Development and Application of a Methodology for Climate Change Vulnerability Assessment –Sea Level Rise Impact on a Coastal City

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and Jin-Hwan Hwang

기후변화 취약성 평가 방법론의 개발 및 적용 해수면 상승을 중심으로

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국문요약

기후변화 적응정책을 수립하기 위해서는 지역에 기초한 취약성 평가가 선행되어야 한다. 지금까지 기후변화 취약성에 관한 연구는 주로 국가별 취약성의 비교 및 분석에 집중되었기 때문에 지역별 기후변화 취약성을 평가하고 비교하기 위한 방법론은 아직 국내외적으로 확립되어 있지 않은 실정이다. 본 논문의 목적은 기후변화 취약성의 개념적 틀을 확립하고 이를 지역적으로 평가하기 위한 일반적인 방법론을 개발하는 데에 있다. 기후변화 취약성을 IPCC (1996) 개념틀에 따라 기후노출과 시스템의 민감도, 그리고 시스템이 대응할 수 있는 적응능력의 함수로 보았다. 여러 기후노출 중 본 논문에서는 기후변화에 의해 일차적으로 피해를 입을 수 있는 해수면 상승을 상정하였다. 방법론 적용 대상도시로는 국내 해안에 위치한 목포시를 선정하였다. 이는 목포시가 포함된 우리나라 서남해 지역의 평균 해수면이 전반적으로 증가추세를 보이고 있고, 특히 목포시가 가장 큰 증가폭을 보였으며, 하구언과 방조제 건설 이후 이상고조 발생 가능성이 현격하게 높아진 해역이기 때문이다. 해수면 상승에 따른 민감도는 GIS 기술을 활용하여 해수면이 1~5m 상승할 경우의 침수 시뮬레이션 결과를 기반으로 계산하였다. 행정구역(동)별 침수면적 비율에 기초하여 여기에 인구밀도 및 65세 이상 인구비율에 대한 통계자료를 고려하였고, 표준화 과정(dimension index)을 거쳐 민감도 지수를 도출하였다. 적응능력으로는 하드웨어적인 측면과 소프트웨어적인 측면을 고려하였는데, 하드웨어적

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적응능력으로는 방파제와 방조제의 존재여부 및 높이를 고려하였고, 소프트웨어적 적응능력은 목포시 75명 공무원을 대상으로 설문조사를 수행하여 평가하였다. 설문조사 문항에는 기후변화에 대한 인식, 거버넌스, 경제적 능력 및 정책 기반이 포함되었는데, 0~1 사이의 정량적인 값을 설문문항 응답수준에 따라 부여하였다. 해수면 상승에 따른 취약성은 민감도에서 적응능력을 뺀 나머지로 표현하였다. 목포시의 해수면 상승에 따른 취약성은 총 20개 동 중 7개 동이 높은 것으로 나타났다. 본 연구결과를 이용하여 기후변화 적응대책 수립의 방향성을 제시하기 위해서는 첫째, 과거 침수피해와의 상관관계 다이어그램을 통하여 적응정책 시행의 우선순위 지역을 선정하고, 둘째, 우선순위 지역에 대한 단기, 중기, 장기 개발계획 및 프로젝트를 검토한 후 이에 합당한 적응조치를 제언할 수 있을 것으로 사료된다.

❙ 주제어 ❙ 기후변화, 민감도, 적응능력, 취약성, 해수면 상승, 과거재해 기록

Abstract

Climate change vulnerability assessment based on local conditions is a prerequisite for establishment of climate change adaptation policies. While some studies have developed a methodology for vulnerability assessment at the national level using statistical data, few attempts, whether domestic or overseas, have been made to develop methods for local vulnerability assessments that are easily applicable to a single city. Accordingly, the objective of this study was to develop a conceptual framework for climate change vulnerability, and then develop a general methodology for assessment at the regional level applied to a single coastal city, Mokpo, in Jeolla province, Korea. We followed the conceptual framework of climate change vulnerability proposed by the IPCC (1996) which consists of “climate exposure,” “systemic sensitivity,” and “systemic adaptive capacity.” “Climate exposure” was designated as sea level rises of 1, 2, 3, 4, and 5 meter(s), allowing for a simple scenario for sea level rises. Should more complex forecasts of sea level rises be required later, the methodology developed herein can be easily scaled and transferred to other projects. Mokpo was chosen as a seaside city on the southwest coast of Korea, where all cities have experienced rising sea levels. Mokpo has experienced the largest sea level increases of all, and is a region where abnormal high tide events have become a significant threat; especially subsequent to the construction of an estuary dam and breakwaters. Sensitivity to sea level rises was measured by the percentage of flooded area for each administrative region within Mokpo evaluated via simulations using GIS techniques. Population density, particularly that of senior citizens, was also factored in. Adaptive capacity was considered from both the “hardware” and “software” aspects. “Hardware” adaptive capacity was incorporated by considering the presence (or lack thereof) of breakwaters and seawalls, as well as their height. “Software” adaptive capacity was measured using a survey method. The survey questionnaire included economic status, awareness of climate change impact and adaptation, governance, and policy, and was distributed to 75 governmental officials working for Mokpo. Vulnerability to sea level rises was assessed by subtracting adaptive capacity from the sensitivity index. Application of the methodology to Mokpo indicated vulnerability was high for seven out of 20 administrative districts.

The results of our methodology provides significant policy implications for the development of climate change adaptation policy as follows: 1) regions with high priority for climate change adaptation measures can be selected through a correlation diagram between vulnerabilities and records of previous flood damage, and 2) after review of existing short , mid, and long-term plans or projects in high priority areas, appropriate adaptation measures can be taken as per this study. Future studies should focus on expanding analysis of climate change exposure from sea level rises to other adverse climate related events, including heat waves, torrential rain, and drought etc.

❙ Keywords ❙ Climate Change, Sensitivity, Adaptive Capacity, Vulnerability, Sea Level Rises, Previous Damage Records

Ⅰ. Introduction

"Vulnerability" per se is a relatively new concept for climate change science and policy and is borrowed from other areas of disaster management, including poverty and food security etc. In the area of disaster management, the concept of vulnerability is based on a dose-response" relationship (Fussel and Klein, 2002). The "dose" in this framework refers to disasters, including earthquakes or hurricanes which are beyond human control. The magnitude of the "response," including casualties or property damages is regarded as "vulnerability." On the other hand, in the areas of poverty and food security, vulnerability is regarded as an "intrinsic feature of the system". Population structure or economic status can be proxies to evaluate the degree of vulnerability. The IPCC (Intergovernmental Panel on Climate Change; 1996) introduced the concept of climate change vulnerability as a combination of a "dose-response relationship" and an "intrinsic feature of the system". There are three components comprising climate change vulnerability including climate exposure, sensitivity of a system, and adaptive capacity.

Assessment of vulnerability to climate change is a first step to set up climate change adaptation policies. International financing bodies, including the GEF (Global Environment Facility) require tools or indices for assessing climate change vulnerability among countries to allocate adaptation funds.

Recently, there have been some efforts to develop a framework or methodology to assess climate change vulnerability. Most of the efforts were concentrated on the development of a national index to compare climate change vulnerability among different countries (UNDP, 2005; Moss et al., 2001; Brooks et al., 2003). This approach is useful when an international agency including the World Bank, UNEP, UNDP, UNFCCC, etc. is planning an adaptation program or project because it needs a reasonable standard to determine the priority of adaptation.

However, climate change impact varies widely by location, and adaptation to climate change impact should be designed at the local as well as the national scale. Eriksen and Kelly (2007) argued that many studies of vulnerability on the national scale have emphasized aggregate environmental and social conditions at the expense of detailed capture of the processes that shape vulnerability. The process of vulnerability indicates the detailed mechanism comprising local vulnerability distribution. This is not averaging the "hotspots" or "pockets" of vulnerability to destroy response capacity. As far as we know, there have been few attempts to develop an assessment method of local vulnerability compared to that of national vulnerability. In this sense, a methodology for assessment of local climate change vulnerability needs to be developed to implement relevant and concrete climate change adaptation policies.

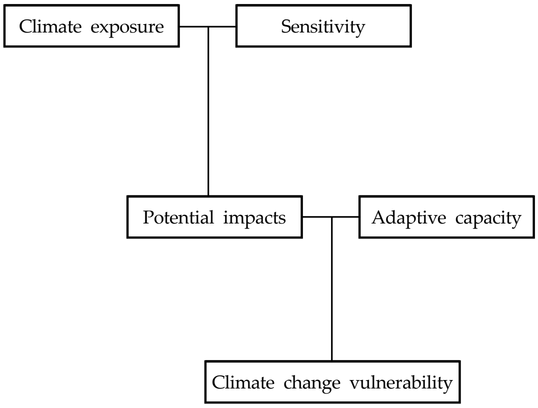
Our extensive review on current case studies which conducted climate change vulnerability assessment showed that: 1) most of the studies deal with vulnerability assessment on a national scale, 2) assessments are dependent on international and/or national statistical data, hence, they are limited to the past condition of vulnerability, 3) not many studies were found using GIS (Geographic Information System) techniques to incorporate land cover information with climate change risk (Bohle et al., 1994; Downing et al., 1995; Kelly and Adger, 2000; Dilley and Boudreau, 2001; Brooks and Adger, 2003; Fussel, 2005; Fussel and Klein, 2006; Eriksen and Kelly, 2007). In this study, we suggest a framework on assessment of climate change vulnerability on a local scale incorporating the GIS technique with statistical data collection. Among many climate exposure factors, we chose sea level rises as the main climate exposure factor because the sea level of the Korean peninsula (especially on the southwest coast) has been increasing gradually (Kang et al., 2008), thus mandating consideration of vulnerability to sea level rises in urban planning from a long term perspective.

The objectives of this study are to develop a methodology assessing climate change vulnerability on a local scale and apply it to a city located on the southwest coast of Korea.

Ⅱ. Methodology development

The concept of climate change vulnerability follows that defined by the IPCC (1996), as shown in Figure 1.

Figure 1 Conceptual framework of climate change vulnerability



Source: IPCC (1996).

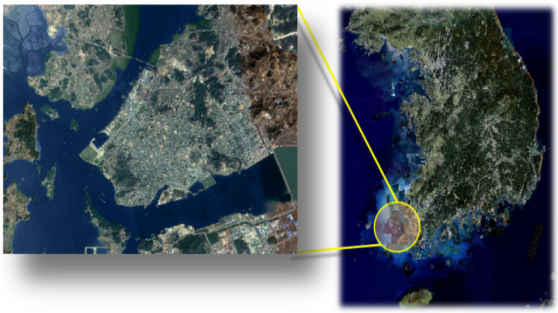
Climate change exposure includes sea level rises, temperature rises, precipitation changes, heat waves, heavy storms, and drought, etc. Sensitivity is defined as "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli" (IPCC, 2001). Adaptive capacity is the ability of a human or natural system to adjust to climate change (World Bank, 2009). Climate change vulnerability was defined as the function of climate exposure, sensitivity and adaptive capacity,

We used the conceptual framework shown in Figure 1 and applied it to a sample city, Mokpo, Jeolla province, which is located on the southwest coast of Korea.

Mokpo was selected to apply the methodology developed in this study. The sea level of the southwestern coastal area in Korea was reported to have increased relatively faster than other areas. Kang et al. (2008) also reported that tidal levels have increased in all observation sites, and that the observed tidal maximum height in Mokpo increased around 3 cm, which is the most significant increase. Moreover, after construction of estuary dams and levees, abnormal high water has tended to occur more frequently in this region.

The sea level rises of 1, 2, 3, 4 and 5 meter(s) were treated as "climate change exposure." As the aim of this study is to develop a methodology to assess vulnerability, not to predict vulnerability in this area in the future, the scenario approach using an arbitrary number of sea level rises is justified. Vaughan and Spouge (2002) reported that complete collapse of the west Antartic ice sheet (WAIS) would raise global sea levels by around 5 meters. By the time a more sophisticated projection of sea level rises in this area is available, our method can readily incorporate such projections.

Figure 2 Satellite image of Mokpo city, Jeolla province.



The sensitivity to sea level rises was measured based on the percentage of flooded areas (flooded area/total area) simulated using DEM (Digital Elevation Model), a land cover map (MoE, 2009), and satellite images. The percentages of flooded areas in each administrative unit (dong) were standardized using a dimension index (UNDP, 2005).

$$\text{Dimension index (DI)} = \frac{X - Min}{Max - Min} \cdots\cdots\cdots\cdots\cdots\cdots \text{(Eq. 1)}$$

where X is the actual value, Min is the minimum value, and Max is the maximum value of the data set.

The sensitivity index was determined as the average of the DI values of the percentage of flooded area, population density (Korean Statistical Information Service, 2009), and the population at age 65 and up (Korean Statistical Information Service, 2009). The resultant value of sensitivity ranges from 0 to 1. Sensitivity was divided into five levels, 1 (not sensitive), 2 (low sensitivity), 3 (medium sensitivity), 4 (high sensitivity), and 5 (very high sensitivity) (Table 1).

Table 1 Sensitivity index and class

Sensitivity index (SI)	Sensitivity class
0.00~0.10	1 (not sensitive)
0.11~0.20	2 (low sensitive)
0.21~0.30	3 (medium sensitive)
0.31~0.40	4 (high sensitive)
〉0.41	5 (very high sensitive)

Two aspects of adaptive capacity were considered, “hardware” and “software”. As a hardware adaptation to sea level rises, the presence and height of breakwaters and seawalls was considered. The degree of software adaptation was measured using the survey method. The questionnaire included economic status, degree of awareness of climate change, governance, and policy foundations, and was distributed to 75 governmental officials working for the Mokpo municipal government. Based on the survey results, an adaptive capacity index (ACI) for Mokpo city was devised and evaluated In each section for software adaptive capacity (economic status, awareness level of climate change, governance, and policy foundation), we used standards to determine high, medium and low adaptive capacity following BDI (2010) and the numbers of 1, 0.6, and 0.3 were given to each class of adaptive capacity. Finally, we averaged the number in each section and considered the result as ACI.

Climate change vulnerability was calculated as the difference between sensitivity and adaptive capacity indices.

VI = SI - ACI ·· (Eq. 2)

where VI is a vulnerability index ranging from 0 to 1 (Moss et al., 2001)

Vulnerability was divided into five classes: 1 (resilient, not vulnerable), 2 (less vulnerable), 3 (vulnerable), 4 (highly vulnerable), 5 (very highly vulnerable).

Table 2 Vulnerability index and class

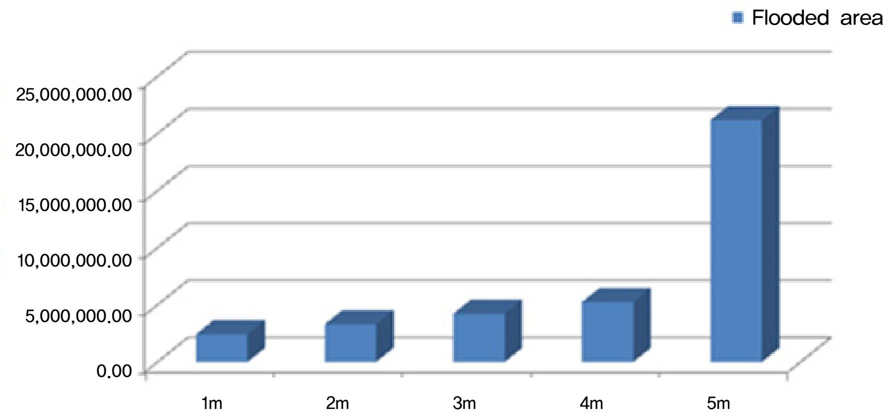
Vulnerability index (VI)	Vulnerability class
〈 0.00	1 (resilient)
0.01～0.10	2 (less vulnerable)
0.11～0.20	3 (vulnerable)
0.21～0.30	4 (highly vulnerable)
〉0.31	5 (very highly vulnerable)

Ⅲ. Results and Discussion

The flooded area obtained from the results of flood simulation when the sea level rise was 1, 2, 3, 4, and 5 meter(s) was summarized in Figure 3.

The reason for the sharp increase in flooded areas with a 5 meters sea level rise was attributed to the fact that the slope of the regions with altitude between 4 ~5 meters is relatively low in Mokpo.

Figure 3. The flooded area as a result of flood simulations of 1, 2, 3, 4, and 5 meter(s)

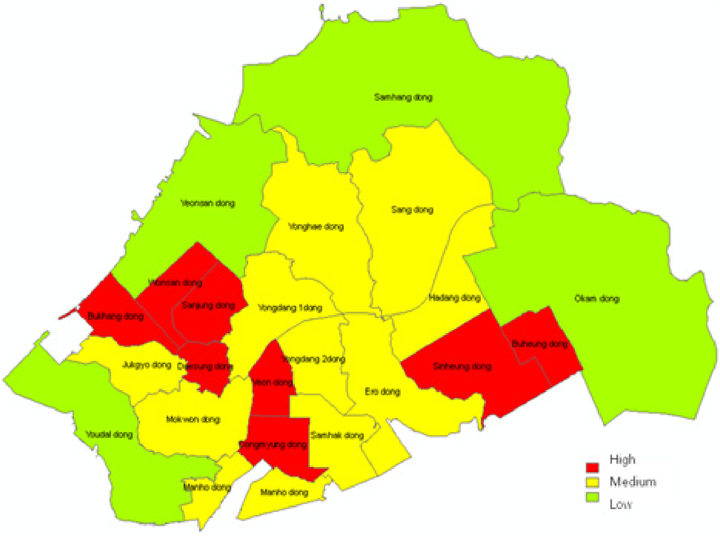


The main land use affected by sea level rises was different with the degree of sea level rises. When the sea level rise was 1 or 2 meter(s), the most affected land use was in coastal wetlands. However, when the sea level rise was 3 meters and higher, the most affected land use was residential, industrial and commercial areas.

The population density of each administrative unit (dong) is shown in Figure 4. Based on DI values, we divided population density into three classes which are high (>11,000 individuals/km^2), medium (3,000~11,000 individuals/km^2) and low (<3,000 individuals/km^2).

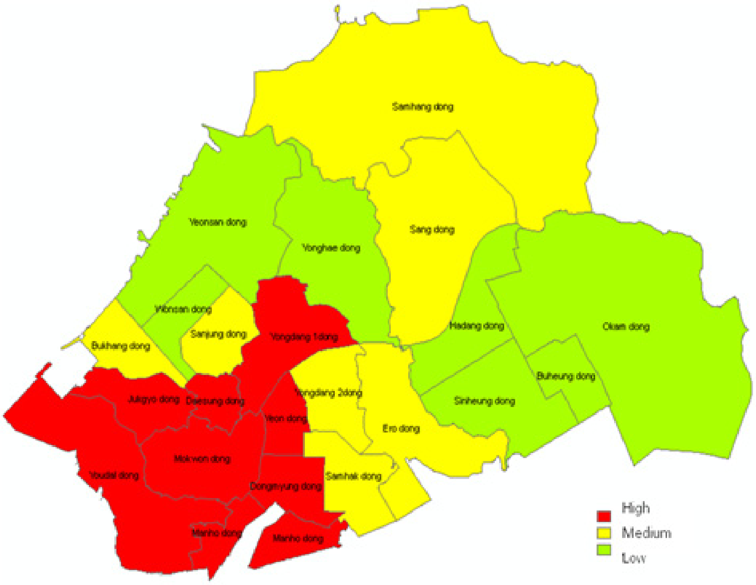
The population at age 65 and over in each administrative unit (dong) is shown in Figure 5. This data was also divided into three classes.

Figure 4 Distribution of population density in Mokpo



Note: Red: high (〉11,000 individuals/km^2), Yellow: medium (3,000～11,000 individuals/km^2), and Green: low (〈3,000 individuals/km^2)

Figure 5 Distribution of population at age of 65 and over in Mokpo



Note: Red: high (〉1,300 individuals), Yellow: medium (1,000～1,300 individuals), and Green: low (〈1,000 individuals).

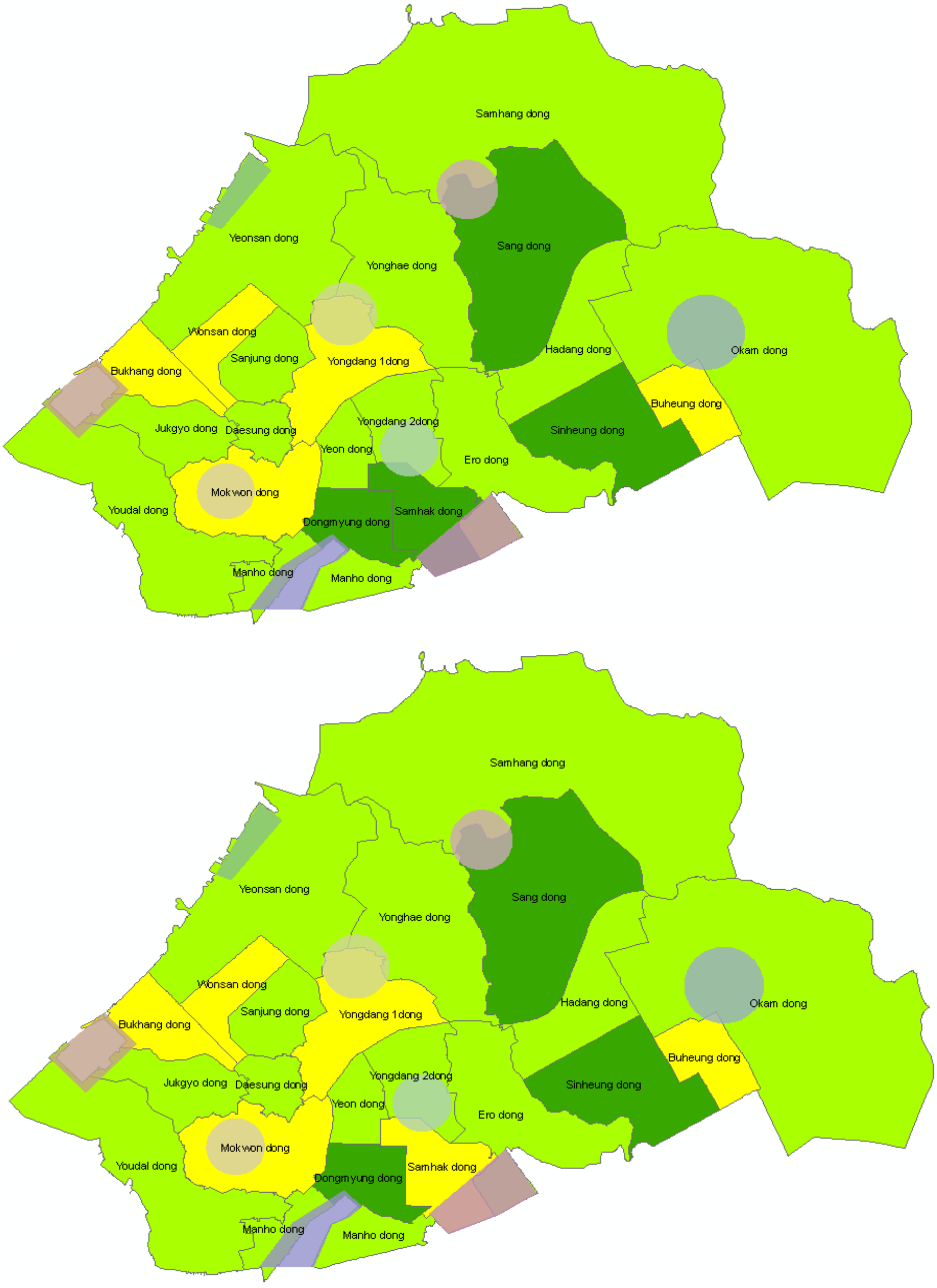
Using the DI values of the percentage of flooded area, population density, and the population at age 65 and over, a sensitivity index (SI) was devised and the distribution of sensitivities was shown in Figure 6. Sensitivity to sea level rises was generally low when the sea level rise was 1 and 2 meter(s). When the sea level rise was above 3 meter(s), 10 regions (administrative unit) out of 22 (Wonsan, Bukhang, Yongdang, Yeon, Mokwon, Dongmyung, Samhak, Sinheung, Booheung dongs) were becoming highly sensitive.

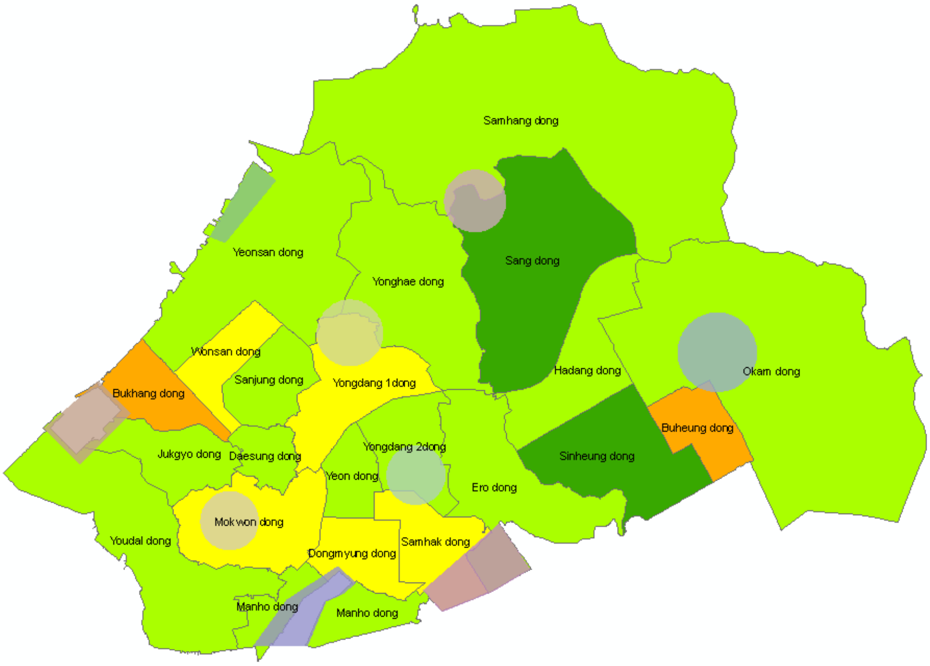
Adaptive capacity for Mokpo was summarized in Table 3. As all the breakwaters and seawalls surrounding Mokpo have a height of 2.0~2.5 meters, we considered that when the sea level rise was 1 and 2 meter(s), the hardware adaptive capacity was relatively high. Investigation of the software adaptive capacity in Mokpo by the survey method showed that Mokpo has a medium level of climate change awareness and governance, and a low level of economic status and policy environment compared to Jeolla province, which is the higher administrative unit.

Table 3 Adaptive capacity index

Sector	Mokpo	Jeolla-do
Economy	0.3	0.6
Awareness	0.6	0.6
Governance	0.6	0.6
Policy foundation	0.3	0.6
Summary	0.28	0.6

Figure 6 Distribution of sensitivity classes in Mokpo for sea level rises of 1, 2, 3, 4, and 5 meter(s)

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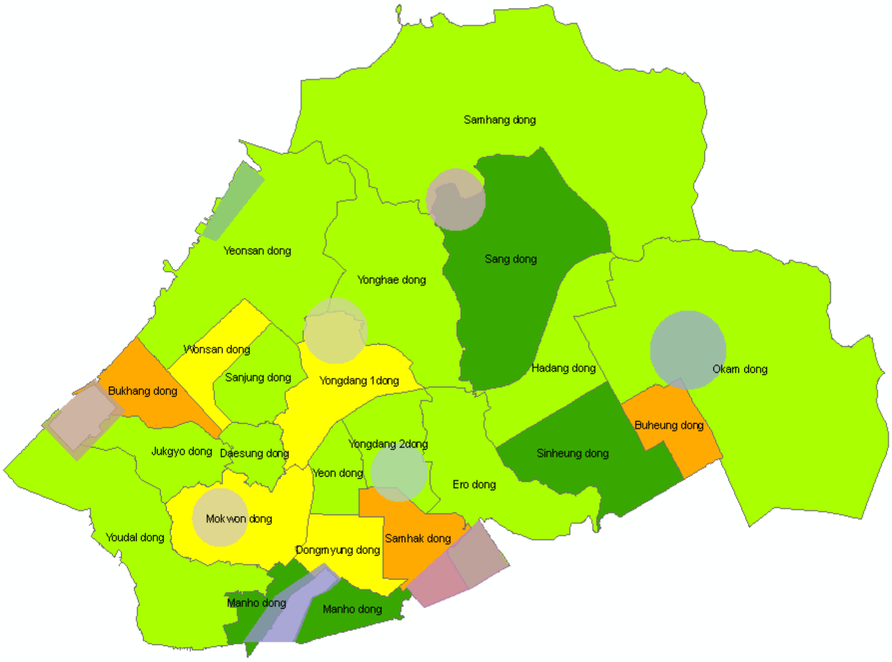
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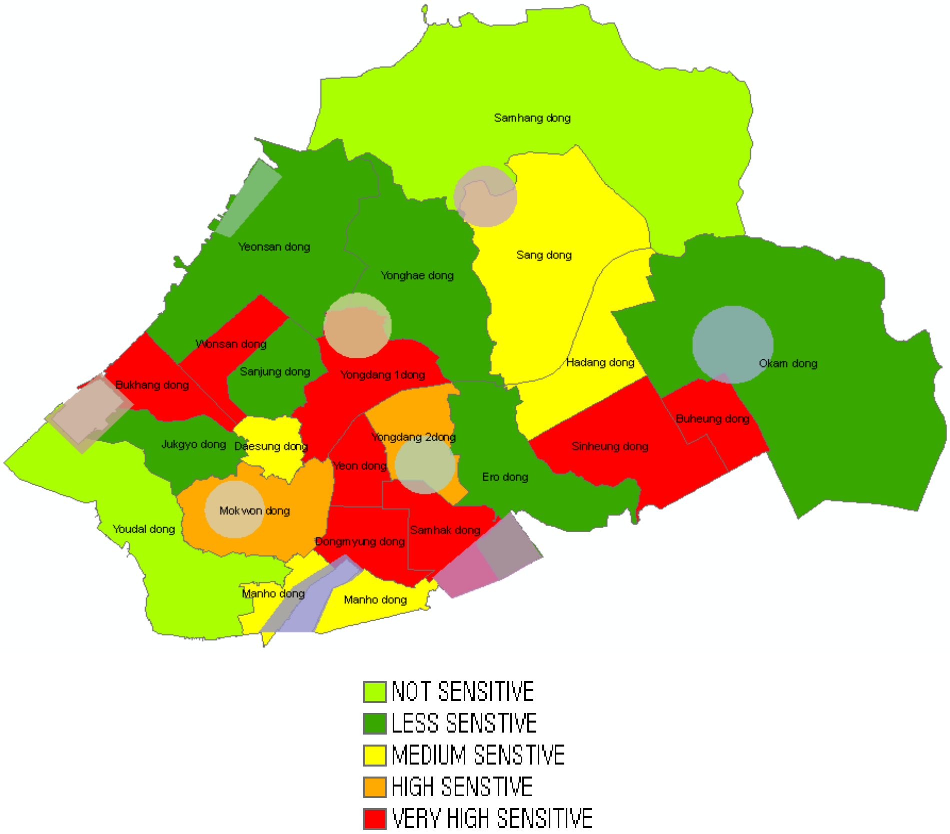


··· Moderately Sensitive, Highly Sensitive, Very Highly Sensitive

A vulnerability index was calculated as per Figure 7. The distribution pattern of vulnerability to sea level rises was similar to that of sensitivity. The most vulnerable group comprised Buheung, Wonsan, and Bukhang dong.

Our results show the overall distribution of vulnerability to sea level rises and are able to provide some important policy implications after we follow the suggested procedures below.

The first step is to determine the regions (or dong) of high priority for adaptation measures. To do that, we suggested relating our vulnerability results with the previous damage records from flooding. As Mokpo does not currently compile statistical data on flood damage in each administrative unit (dong), the diagram had to use anonymous data to illustrate the means of application (Figure 8). The upper-right quadrant of the diagram indicates the regions with high vulnerability and previous damage records. In this case, the priority for adaptation measures is relatively high. The upper-left quadrant indicates the regions with high vulnerability and low previous damage records. This case also has high priority for adaptation next to the upper-right quadrant due to the low previous damage records. These regions may not possess the relevant adaptive measures for damage. The lower-right and lower-left quadrants were classified as medium to low vulnerability regions. However, careful monitoring of these regions will be required to prepare unpredictable variability

The second step is to review short- and long-term development plans or projects in high priority regions. If the regions have road construction plans in their area, adaptive measures (including building water proof seawalls) may be incorporated (mainstreamed) into the existing plans. If the regions have a development plan for construction of a new apartment complex, regulations related to setback may be reconsidered. The effectiveness of adaptation measures including regulations in zoning, emigration policy, and changes in construction standards should be carefully tested before implementation.

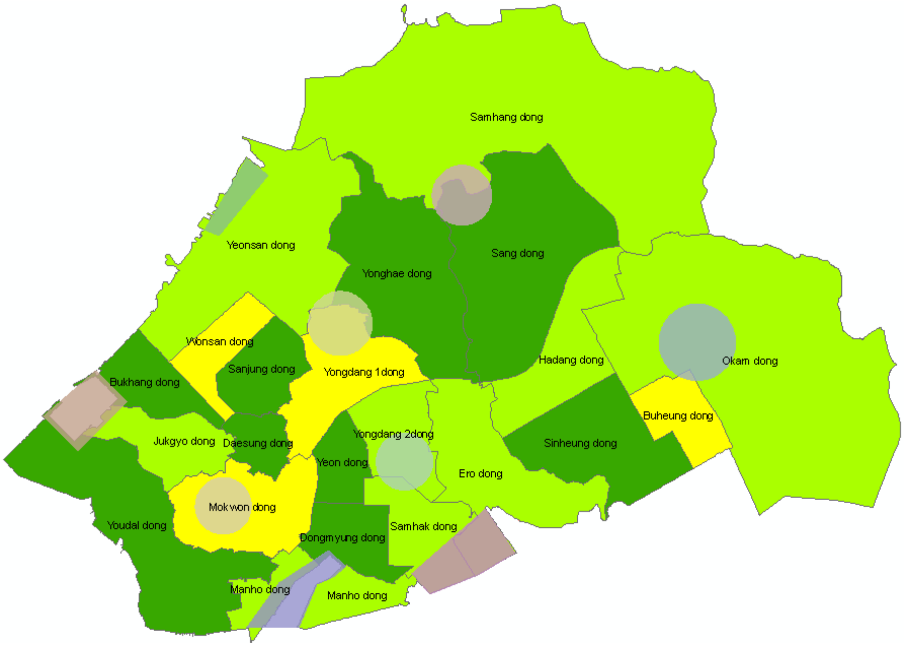
Ⅳ. Conclusion

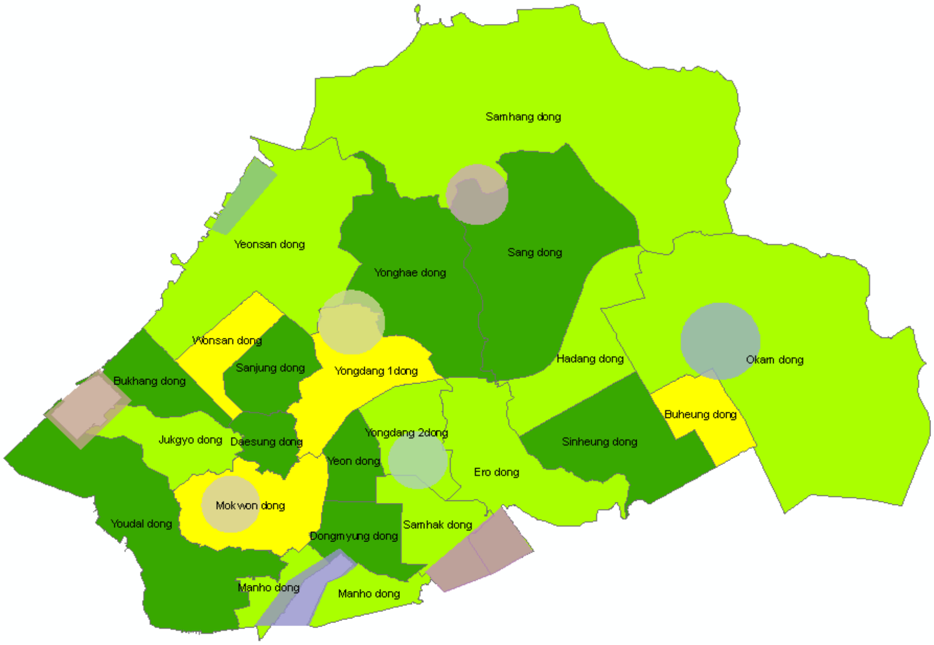
This study provides a practical methodology to assess climate change vulnerability. The conceptual framework for climate change vulnerability used herein is easily integrated into the current academic challenge, i.e. the integration of biophysical impact with socio-economic aspects of climate change. Application of this methodology to a coastal city in Korea (Mokpo) indicated that this method is easy to use as long as statistical data and GIS techniques are available. Distribution of vulnerabilities to sea level rises in Mokpo provides a sound basis for setting local adaptation policies to climate change. In particular, as we utilized land cover information, our results supply concrete suggestions in urban planning and zoning schemes.

This study also provides a concrete basis for setting up integrated coastal zone management plans. Due to high uncertainties for climate change, policy makers are having a hard time setting up specific adaptation plans to prepare for sea level rises. As a win-win strategy, vulnerability to sea level rises should be considered in the framework for integrated coastal zone management.

Future study needs to expand the scope of climate exposure from sea level rises to heat waves and/or heavy rainstorms. Tools to relate the results of vulnerability assessment with the establishment of adaptation measures should be developed for local governmental officials.

Figure 7 Distribution of vulnerability classes in Mokpo for sea level rises of 1, 2, 3, 4, and 5 meter(s)

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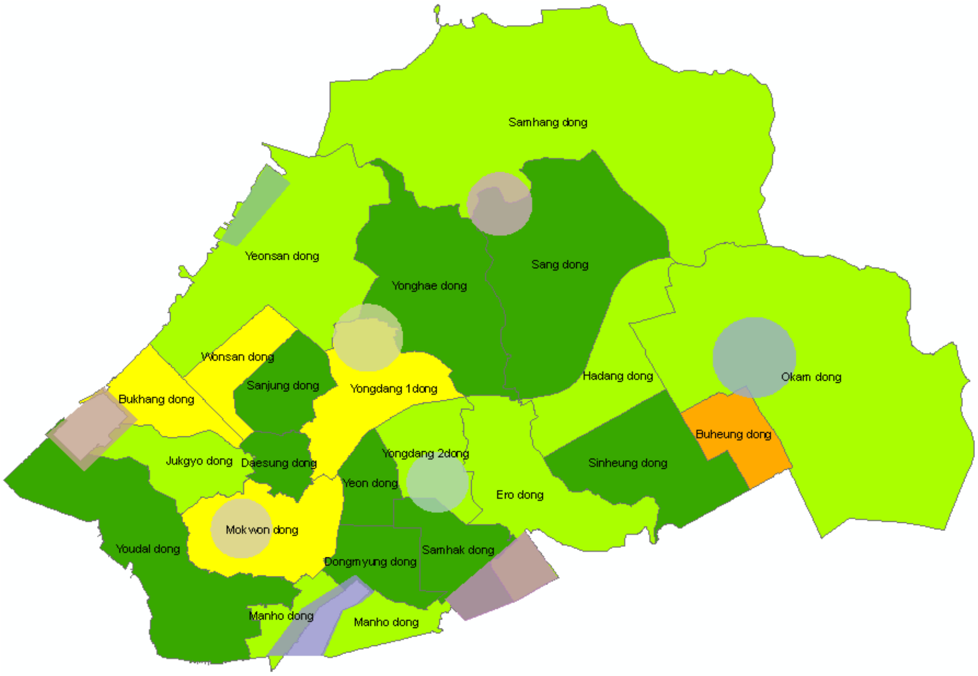
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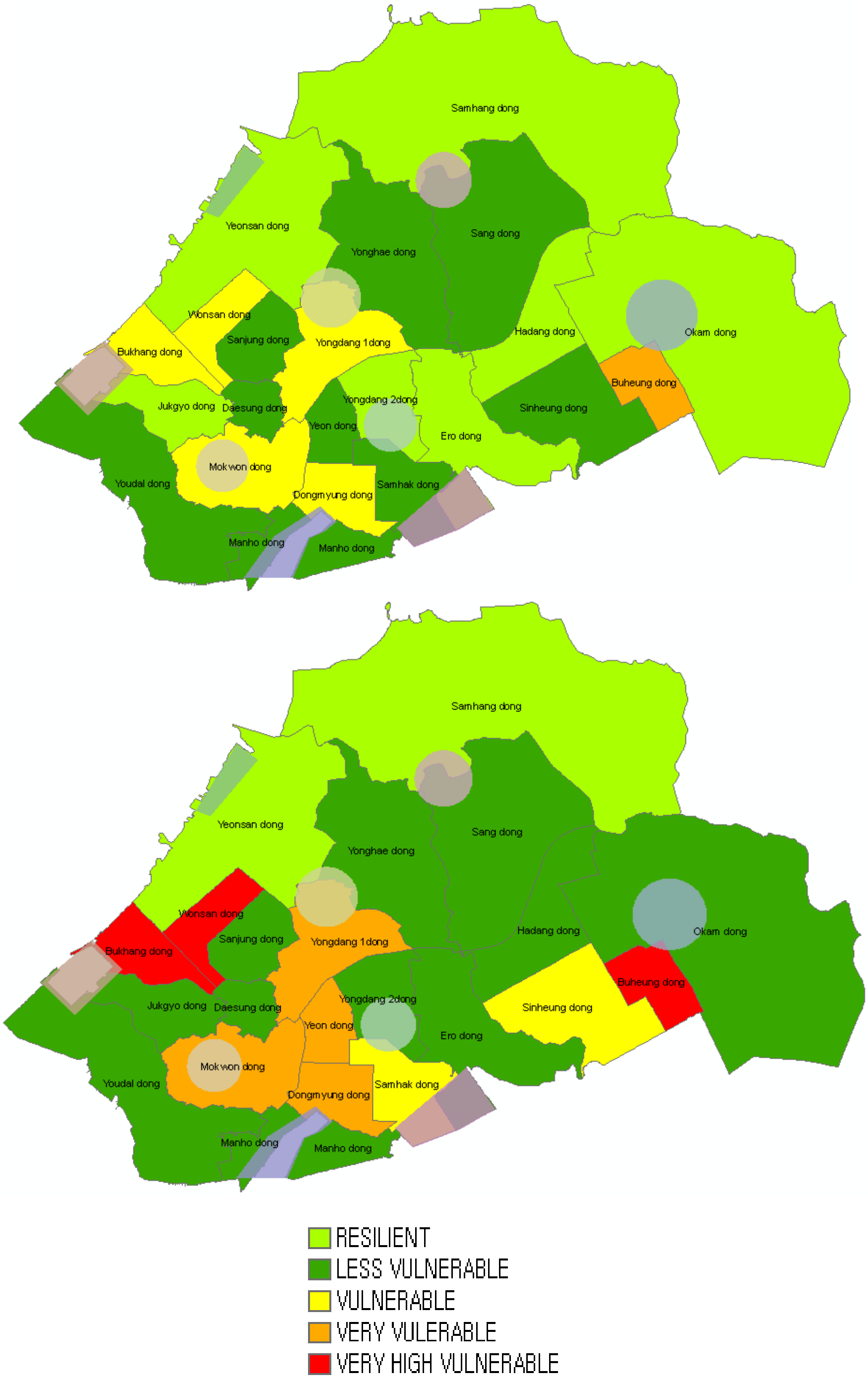
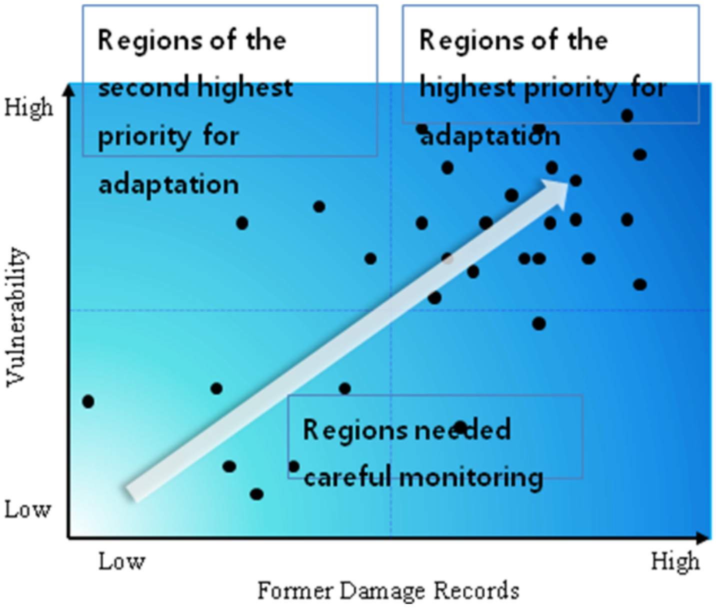
Wonsan dong
Hadang dong
Okam dong
Sanjung dong
Yongdang 1dong
Bukhang dong
Buheung dong
Jukgyo dong
Daesung dong
Yongdang 2dong
Sinheung dong
Yeon dong
Ero dong
Mokwon dong
Youdal dong
Samhak dong
Dongmyung dong
Manho dong
Manho dong



··· Very Highly Vulnerable

Figure 8 Relationship between previous damage records and vulnerabilities



Notes: Former damage records → Previous damage records
Regions needed careful monitoring→Regions needing careful monitoring
Regions of the highest priority→Regions with the highest priority

Source: Modified from BDI (2010).

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