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연구논문

Vulnerability assessment on the location of industrial complex considering climate change

-Focusing on physical and economic features of province · industrial complex -

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산업단지의 입지적 요건을 고려한 기후변화 취약성 평가

- 지자체 및 산업단지의 물리적・경제적 특성에 집중하여 -

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Abstract

기후변화가 산업단지에 미치는 영향은 지자체에까지 확산될 수 있으며 물리적, 경제적인 영향이 미쳐지므로 어떠한 물리적, 경제적 변수에 의해 산업단지의 피해가 초래되는지 규명될 필요가 있다. 따라서 본 연구는 국가 산업단지를 대상으로 산업단지 및 입지 시군구의 물리적, 경제적 특성을 기반으로 한 기후변화 취약성 평가를 수행하고 산업단지 입지에 영향을 미치는 시간, 공간별 극한기후를 규명하고자 하였다. 산업단지의 극한기후에 의한 취약성은 IPCC에서 제안한 상향식 취약성 평가 방법을 따라 분석되었으며 전력요구도, 위험지역유무 등 단지의 물리적 입지조건과 입지 지자체의 기반시설 현황, 지자체와 산업단지의 경제적 특성 등이 평가 기준으로 연구되었다. 기후노출, 민감도, 적응능력의 항목별 가중치와 항목내 변수들의 가중치 분석에 AHP가 적용되었다. 본 연구는 홍수, 가뭄, 혹서, 혹한, 해수면상승에 대해 취약 입지 시군구를 밝혔고 홍수와 가뭄, 혹서와 혹한별로 대비되는 취약성 결과가 나옴을 고찰하였다. 또한, 각 극한기후별로 적응능력 함양이 시급한 시군구를 밝혀 지자체 차원의 노력이 필요한 시군구를 규명하였다. 서울시 금천구는 산업단지 입지에 가장 취약한 지역으로 나타났으며 홍수, 혹한에서 높은 취약성을 보임이 분석되었다. 한편, 극한기후의 발생에도 불구하고 전반적으로 낮은 취약성을 보인 산업단지 입지 지자체는 광주광역시, 전라북도 익산, 제주시

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등으로 분석되었다. 따라서 본 연구는 산업단지의 업종에 따라 적합하지 않은 입지 지역을 규명하였으며 향후 산업단지 입지의 잠재 기후변화 영향을 고려한 의사결정을 지원할 수 있다.

주요어 : Industrial complex location, extreme climate, climate vulnerability, climate adaptation

I. Introduction

According to Yuk (2012), until recently, location of industrial complex was mainly determined by local economic condition and several physical characteristics, including the factors such as GRDP, distance to major city, percentage of green spaces. This supports for traditional knowledge on industrial location. However, as attention on climate change has been kept growing, the needs to inspect the impacts of extreme events and to reflect those issues on adaptation acts became important issue to cope with.

Carter *et al*. (2007) pointed out that little is known about adaptability of industrial complex facing extreme climate events. On the other hand, many researchers already proved the fact that growing frequency of extreme climate events and rising mean temperature will eventually affect economic, industrial, and firm-level structures (Hay, 2002; Hertin *et al*., 2003; Lash & Wellington, 2007). However, not so much researches were undertaken concerning extreme climate events and locational issues on industrial complex.

In the mean time, traditionally, local economic conditions and physical features of industrial complex were important elements to decide location of industrial complex. Thus, we concluded that when we have been concerning climate change for locational issues of industrial complex, it is important to analyze extreme climate events' impacts based on 1) physical characteristic and 2) economic condition not only covering industrial complex's level, but also focusing to province's level.

This study, therefore, aims to perform vulnerability assessment on the location of industrial complex through selecting the representative indices concerning physical, economical features. That covers both physical, economical characteristic of industrial complex and province level. The results of vulnerability assessment were utilized to determine vulnerable provinces requiring urgent adaptation actions. We believe this will supports to discover which and what elements are to be considered in future for industrial complex's location, and how to achieve adaptation ability in threatened location.

II. Method

1. Study site

This study focused on national industrial complexes among provinces. Chosen national industrial complexes included various types of busi-

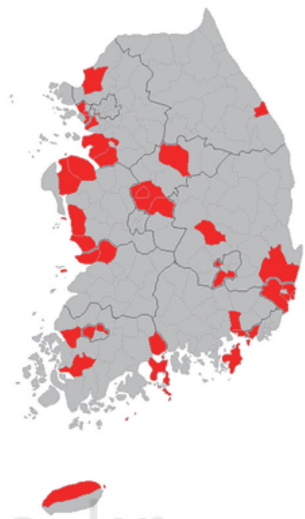

Figure 1. site distributions

Table 1. Study sites

Region	Industrial complex
Seoul	Korea export(Seoul digital)
Pusan	Myeongji·Noksan(Myeongji district)
Daegu	Science park
Incheon	Korean exort(Bupyeong district), Daeduk research
Kwangju	Kwangju science industrial complex
Ulsan	Korean export(Juan), Ulsan-mipo, Kwangju science, Onsan
Gyeonggi-do	Asan(poseung), Banwol special district, Paju-tanhyeon
Gangwon-do	Bukpyeong
Chungcheongbuk-do	Osong life science, Boeun
Chungcheongnam-do	Gojung, Daejuk, Janghang, Asan(Bugok)
Jeollabuk-do	Gunjang,Iksan1
Jeollanam-do	Yeosu, Kwangyang
Gyeongsangbuk-do	Wolseoung, Gumi 4
Gyeongsangnam-do	Changwon, Jinhae
Jeju Island	Jeju science park

ness such as oil, metal manufacture and so on (Table 1). The study sites were distributed across the country (Figure 1). Many of the industrial complexes were located near the sea. Few knowledge-based industrial complexes were located in inland area.

2. Extreme climate events

Five extreme climate events were chosen for this study. Refer to CSIRO(2007), Myeong(2009), and URS(2010)'s studies, the most important extreme climate events under climate change were heat wave, extreme cold, flood, drought, and rise in sea level. All chosen extreme climate events had damaged industrial complex, before (Bae *et al*., 2013).

3. Vulnerability assessment

Smith (1992) said vulnerability to impact is a multi-dimensional concept, encompassing biogeophysical, economic, institutional and sociocultural factors, so vulnerability is usually considered to be a function of a system's ability to cope with stress and shock. Moreover, vulnerability assessment reveals the degree of incapability, and this makes vulnerability assessment to predict anticipated impact and available adaptation options (Linnenluecke M.K. *et al*., 2011).

To evaluate those impacts and adaptation options, IPCC (2001) settled the assessment methodology comprised of Exposure (E), Sensitivity (S), and Adaptation (A). According to IPCC (2001), Exposure (E) standed for the nature and degree to which ecosystems are exposed to environmental change, Sensitivity (S) represented the degree to which a human-environment is affected by environmental change, and Adaptation (A) referred to adjustment in natural or human systems to a new or changing environment. Finally, to assess the vulnerability, those E, S, and A were first defined through selected representative variables. Secondly, each defined E, S, and A values were aggregated within following mathematical form. Lastly, weighting parameter (a,b,c), vulnerability (V), Sensitivity (S), and Adaptation (A) were parameters for calculation.

$$V = (aE + bS) - cA$$

In this study, Vulnerability (V) was calculated for each extreme climate events. The variables of Exposure (E) were chosen to reflect frequency and degree of each extreme weather events (e.g. the number of days without rain). All of variables of Exposure (E) were the most relevantly used indices of former studies on vulnerability assessment. The standard to choose each Sensitivity (S) and Adaptation (A) variables were based on physical and economical features of industrial complex and province (Figure 2).

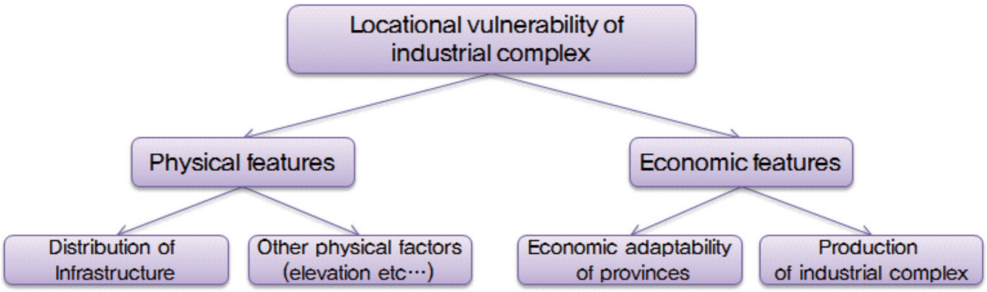

Figure 2. Assessment criteria of Sensitivity (S) and Adaptation (A)

Physical locational features of industrial complex were covering following issues.

- Quantitative amount of transportation infrastructure in province scale (e.g. Kwangyang, Donghae)
- Area and other physical features of industrial complex (e.g. Water area ratio, Impermeable area ratio)
- Whether industrial complex have been classified as affected area of extreme climate events
- Quantitative amount of adaptation facilities, which reduces the impacts of extreme climate events (e.g. Electricity usage rate, Previously inundated area)

As for the economical features, Linnenluecke and Griffiths (2010) attested that climatic responses of industrial system and local economic condition were having visible relationship. For that reason, financial capacity for industrial complex and province was considered. To reflect economic condition of industrial complex, indices such as gross regional domestic product and annual production of each industrial complex were considered.

To validate the each chosen variables, and to assess the weighting parameters, AHP (Analytic Hierarchy Process) were conducted. AHP is one of the decision making process dealing with multi-standards or multi-variables (Kyeon *et al*., 2006). In this study, pairwise comparison was conducted to rank the weights among the each variable for E, S, and A. Thirteen participated experts who conducted the researches about industrial complex, infrastructure and vulnerability assessment were chosen for weight assessment. According to Jeoun *et al*. (2011), the consistency ratio can be reasonable under 0.1 values. Thus, this study only covered the answers that include consistency ratio under 0.1 values.

Finally, the overall vulnerability assessment was carried out with ArcGIS 9.3. for 2010, 2020, 2030, 2040, 2050, 2075 and 2100 years. All of the values for each variable were rescaled between 0~1 values. A changing temperature and precipitation were predicted through RCP 8.5 pathway scenario (Korean meteorological Administration, 2013).

III. Results and Discussion

1. Assessment variables and weighting parameters

Chosen variables and assessed weights are illustrated in Table 2. The selected variables referred the former researches that include keywords such as climate change, extreme climate, industrial complex, industrial complex relocation and vulnerability assessment.

Overall, variables for Sensitivity (S) mainly consisted of physical factors regarding area of climate-sensitive infrastructure, size of industrial complex, electricity usage rate and so on. Selected variables for Adaptation (A) reflected economic factors such as GRDP and production rate of industrial complex. Exposure (E) representing

Table 2. Chosen variables

extreme events (weight)	indices	variables	weight	reference
Heat wave	Exposure (0.37)	Number of days of daily maximum temperature over 33˚C	0.54	J. K. Go(2011)
		Number of days of daily minimum temperature under 25˚C	0.29	J. K. Go(2011)
		Heat wave index	0.17	J. K. Go(2011)
	Sensitivity (0.24)	Cooling-degree day	0.43	Gh. R. Roshan *et al.*(2012)
		Area of industrial complex	0.18	J. K. Go(2011)
		Water area ratio(water area/area of industrial complex)	0.26	C. Y. Bae *et al.*(2013)
		Area of road(m^2)	0.3	M. J. Kang(2011)
	Adaptation (0.49)	GRDP	0.23	S. J. Myeong(2009) J. K. Go(2011) H. G. Kim *et al.*(2012)
		Production of industrial complex	0.37	M. K. Linnenluecke *et al.*(2011)
		Available water volume through nearby dam	0.49	Bull SR *et al.*(2012)
Extreme cold	Exposure (0.265)	Number of days under -10˚C	0.76	Korean occupational safety & health agency (2009)
		Number of days of maximum temperature under 0˚C	0.23	C. Y. Bae *et al.*(2013)
	Sensitivity (0.414)	Warming-degree day	0.34	Gh. R. Roshan *et al.*(2012)
		Area of industrial complex	0.33	J. K. Go(2011)
		Electricity usage rate	0.32	Kopytko N.(2011)
	Adaptation (0.32)	GRDP	0.21	S. J. Myeong(2009) J. K. Go(2011) H. G. Kim *et al.*(2012)
		Production of industrial complex	0.31	M. K. Linnenluecke *et al.*(2011)
		Area of heat supplying facilities (m2)	0.48	Kehlhofer R *et al.*(2011)
Flood	Exposure (0.232)	Number of days of daily precipitation over 80mm	0.64	S. J. Kim(2011)J. K. Go(2011)
		Maximum precipitation per every 5 days	0.35	H. K. Kim *et al.*(2012)
	Sensitivity (0.544)	impermeable area ratio	0.26	Bull SR *et al.*(2007)
		Area of industrial complex	0.14	J. K. Go(2011)
		Area of previous inundated area	0.30	S. J. Myeong(2009) M. J. Kang(2011)
		Area of road	0.11	M. J. Kang(2011)
		Area of airport	0.09	M. J. Kang(2011)
		Area of harbors	0.10	M. J. Kang(2011)
	Adaptation (0.224)	GRDP	0.17	S. J. Myeong(2009) J. K. Go(2011) H. G. Kim *et al.*(2012)
		Production of industrial complex	0.22	M. K. Linnenluecke *et al.*(2011)
		Stream improvement rate	0.28	J. K. Go(2011)
		Area of stream, reservoir or river	0.33	M. J. Kang(2011)

Table 2. Contiuned

extreme events (weight)	indices	variables	weight	reference
Drought	Exposure(0.484)	Number of days without rain	1	C. Y. Bae *et al*.(2013)
	Sensitivity (0.212)	Area of industrial complex	0.32	J. K. Go(2011)
		Usage of industrial water per ha(ton/day)	0.44	S. J. Kim(2011)
		Water area ratio(water area/area of industrial complex)%	0.18	C. Y. Bae *et al*.(2013)
	Adaptation (0.303)	GRDP	0.27	S. J. Myeong(2009) J. K. Go(2011) H. G. Kim *et al*.(2012)
		Production of industrial complex	0.39	M. K. Linnenluecke *et al*.(2011)
		Area of stream, reservoir or river	0.34	M. J. Kang(2011)
Rising sea level	Exposure(0.439)	Rising water level(cm)	1	K. W. Cho(2004)
	Sensitivity (0.273)	Area of industrial complex	0.175	J. K. Go(2011)
		Area of previous inundated area	0.327	S. J. Myeong(2009) M. J. Kang(2011)
		Elevation	0.32	K. W. Cho(2004)
		Area of road	0.104	M. J. Kang(2011)
		Area of harbors	0.185	M. J. Kang(2011)
	Adaptation (0.288)	GRDP	0.269	S. J. Myeong(2009) J. K. Go(2011) H. G. Kim *et al*.(2012)
		Production of industrial complex	0.211	M. K. Linnenluecke *et al*.(2011)
		Area of seawall(m^2)	0.429	K. W. Cho(2004)

intensity and occurrence of each extreme climate events illustrated meterological thresholds. Generally, Adaptation (A) had highest weight, and Exposure (E) was the second important indices.

2. industrial complex's vulnerability assessment

Vulnerability map of each extreme climate events were suggested (Figure 2). Overall, the highest vulnerable tendency was observed in vulnerability assessment of rise in sea level (Figure 3). Whereas, extreme cold had lowest vulnerable influence to industrial complex. Looking at vulnerability map among 2010~2100 years, vulnerability values between flood and drought shown contrary results. Flood tended to be increased in Gyeonggi province and Chungcheongnam-do, but vulnerability of drought has been kept decreasing in these regions. In line with this fact, the results suggested that industrial complex will become more vulnerable to flood, but become safer to drought.

As flood and drought illustrated opposing results, heat wave and extreme cold had different vulnerable tendencies. Vulnerability of heat wave showed decreasing phase in initial stage, but it constantly increased after 2040 year. The results suggested that Cheongju and Gumi province's industrial complex will constantly become vulnerable to heat wave after 2040 year. Whereas, industrial complex will become more safer to extreme cold. Except for industrial complex in Donghae province, majority of industrial complexes become safe.

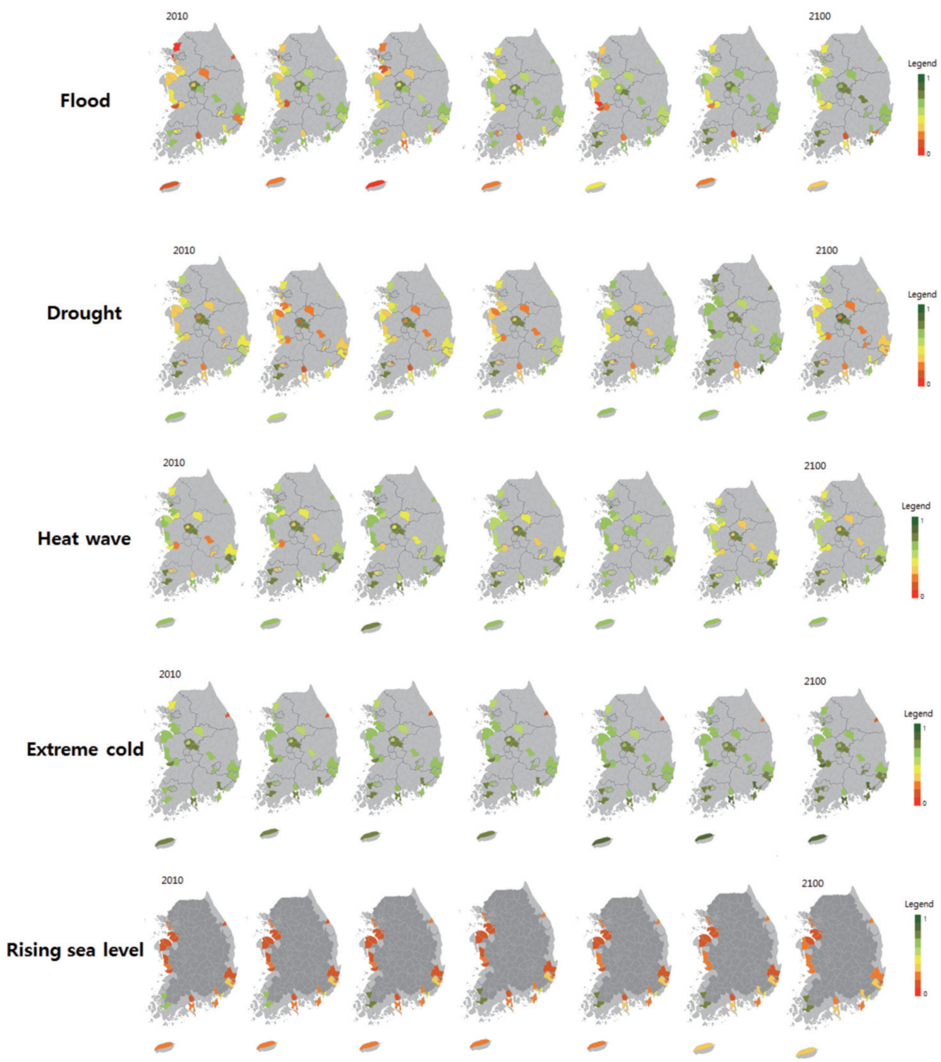

Figure 3. Vulnerability map

In the meantime, industrial complex's vulnerability of rising sea level continually illustrated high vulnerable tendency. However, industrial complexes in Hampyeong-gun and Yeoungam-gun had lower vulnerability.

3. Influences of Exposure and Adaptation factors

Illustrated vulnerability in figure were the results of factors reflecting Exposure (E), Sensitivity (S), and Adaptation (A). Within these factors, especially Exposure (E) and Adaptation (A)'s influence were observed in Fig 4. Exposure (E) represents occurrence tendency of extreme whether, which can explain pure extreme whether's climatic impact. On the other hand, Adaptation (A) makes available to judge adaptive capacity of industrial complexes. Thus, it can be utilized to assess how industrial complex mitigate the impact of climate change.

In line with that, in this study, values for Exposure (E) and Adaptation (A) were predicted from the present to the future. That is, whole val-

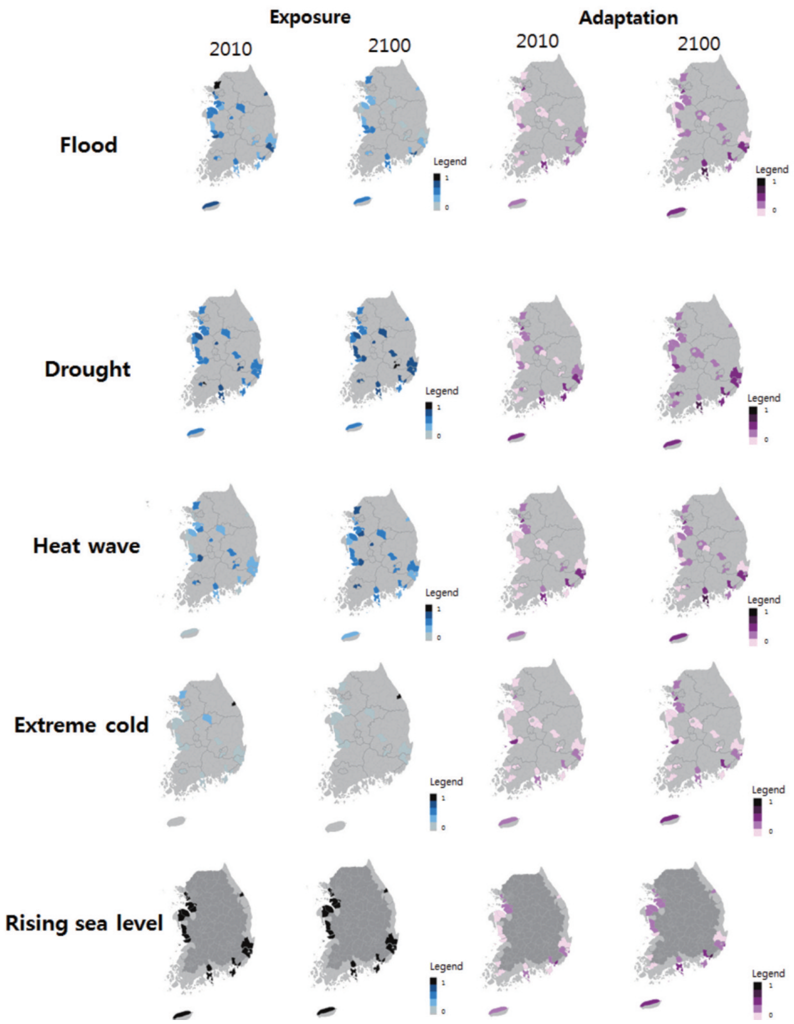

Figure 4. Map of Exposure and Adaptation

ues were separately assessed on each predicted years of 2010~2100. However, we started from the basic premise that values for Sensitivity (S) were same across whole years because there were no predicted factors for the future. Thus, observing the results of Exposure (E) and Adaptation (A) make possible to evaluate the specific changing tendency throughout assessment years.

The results illustrated that occurrences of flood and extreme cold were decreased during 2010~2100 years. At the same time, adaptive capacity between province and industrial complex were increased, so the overall result indicated lower vulnerability. Whereas, occurrences of drought and heat wave analyzed to be increased. However, growing adaptive capacity due to economic growth tend to mitigate the vulnerabilities. Vulnerability map, therefore, illustrated mitigated results, even though climatic hazards were high. In the meantime, Exposure (E) values of rise in sea level shown constant same results, because it had been predicted by RCP 8.5 pathway scenario's constant national sea level rising rate.

Table 3. List of provinces obtained high vulnerability

Province	Extreme climate events					Count
	Flood	Drought	Heatwave	Extreme cold	Rising Sealevel	
Seoul Guro			○			1
Seoul Geumcheon	○			○		2
Pusan Gangseo	○					1
Daegu Dalseoung		○				1
Incheon Namdong			○		○	2
Incheon Bupyeong			○			1
Incheon Seogu			○			1
Kwangju Bukgu						0
Kwangju Kwangsan						0
Ulsan Namgu		○				1
Ulsan Donggu				○		1
Ulsan Bukgu		○				1
Ulsan Ulju		○				1
Gyeonggi-do Pyeongtak					○	1
Gyeonggi-do Sigeung			○			1
Gyeonggi-do Paju					○	1
Gyeonggi-do Hwaseong					○	1
Kangwondo Donghae				○		1
Chungcheongbuk-do Cheongwon				○		1
Chungcheongbuk-do Boeun	○			○		2
Chungcheongnam-do Boryeong			○			1
Chungcheongnam-do Seosan			○			1
Chungcheongnam-do Seocheon	○					1
Chungcheongnam-do Dangjin						0
Jeollabuk-do Gunsan						0
Jeollabuk-do Iksan						0
Jeollanam-do Yeosu	○					1
Jeollanam-do Kwangyang	○					1
Jeollanam-do Yeongam				○		1
Jeollanam-do Hampyeong				○		1
Gyeongsangbuk-do Kyeongju		○				1
Gyeongsangbuk-do Gumi						0
Gyeongsangnam-do Changwon		○				1
Gyeongsangnam-do Jinhae	○					1
Gyeongsangnam-do Geoje						0
Jeju Isaland Jeju						0

4. Top 20% vulnerable industrial complex located provinces

Comparing overall results, province which shown among the top 20% of vulnerability were suggested (Table 3). Provinces that have repeatedly illustrated top 20% of vulnerability were also shown in Figure 5.

Overall, the majority of vulnerable provinces to flood were also resulted not to be vulnerable to drought. The most redundant vulnerable

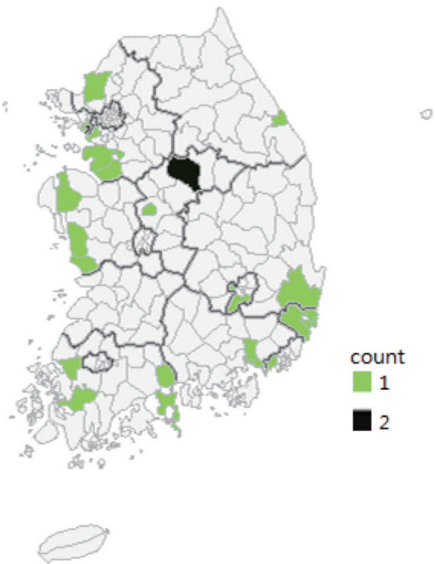

Figure 5. Top 20% vulnerability ranked count

province among assessed extreme whether events illustrated high vulnerability for two extreme climate events. Seoul Geumchungu, Incheon Namdong-gu, Chungcheongbuk-do Choongju, and Chungcheongbuk-do Boeun assumed to have top vulnerabilities.

The provinces, which were analyzed to have lowest vulnerability include Kwangju, Jeollabuk-do Iksan, gunsan, Jeju and so on. Due to the lowest vulnerability under occurrences of extreme climate events, those provinces can be assumed to be the most appropriate location for industrial complex considering climate change.

IV. Conclusion

This study has undergone vulnerability assessment of industrial complex considering physical and economical factors to assume locational climatic impacts under extreme whether events.

The results indicated that upmost redundantly vulnerable provinces were located in Seoul, Incheon and Chungcheongbuk-do. Each assessed extreme climate events were shown opposed vulnerability in accordance with general climate change trend. In line with that, results of flood and drought were in contradiction, and also extreme climate and heat wave had opposed vulnerability.

Consideration of both industrial complex and province allowed to reflect not only industrial complex, but also located province's adaptive capacity. This enabled to discern which province needed to enhance their adaptive capacity. Moreover, assessing process and results of this study can be used to decide location or relocation of industrial complex.

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