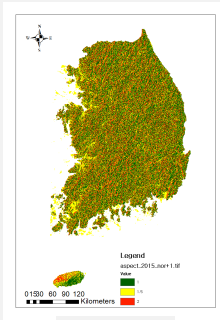
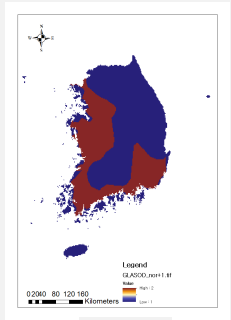
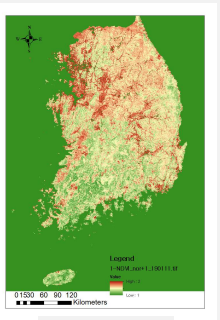
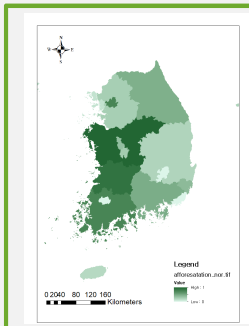
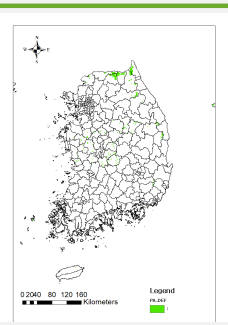
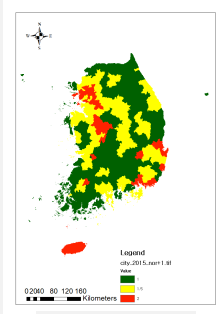
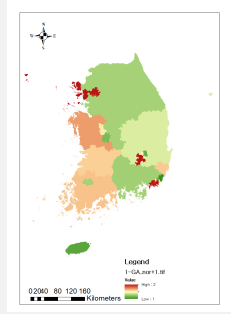
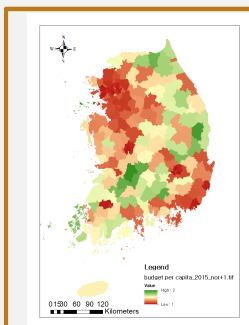
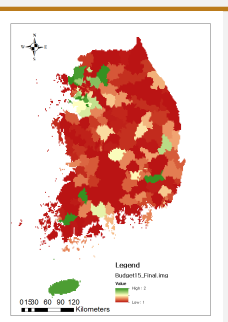
Description

This index is developed to assess the potential vulnerability of Sand and Dust Storm considering land condition, government's financial commitment to prevent disaster.

3. Result

B. Indices

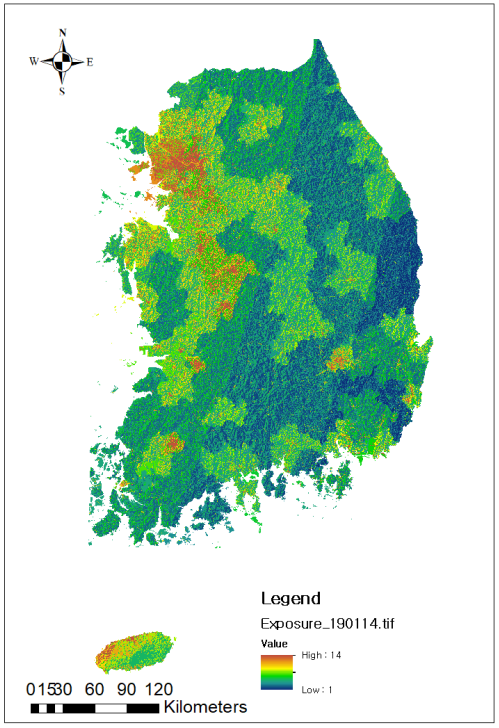
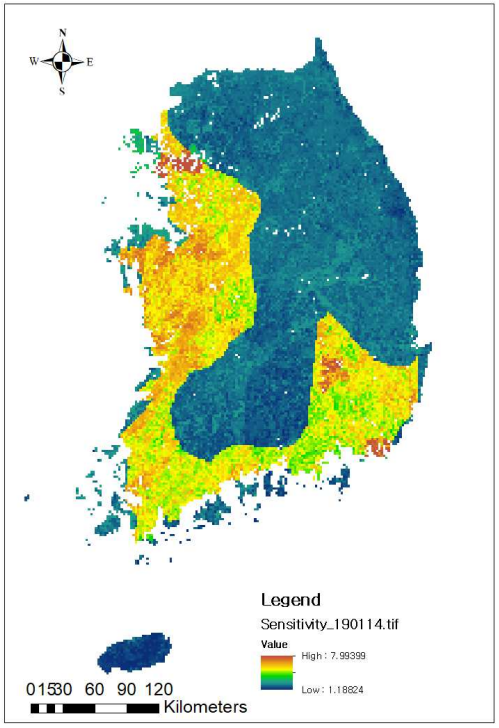
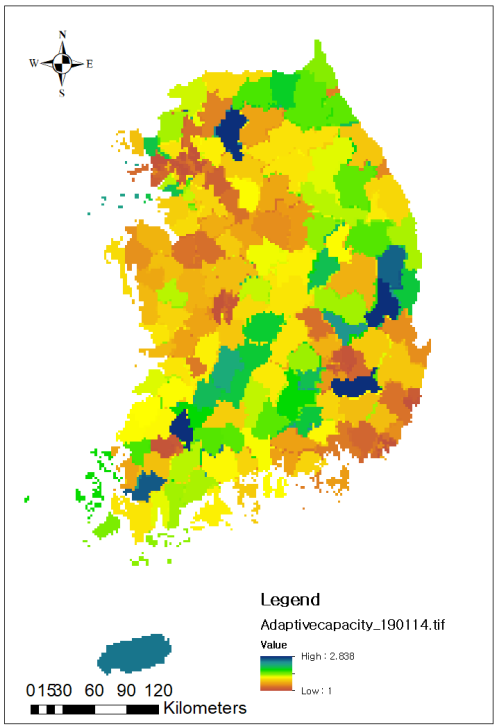
2015 – Observation **Sand and Dust Storm**

Exposure	Sensitivity	Adaptive Capacity	
 Distance from SDS Source area	 Aspect	 HISD	 1 - NDVI	 Afforestation ratio	 Forest protection area	Infra
 Road concentration	 City grade	 1 – Green area ratio		 Budget per capita	 Local budget for SDS	Inst. & Policies

3. Result

B. Indices

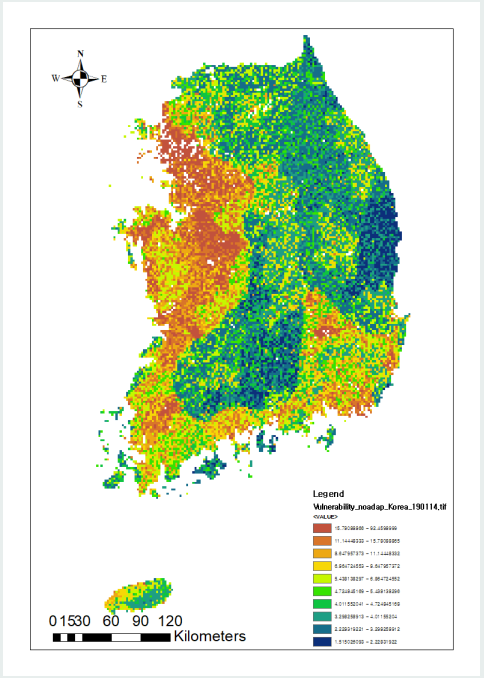
2015 – Observation **Sand and Dust Storm**

Exposure	Sensitivity	Adaptive Capacity
		

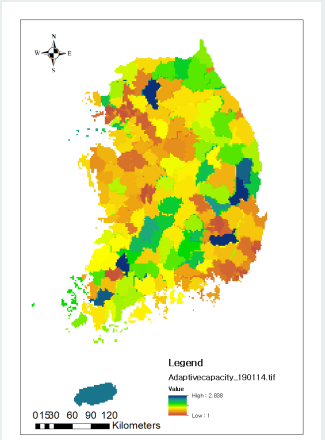
3. Result

B. Indices

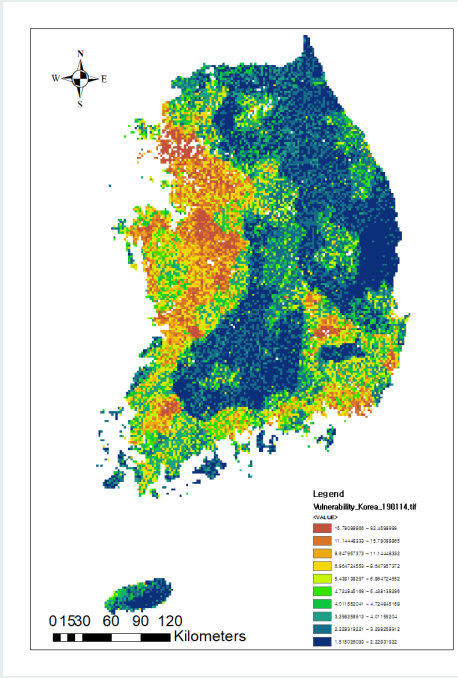
2015 – Observation **Sand and Dust Storm**



Exposure*Sensitivity



Adaptive Capacity

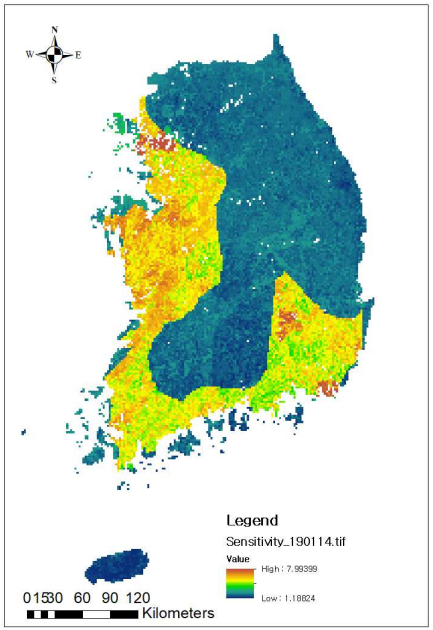


Vulnerability

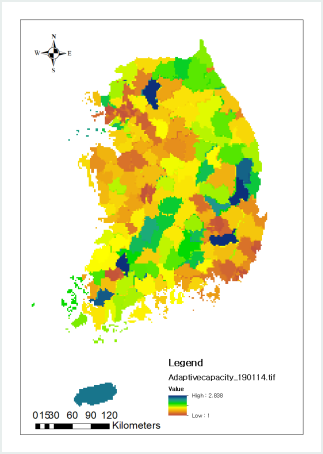
3. Result

B. Indices

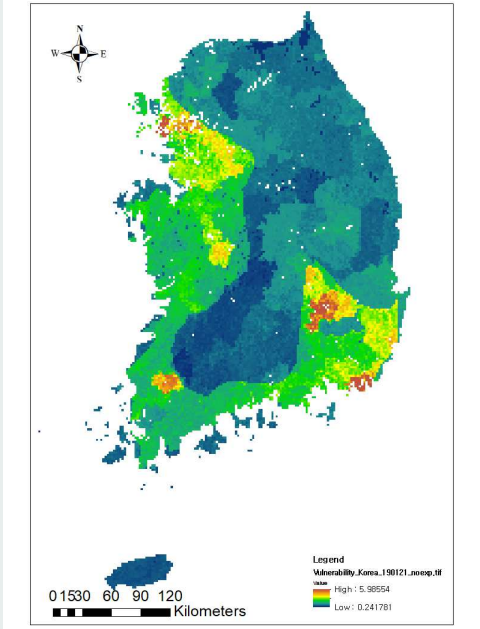
2015 – Observation **Sand and Dust Storm**



Sensitivity



Adaptive Capacity

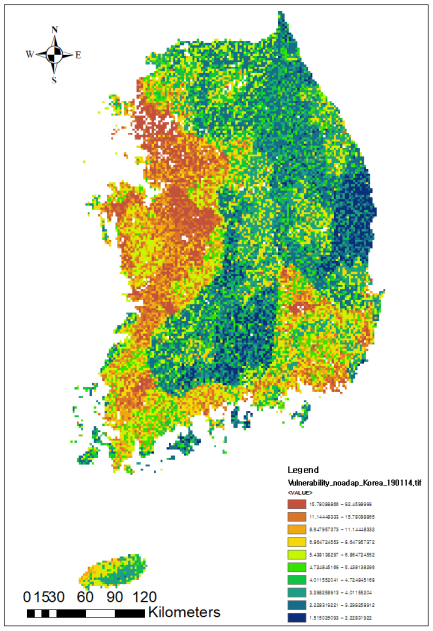


Vulnerability

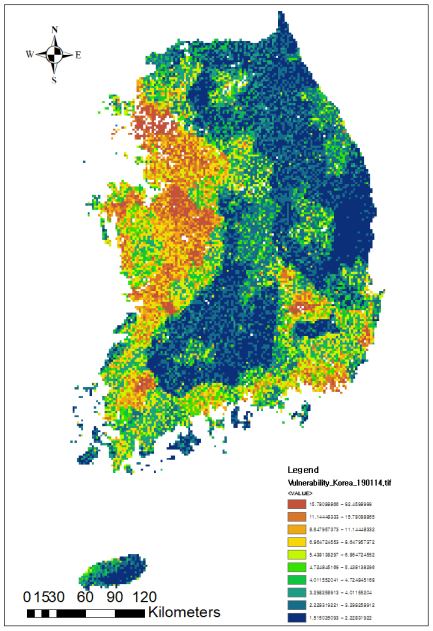
3. Result

B. Indices

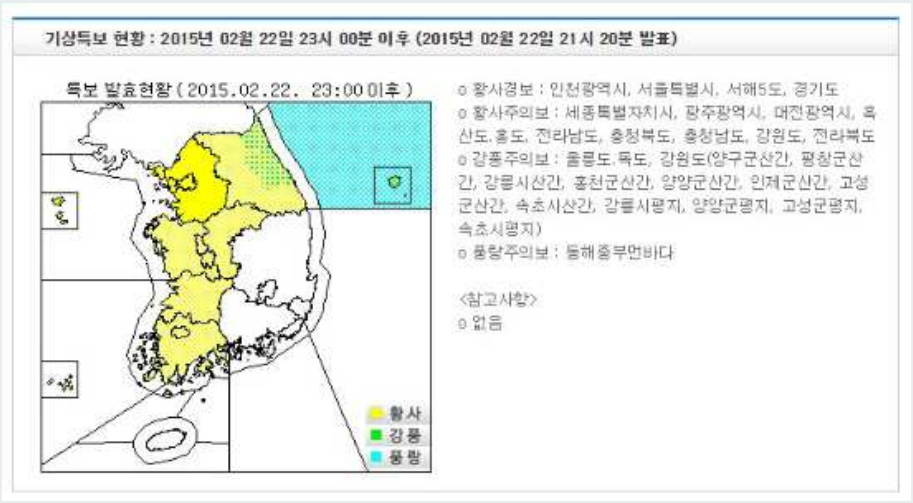
2015 – Observation **Sand and Dust Storm**



Sand and Dust storm exposure * sensitivity



Sand and Dust storm vulnerability

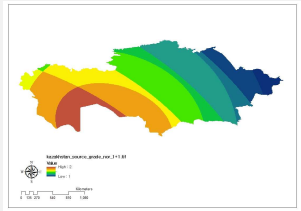
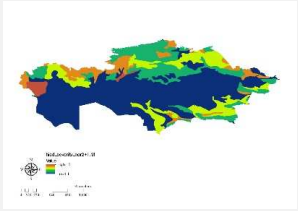
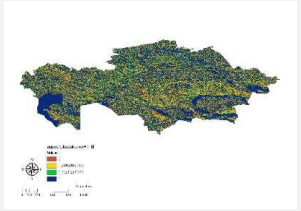
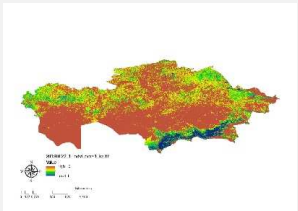
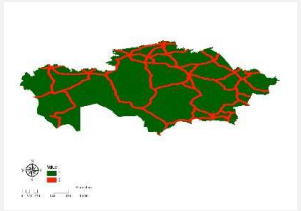
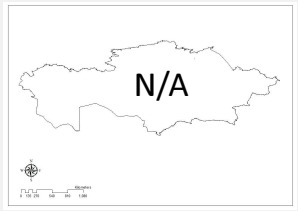
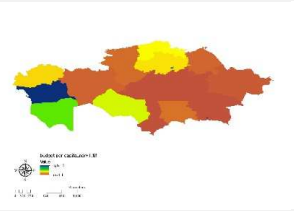
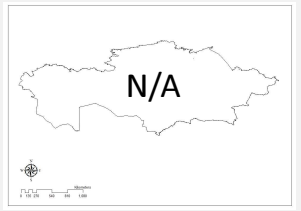
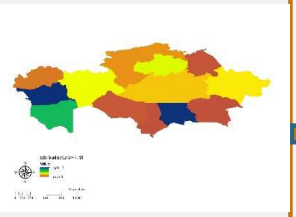


2015 Yellow dust warning

3. Result

B. Indices

2015 – Observation **Sand and Dust Storm**

Exposure	Sensitivity	Adaptive Capacity
 Distance from SDS Source area	 HISD	 Afforestation ratio
 Aspect	 1 - NDVI	 Forest protection area
 Road concentration	 1 – Green area ratio	 Budget per capita
 City grade		 Local budget for SDS

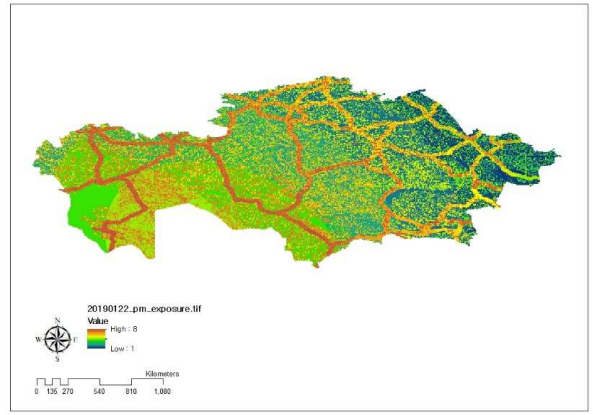
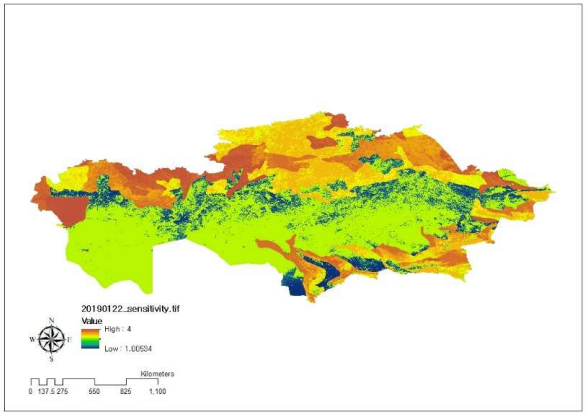
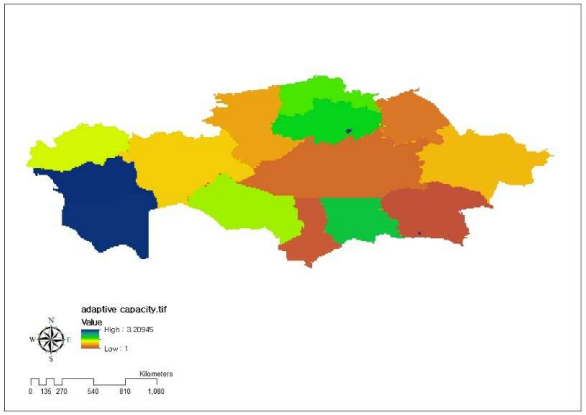
→ Infra

→ Inst. & Policies

3. Result

B. Indices

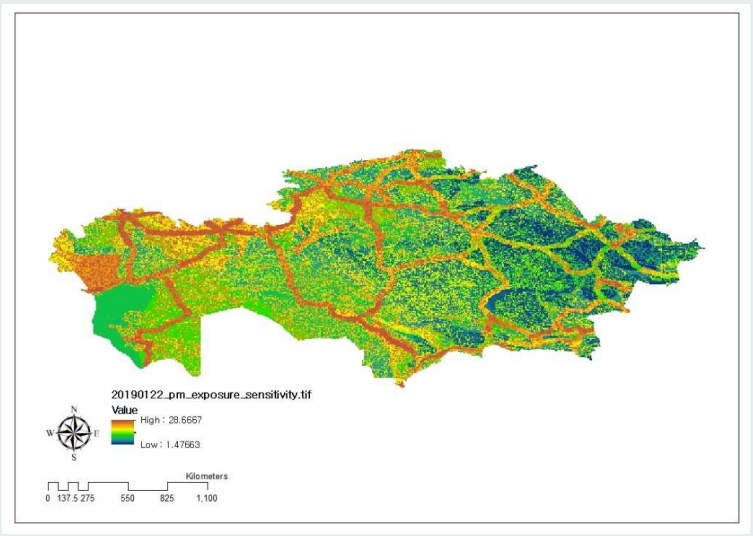
2015 – Observation **Sand and Dust Storm**

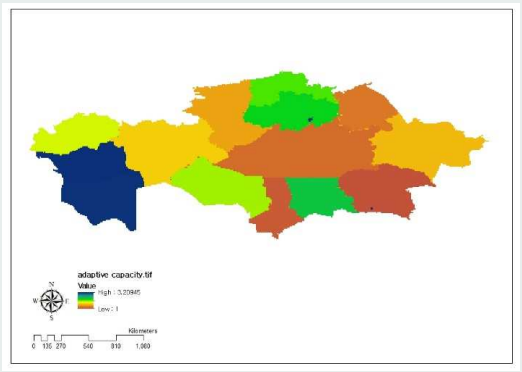
Exposure	Sensitivity	Adaptive Capacity
		

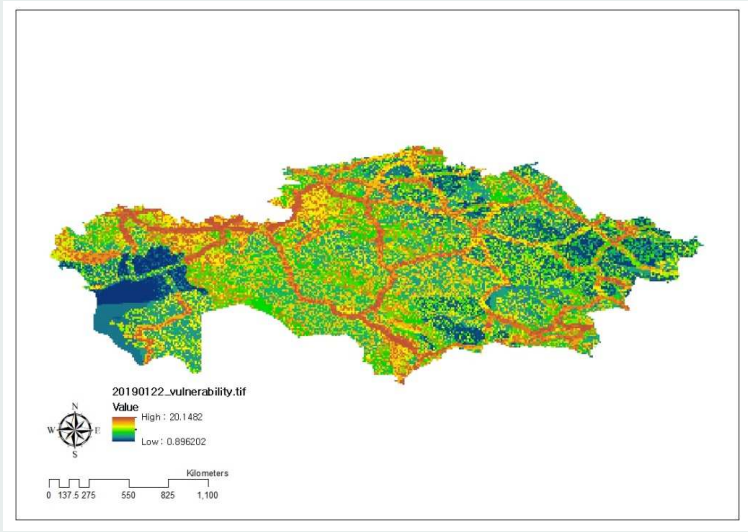
3. Result

B. Indices

2015 – Observation **Sand and Dust Storm**







Exposure*Sensitivity

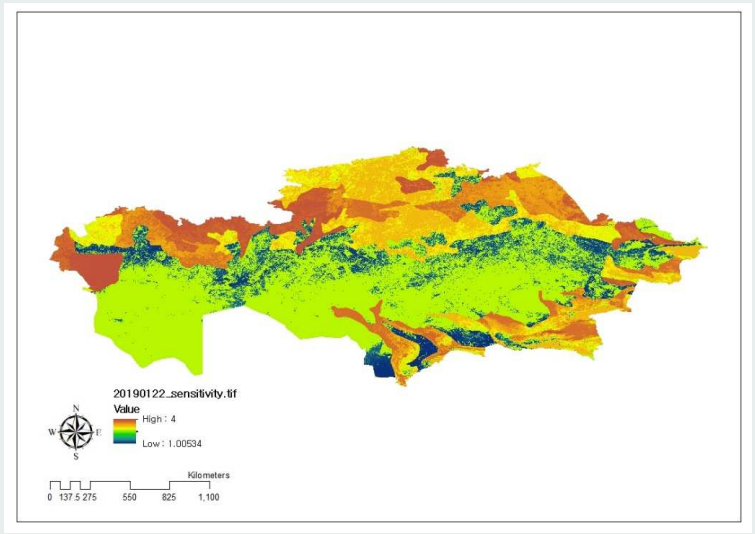
Adaptive Capacity

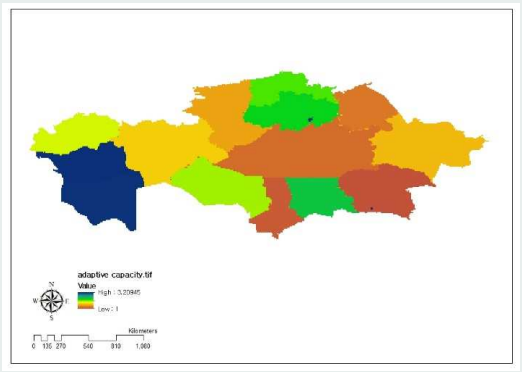
Vulnerability

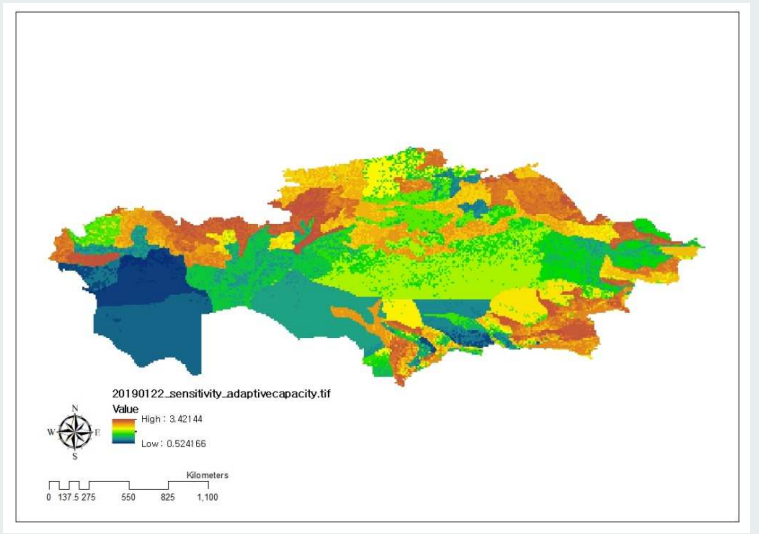
3. Result

B. Indices

2015 – Observation **Sand and Dust Storm**







Sensitivity

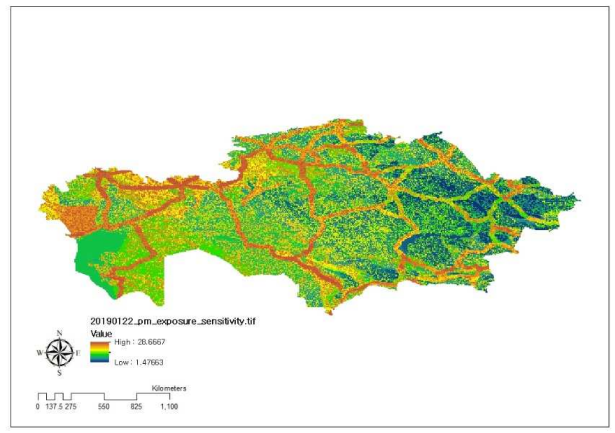
Adaptive Capacity

Vulnerability

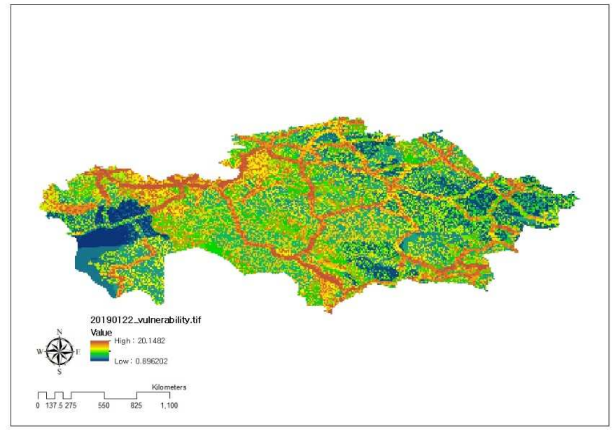
3. Result

B. Indices

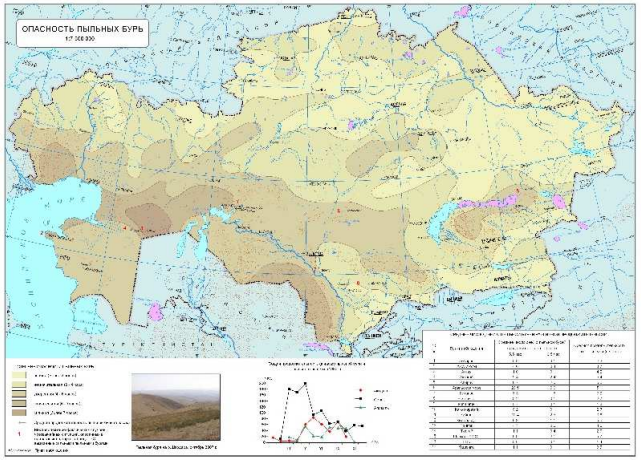
Sand and Dust storm exposure * sensitivity



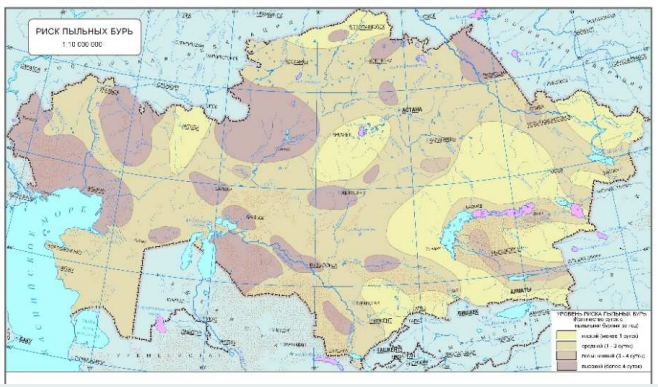
Sand and Dust storm vulnerability



2015 – Observation **Sand and Dust Storm**



Sand and Dust storm risk map



Sand and Dust storm observation records

3. Result

A. Literature review

Air Pollution

Category	Indicator	Availability		Reference
		South Korea	Kazakhstan	
Exposure	Nitrogen Dioxide concentration (NO_2)	O	O	WHO (2016) Pruss-Ustun et al. (2016)
	Particle Matter 2.5 concentration ($PM_{2.5}$)	O	O	WHO (2016) Pruss-Ustun et al. (2016)
	Ozone concentration (O_3)	O	O	WHO (2016) Pruss-Ustun et al. (2016)
	Sulfur dioxide concentration (SO_2)	O	O	WHO (2016) Pruss-Ustun et al. (2016)
	City grade	O	X	This study
Sensitivity	1-Forest ratio	O	O	Irga et al. (2015) Sara et al. (2015)
	Facility for emission source	O	O	IEA, 2016

3. Result

A. Literature review

Air Pollution

Category	Indicator	Availability		Reference
		South Korea	Kazakhstan	
Adaptive Capacity	The ratio of renewable energy generation	O	O	Siwon Park
	The ratio of electric vehicle supply	O	X	Cheong Seog Seo(2017)
	Budget for air pollution	O	X	Hye Yeon Kwon et al (2016)
	Budget per capita	O	O	This study

3. Result

B. Indices

Air pollution

Air pollution Vulnerabilty Index

$$= [(NO2\ concentration) \times (PM2.5\ concentration) \times (\ Ozone\ concentration)$$
$$\times (SO2\ concentration) \times (City\ grade) \times (1 - forest\ ratio) \times (Facility\ for\ emission\ source)]$$
$$\div [(\ The\ ratio\ of\ renewable\ energy\ generation) \times (\ The\ ratio\ of\ electric\ vehicle\ supply\ )$$
$$\times (Budget\ for\ air\ pollution\ ) \times (Budget\ per\ capita)]$$

Description

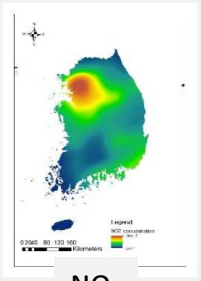
This index is developed to see the potential impact of air pollution by its value, emission source, government's financial commitment to air pollution prevention and preparedness.

3. Result

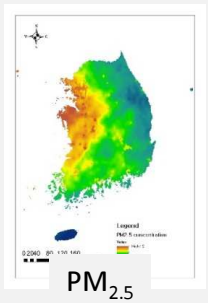
B. Indices

2015 – Observation **Air Pollution**

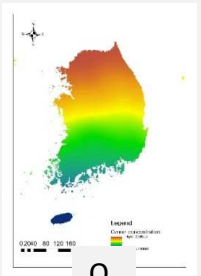
Exposure



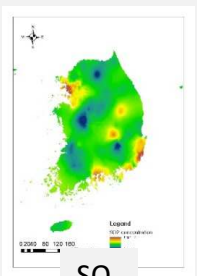
NO_2



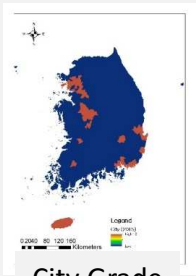
$PM_{2.5}$



O_3

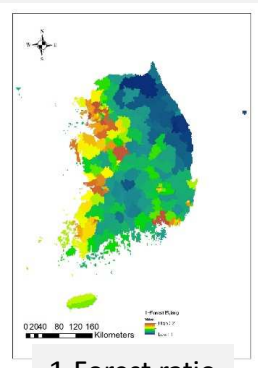


SO_2

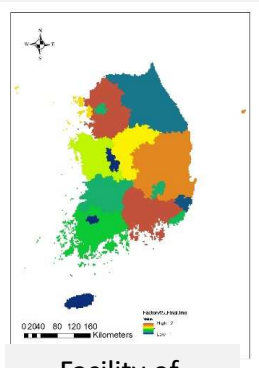


City Grade

Sensitivity



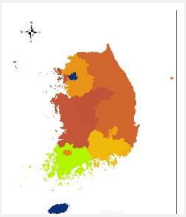
1-Forest ratio



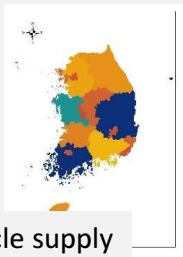
Facility of emission source

Adaptive Capacity

Improved Infrastructure



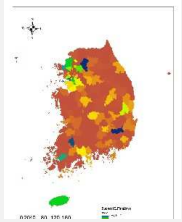
The ratio of electric vehicle supply



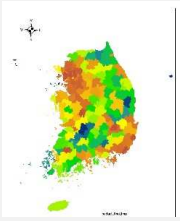
The ratio of renewable energy generation

→ Infra

Budget per capita



Budget for air pollution



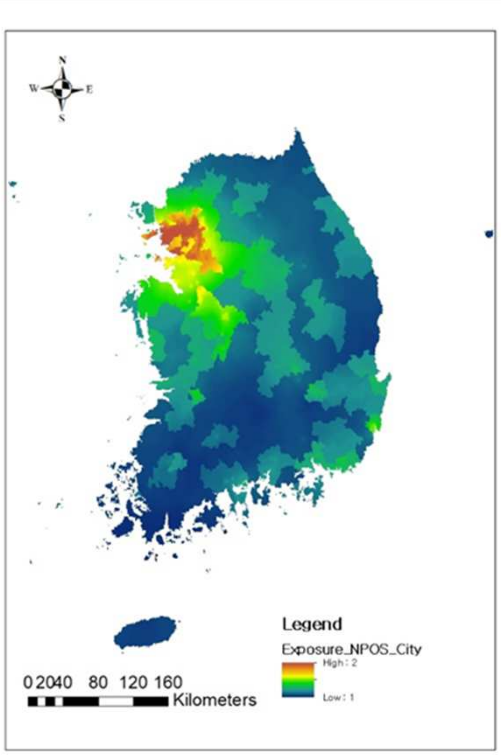
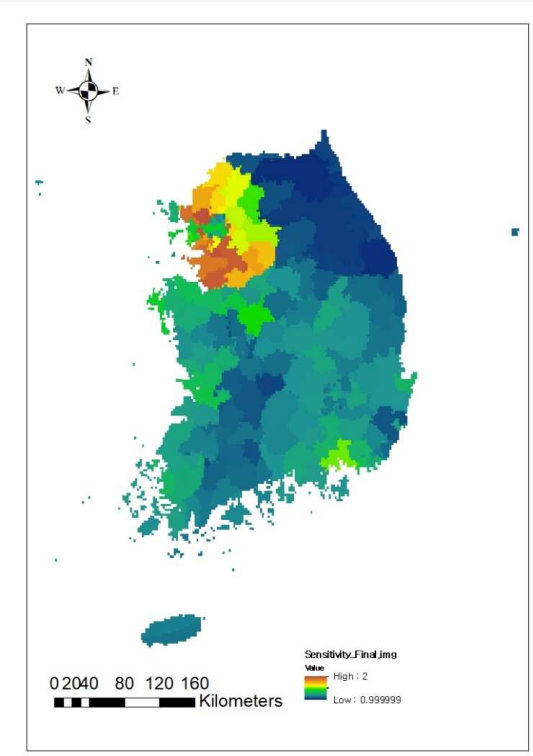
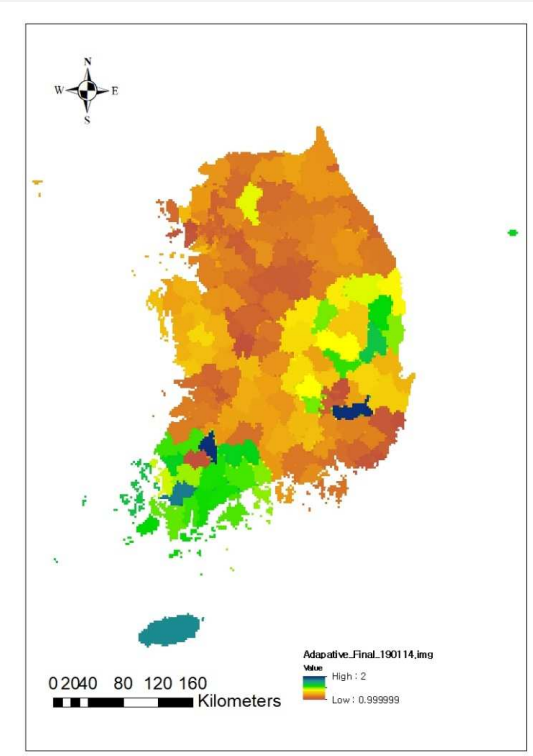
Budget per capita

→ Inst. & Policies

3. Result

B. Indices

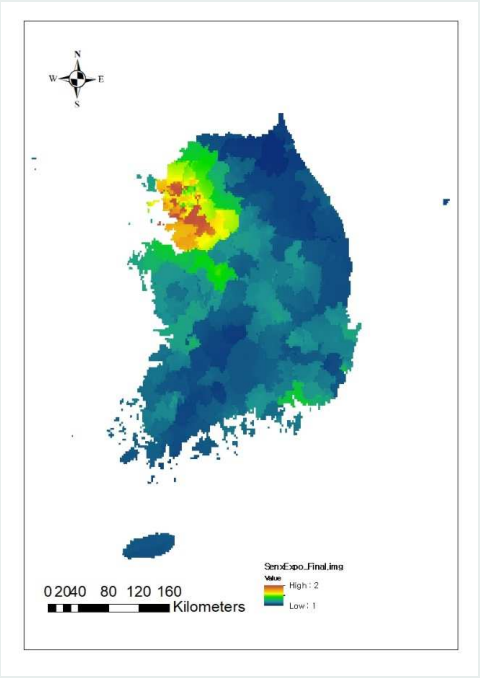
2015 – Observation | **Air Pollution**

Exposure	Sensitivity	Adaptive Capacity
		

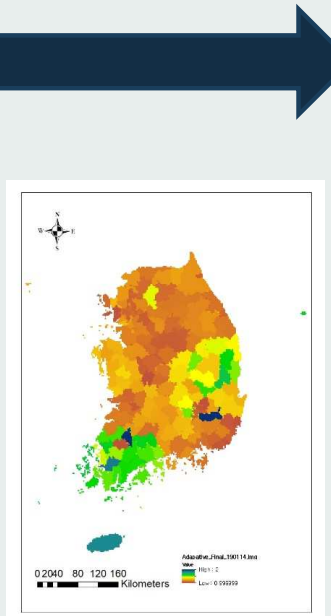
3. Result

B. Indices

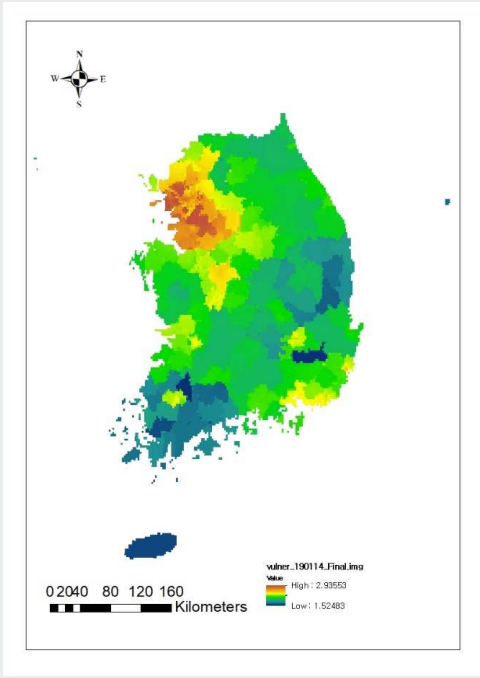
2015 – Observation **Air Pollution**



Exposure*Sensitivity



Adaptive Capacity

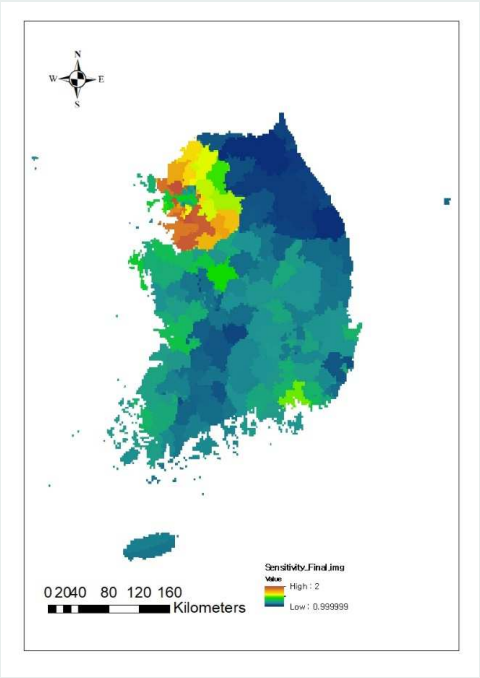


Vulnerability

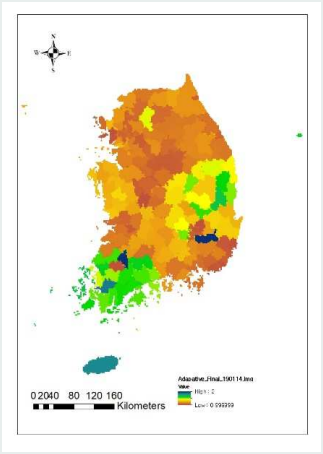
3. Result

B. Indices

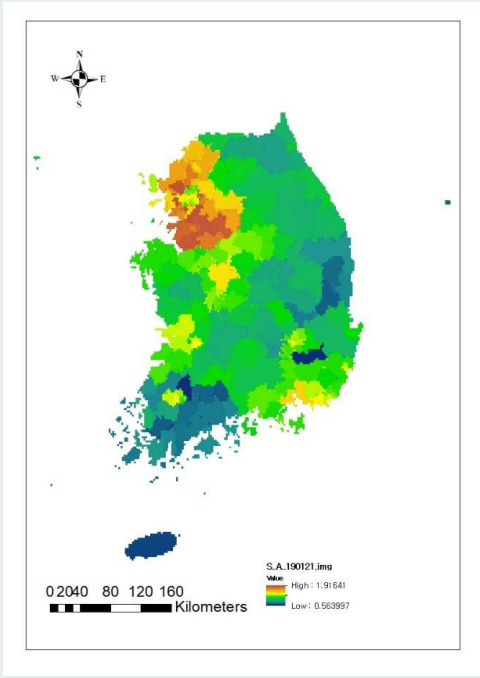
2015 – Observation **Air Pollution**



Sensitivity



Adaptive Capacity



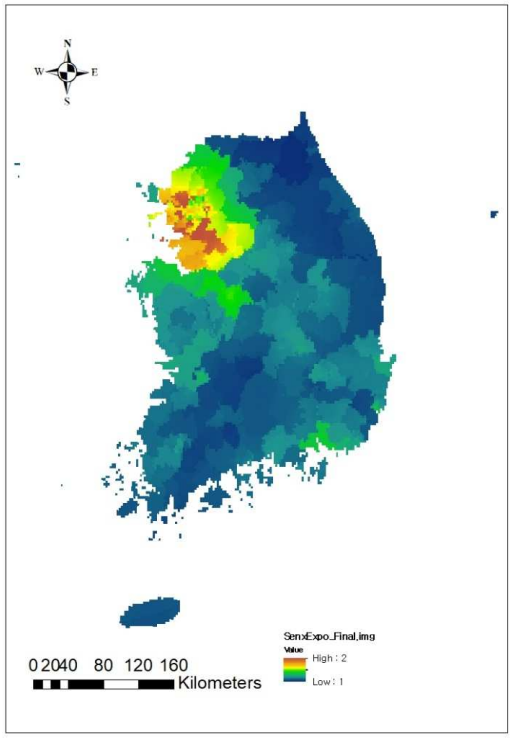
Vulnerability

3. Result

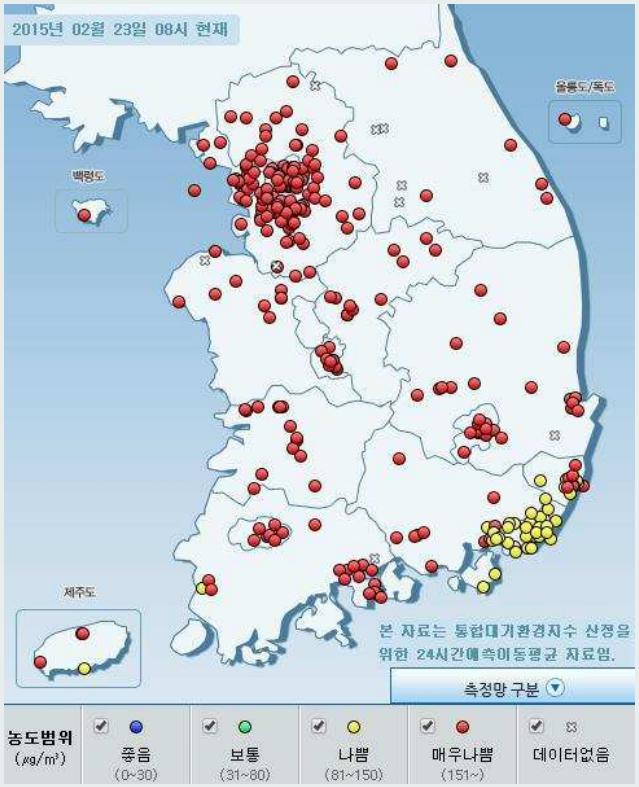
B. Indices

2015 – Observation **Air Pollution**

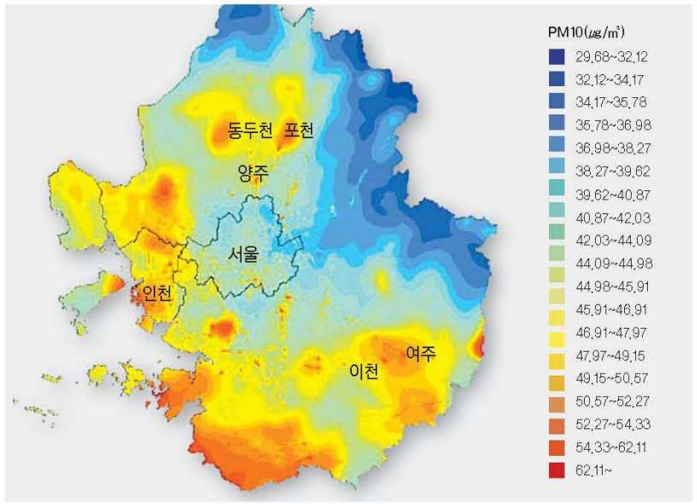
Exposure x Sensitivity of 2015



Comprehensive Air Quality Index of 23 February 2015 from Air Korea



Annual average of air pollution in Metropolitan area, 2015 (Koo Youn Seo et al)



별 차이 없는 서울·제주 미세먼지 오염도 (단위 : ㎍/㎥)

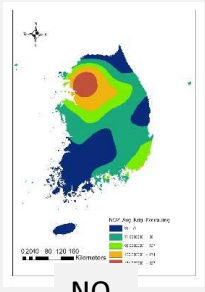
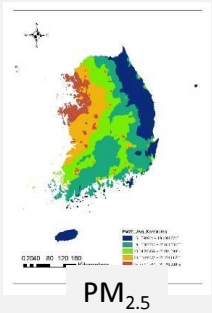
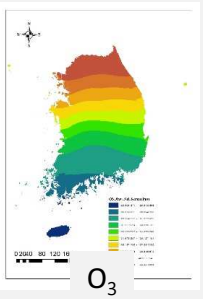
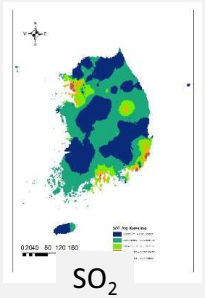
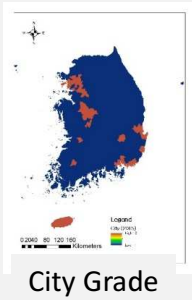
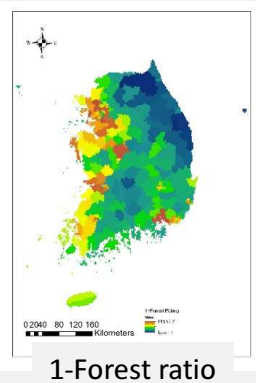
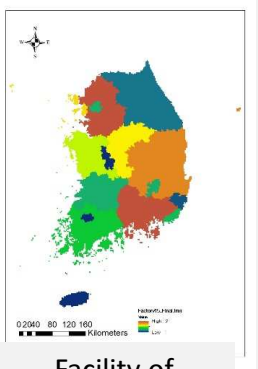
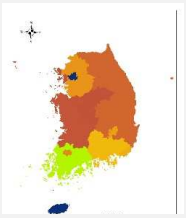
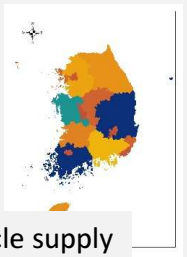
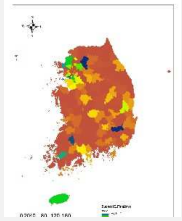
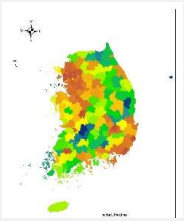
구분	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015년
서울	65	65	69	59	56	55	58	53	51	47	44	41	44	44	42
제주	38	40	37	41	43	47	40	42	41	43	39	33	40	44	42

※황사를 제외한 연평균 오염도, 2015년 값은 최종 확정되기 전의 데이터를 일부 포함한 수치 자료: 환경부

3. Result

B. Indices

2019 – Prediction(Average) **Air Pollution**

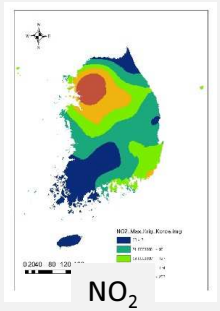
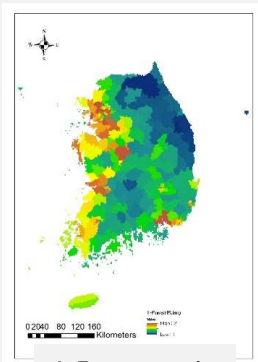
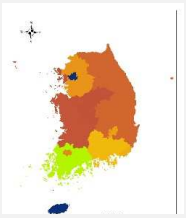
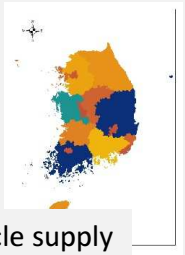
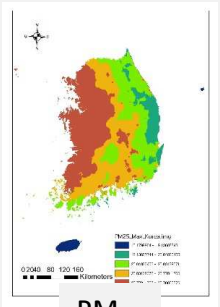
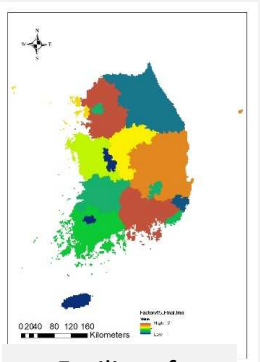
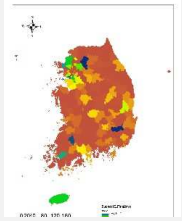
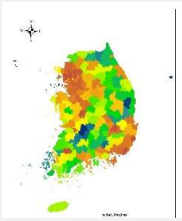
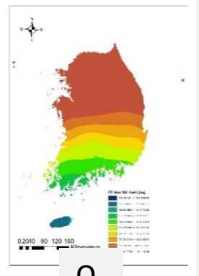
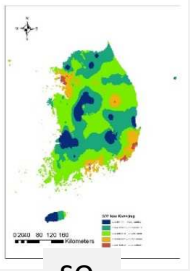
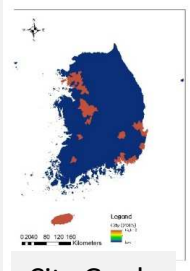
Exposure	Sensitivity	Adaptive Capacity
 NO_2  $PM_{2.5}$  O_3  SO_2  City Grade	 1-Forest ratio  Facility of emission source	Improved Infrastructure   The ratio of electric vehicle supply The ratio of renewable energy generation → Infra Budget per capita   Budget for air pollution Budget per capita → Inst. & Policies

3. Result

B. Indices

2019 – Prediction(Max)

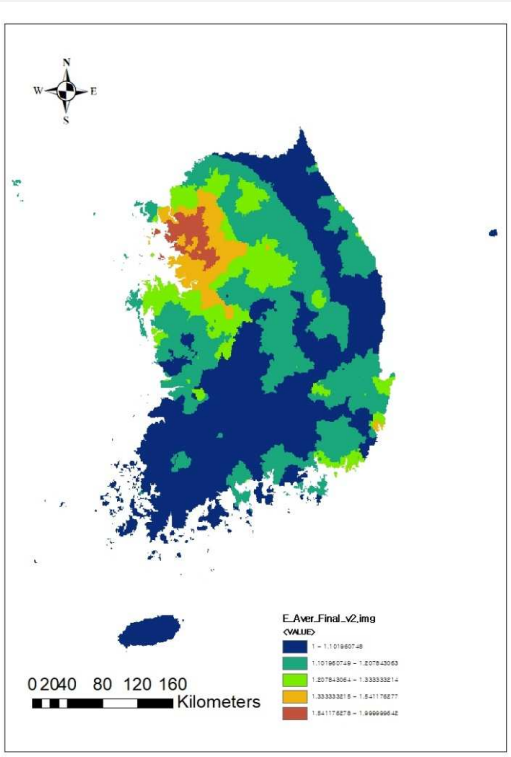
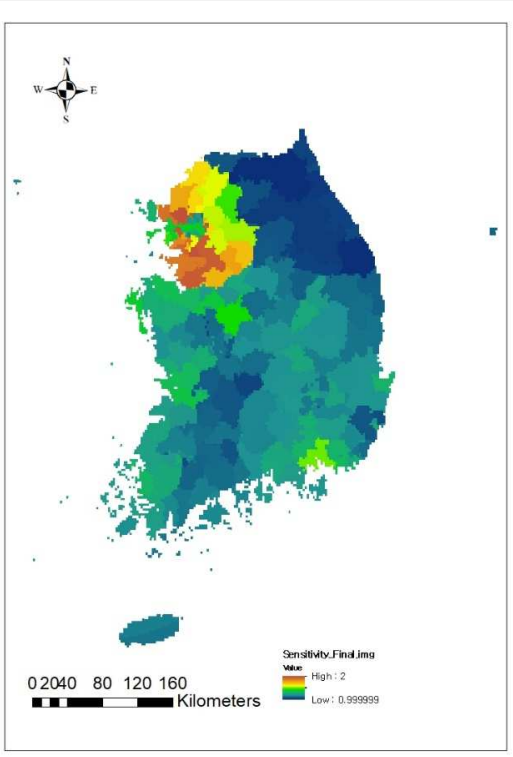
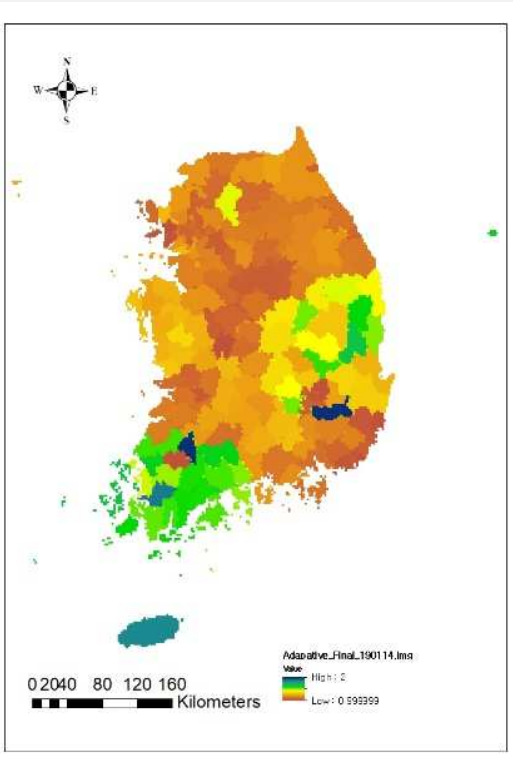
Air Pollution

Exposure	Sensitivity	Adaptive Capacity
 NO_2	 1-Forest ratio	Improved Infrastructure   The ratio of electric vehicle supply The ratio of renewable energy generation → Infra
 $PM_{2.5}$	 Facility of emission source	Budget per capita   Budget for air pollution Budget per capita → Inst. & Policies
 O_3		
 SO_2		
 City Grade		

3. Result

B. Indices

2019 – Prediction(Average) **Air Pollution**

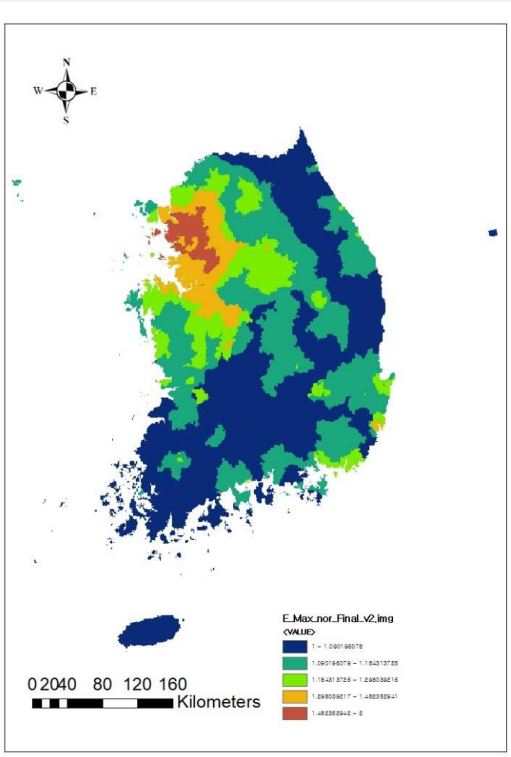
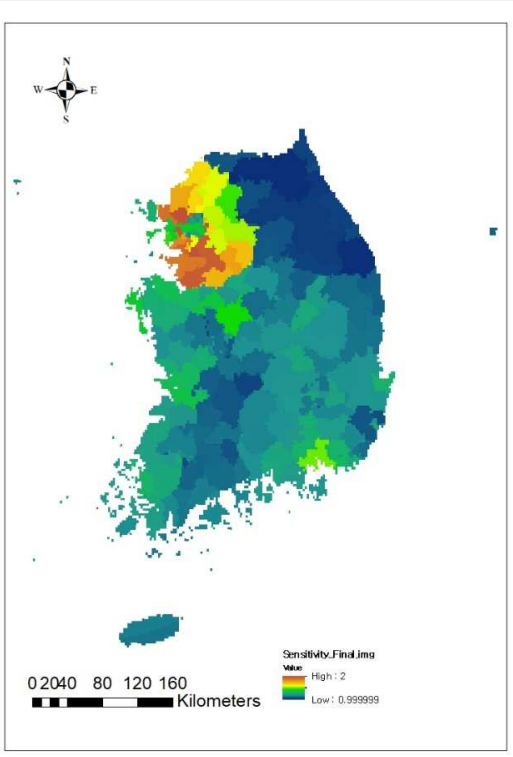
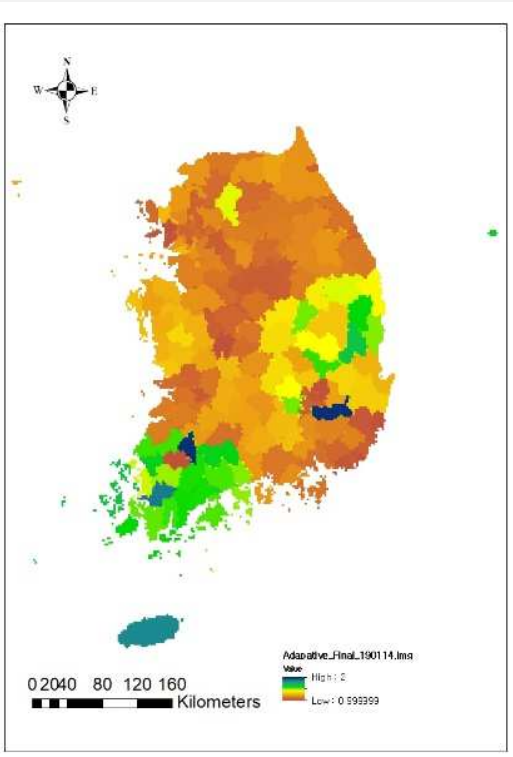
Exposure	Sensitivity	Adaptive Capacity
		

3. Result

B. Indices

2019 – Prediction(Max)

Air Pollution

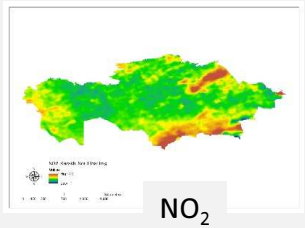
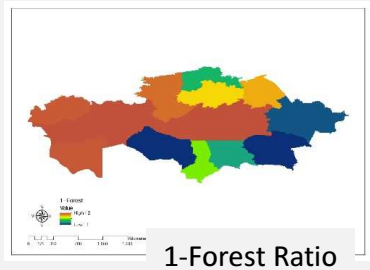
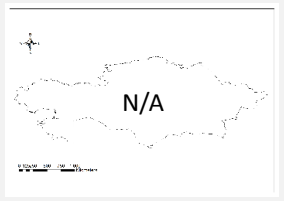
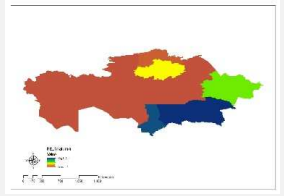
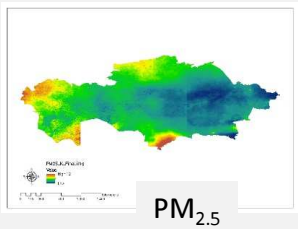
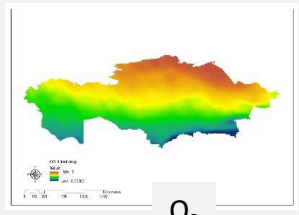
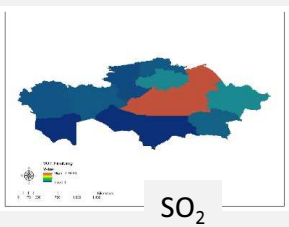
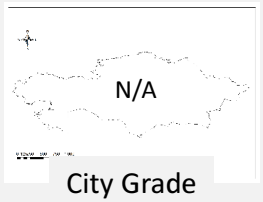
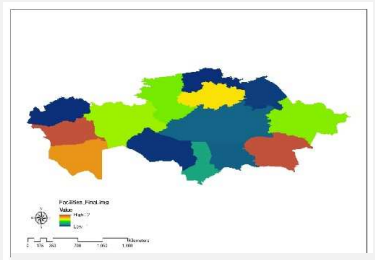
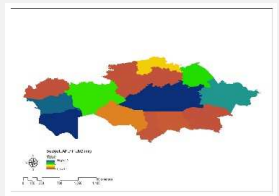
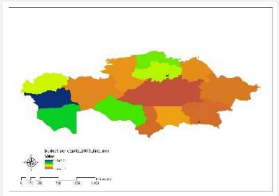
Exposure	Sensitivity	Adaptive Capacity
		

3. Result

B. Indices

2015 – Observation

Air pollution

Exposure	Sensitivity	Adaptive Capacity	
 NO_2	 1-Forest Ratio	 N/A The ratio of electric vehicle supply	 The ratio of renewable energy generation
 $PM_{2.5}$			
 O_3			
 SO_2			
 N/A City Grade	 Facility of Emission Source	 Budget for air pollution	 Budget per capita

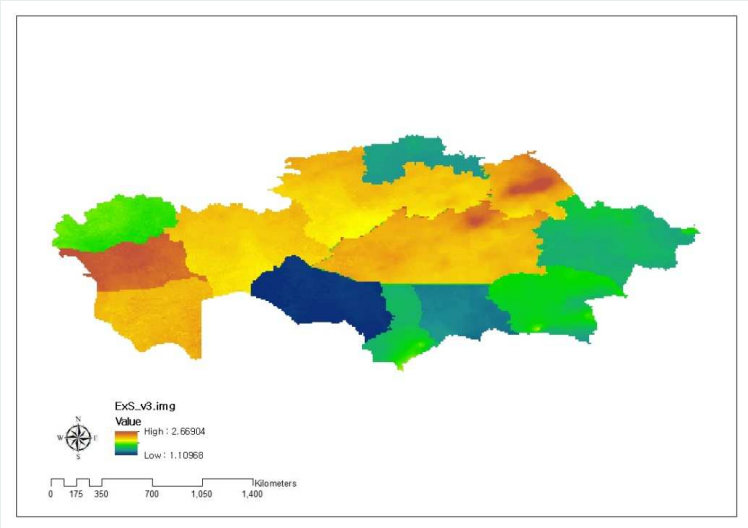
→ Infra

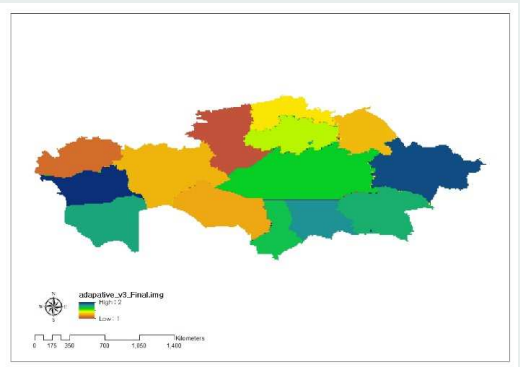
→ Inst. & Policies

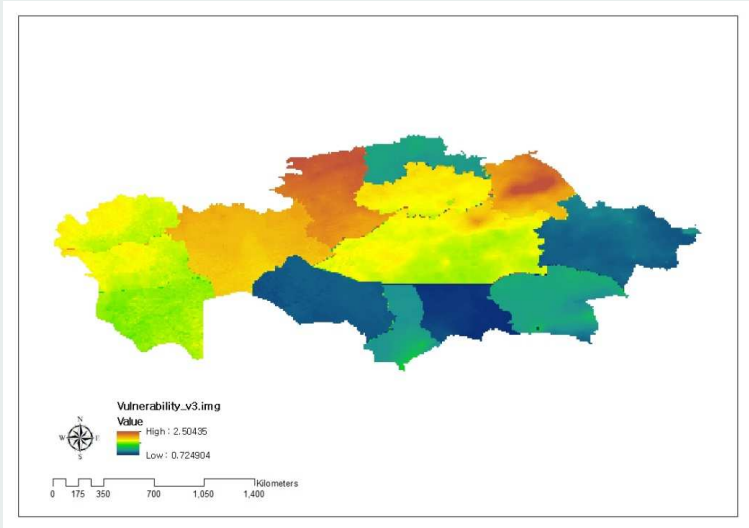
3. Result

B. Indices

2015 – Observation **Air pollution**







Exposure*Sensitivity

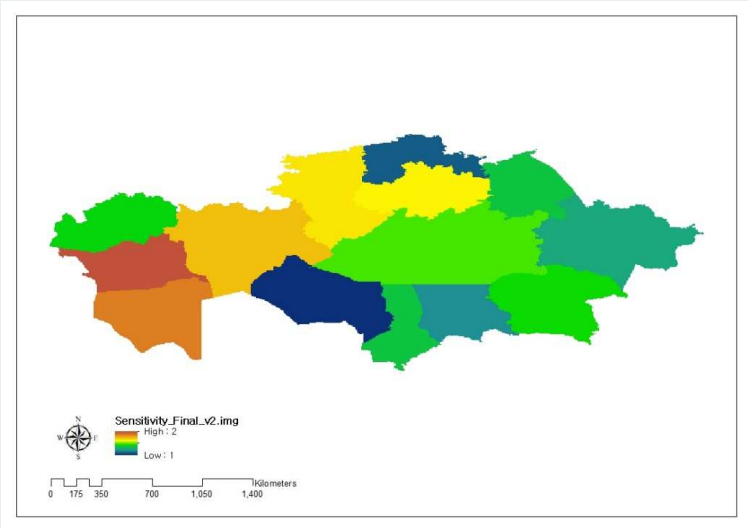
Adaptive Capacity

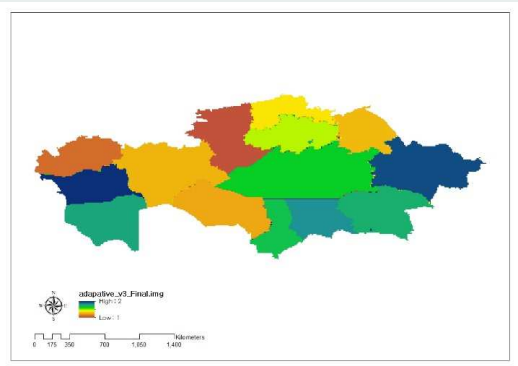
Vulnerability

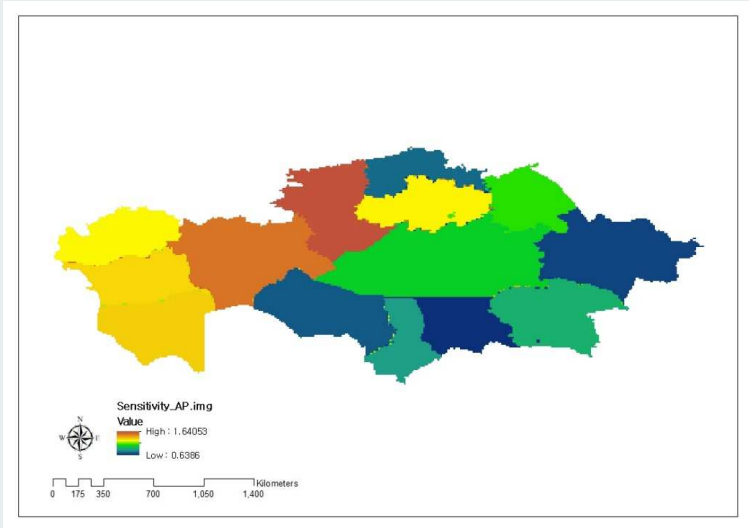
3. Result

B. Indices

2015 – Observation **Air pollution**







Sensitivity

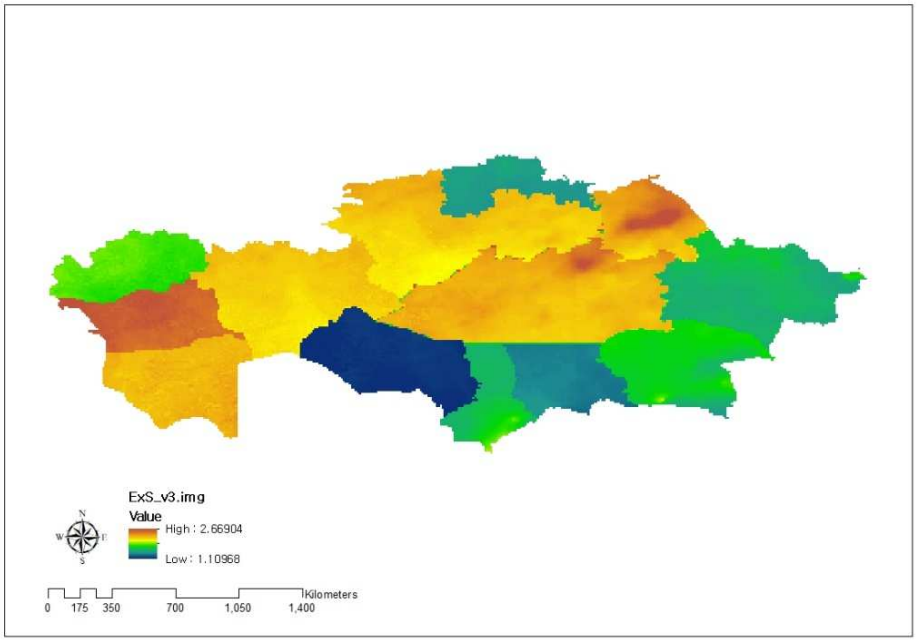
Adaptive Capacity

Vulnerability

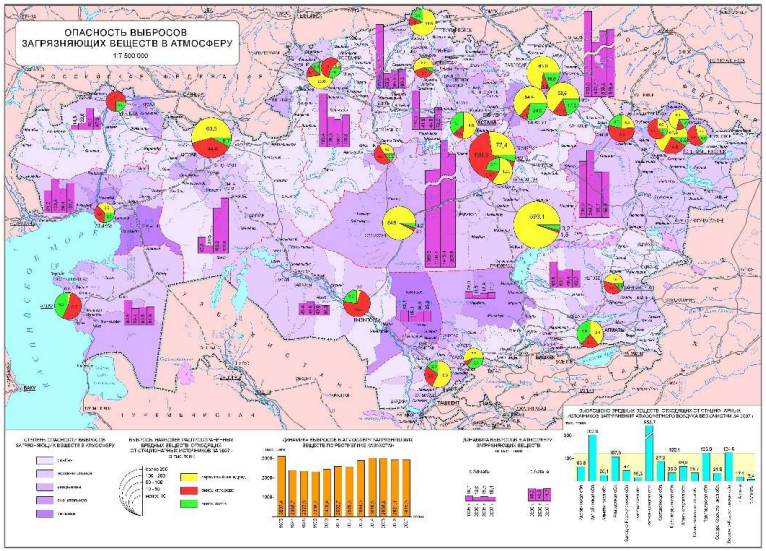
3. Result

B. Indices

2015 – Observation **Air pollution**



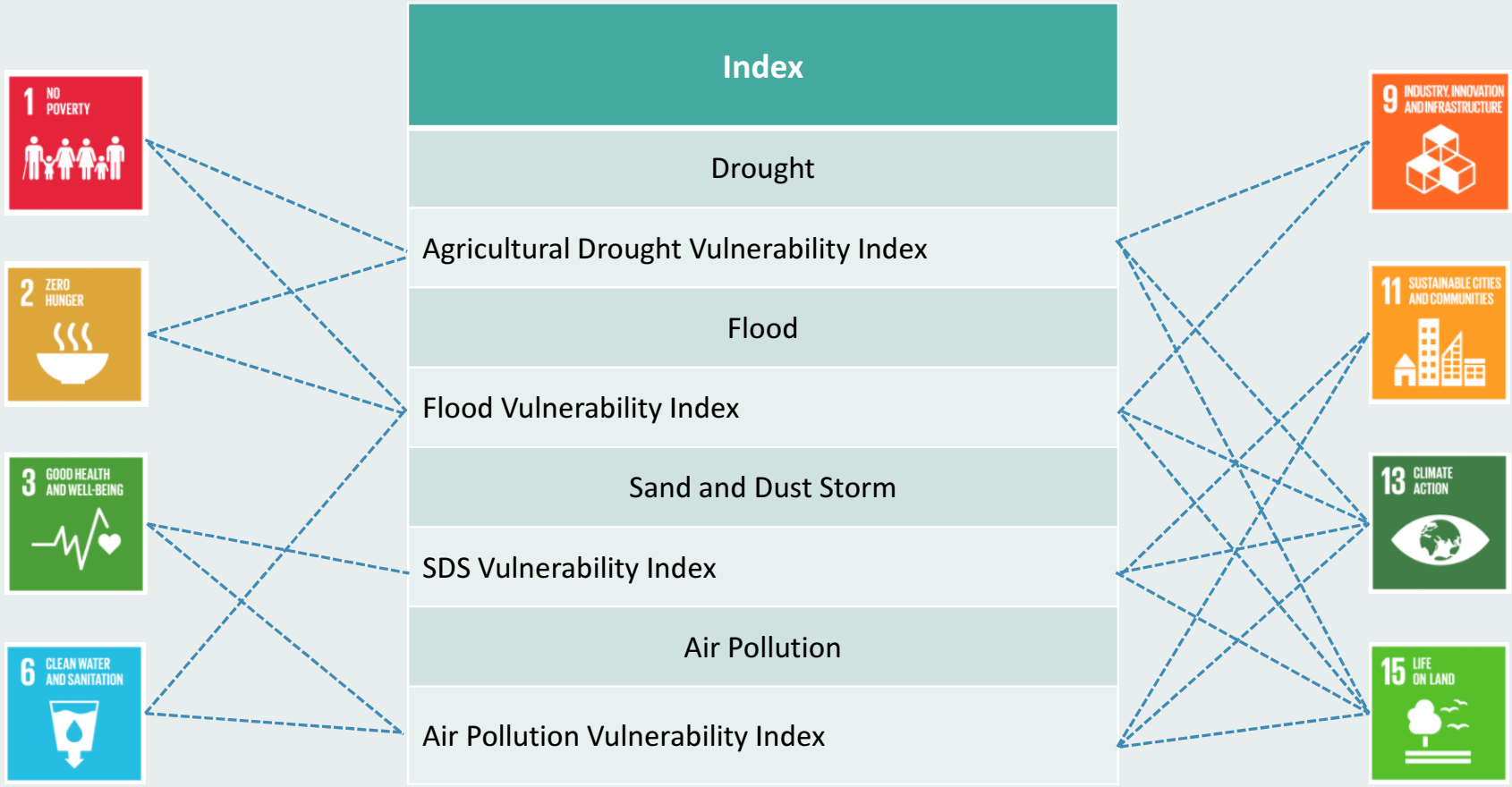
Exposure*Sensitivity



Danger of pollutant emissions

3. Result

C. Linkage with the SDGs



4. Limitation and Discussion

4. Limitation and Discussion

A. Limitation

- Because of some of the lack of data from Kazakhstan, we had to exclude those missing data for research.
- The weights of each indicator were equally given.
- There are several types of drought and we consider only agricultural drought in this study.
- There are several types of flood, the causes and process of which should be different depending on the types. In this study, we only consider a river flood in Korea case and river flood and flash flood in Kazakhstan case.
- In order to assess the vulnerability of the SDS, it is necessary to determine whether the sand breeze originated in the study site or not. In this study, we assumed that Kazakhstan is a place of acceptance.
  - The sand winds originating in Kazakhstan are not reflected.

4. Limitation and Discussion

B. Discussion

- Drought and flood are impacted largely by exposure (climate) but it is difficult to predict and control exposure.
  - It is better to control sensitivity and adaptive capacity.
  - Assuming the worst situation and dealing with disasters will be one way.
- Next step for the further research will be:
  - Giving weights to the indicators to improve the indices
  - Making Nationally Determined Pathway (NDP) for Central Asian countries

Thank You

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