Journal of the Korean Society of Grassland and Forage Science 41(3): 189~197, 2021
https://doi.org/10.5333/KGFS.2021.41.3.189
ISSN 2287-5824 (Print)
ISSN 2287-5832 (Online)

Research Article

Climate Change Vulnerability Assessment of Cool-Season Grasslands Based on the Analytic Hierarchy Process Method

Bae Hun Lee, Dong Won Cheon, Hyung Soo Park, Ki Choon Choi, Jeong Seop Shin, Mi Rae Oh and Jeong Sung Jung*

National Institute of Animal Science, RDA, Cheonan, 31000, Republic of Korea

ABSTRACT

Climate change effects are particularly apparent in many cool-season grasslands in South Korea. Moreover, the probability of climate extremes has intensified and is expected to increase further. In this study, we performed climate change vulnerability assessments in cool-season grasslands based on the analytic hierarchy process method to contribute toward effective decision-making to help reduce grassland damage caused by climate change and extreme weather conditions. In the analytic hierarchy process analysis, vulnerability was found to be influenced in the order of climate exposure (0.575), adaptive capacity (0.283), and sensitivity (0.141). The climate exposure rating value was low in Jeju-do Province and high in Daegu (0.36–0.39) and Incheon (0.33–0.5). The adaptive capacity index showed that grassland compatibility (0.616) is more important than other indicators. The adaptation index of Jeollanam-do Province was higher than that of other regions and relatively low in Gangwon-do Province. In terms of sensitivity, grassland area and unused grassland area were found to affect sensitivity the most with index values of 0.487 and 0.513, respectively. The grassland area rating value was low in Jeju-do and Gangwon-do Province, which had large grassland areas. In terms of vulnerability, that of Jeju-do Province was lower and of Gyeongsangbuk-do Province higher than of other regions. These results suggest that integrating the three aspects of vulnerability (climate exposure, sensitivity, and adaptive capacity) may offer comprehensive and spatially explicit adaptation plans to reduce the impacts of climate change on the cool-season grasslands of South Korea.

(**Key words**: Vulnerability assessment, Climate change, Cool-season grasslands, Analytic hierarchy process)

Ⅰ. INTRODUCTION

The global mean surface temperature has increased by 0.87 °C in 2006–2015 compared to that in 1850–1900 and ongoing global warming is currently increasing at a rate of 0.2 °C per decade owing to greenhouse gases (Masson-Delmotte et al., 2018). In South Korea, compared to the 20th century, in the last 30 years the temperature has risen by 1.4 °C (Riahi et al., 2011). Climate change-related increases in extreme weather conditions have the potential to significantly affect agricultural systems and their productivity (Hopkins and Prado, 2007). Forage crops are especially vulnerable to adverse changes in temperature and precipitation during cultivation (Kurukulasuriya and Rosenthal, 2013). The seeding stage of grass is particularly susceptible to drought stress, and spring drought has the potential to affect grassland productivity during early summer, particularly in newly established grasslands (Lei et al., 2016). The rapid increase in the frequency and severity of climate extremes has a great impact on productivity and species richness (De Boeck et al., 2018). Therefore, it is necessary to enable a better assessment of the future impacts of climate change on grassland ecosystems. In addition, the degradation of grasslands is related to the effects of biotic and abiotic factors regulating this system. Thus, the interactions between biotic and abiotic components and socioeconomic factors are required for understanding damage in grasslands (Emadodin et al., 2021).

According to the forage cultivation status report (South Korea), in 2005, the grassland area was 33 thousand hectare and is continuously decreasing owing to the increasing area under unused grassland and land use change (MAFRA, 2021). In South Korea, cool-season grass such as orchardgrass and tall fescue are mainly used for the establishment of grasslands (Kim et al., 1997; Kim et al., 2011). It is also predicted that ongoing global warming owing to recent climate change may adversely affect

*Corresponding author: Jeong Sung Jung, National Institute of Animal Science, RDA, 31000, Cheonan, Republic of Korea, Tel: +82-41-580-6748, Fax: +82-41-580-6779, E-mail: jjs3873@korea.kr

the growth of cool-season grasses (Choi et al., 2020). The optimum temperature for cool-season grass (C3 grasses) is 5–25 °C; the suitable temperature for regrowth is above 5 °C and growth retardation occurs at the above 25 °C (Kim et al., 2011). Numerous studies have reported that summer depression has a negative impact on grasslands (Emadodin et al., 2021; Kawanabe et al., 1985; Kim et al., 1997; Lee et al., 2000; Oh et al., 2018). In addition, climate change has been identified as a cause of increased frequency and severity of droughts, and these can decrease productivity in temperate grasslands (Emadodin et al., 2021). Grass production decreased by approximately 30% in Europe because of heatwaves and droughts. Precipitation and drought have been used as major indicators for evaluating changes in grass productivity owing to climate change (De Boeck et al., 2018; Oh et a., 2018; Shao et al., 2016). Many studies have been conducted on grasslands to help prevent poor vegetation and productivity because of climate change (Jung et al., 2016; Jung et al., 2018; Jung et al., 2019; Yan et al., 2019). Choi et al. (2020) reported that grassland management practices and techniques and improvement in soil fertility are more important than climate change for increasing the dry matter (DM) yield of grasslands in the central and southern areas of Korea.

According to the IPCC (2001), vulnerability is the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes. Glick et al. (2011) defined climate vulnerability as a combination of the exposure, sensitivity and adaptive capacity of an entity to change in climate conditions. Vulnerability assessment methods are very effective tools that can be used to assess the relative susceptibility of productivity to changing climate (Thorne et al., 2018). In addition, their mitigation and adaptation have become more important in recent decades through impact assessment for evaluating vulnerabilities (Parry et al., 2007).

Since the adoption of the IPCC vulnerability definition, several approaches focusing on different components have been developed in many countries to assess vulnerability of temperate grasslands to climate change (Leclerc et al., 2020). Various methods have been developed, such as quantitative assessment of ecosystem vulnerability, process-based vegetation models, and probabilistic risk assessment to assess the vulnerability of grasslands to climate change (Hunt et al., 1991; Nandintsetseg et al., 2021; Yan et al., 2019). A study reported that assessing the impact of returning grazing land to grassland projects on regional eco-environmental vulnerability using the spatial projection pursuit model and a geographic information system, is limited by the choice of suitable evaluation indexes in accordance with regional eco-environmental traits (Shao et al., 2016). The analytic hierarchy process (AHP), a multi-criteria decision-making method, is a very effective means of evaluating and supporting decisions with competing and multiple objectives (Saaty, 1988). The AHP analysis can determine a weight vector that is most likely to cause the associated pairwise comparison matrix (Hashimoto, 1994, Lee et al., 2018). However, there have been no studies on climate change vulnerability assessments in grasslands in South Korea.

The present study therefore aimed to perform the climate change vulnerability assessments of cool-season grasslands based on the AHP method to contribute to effective decisions in order to reduce grassland damage because of climate change and extreme weather conditions.

Ⅱ. MATERIALS AND METHODS

1. Study area

The study was conducted in South Korea, located at latitude 33°9′–38°72′ and longitude 124°54′–131°6′. The climate change vulnerability assessment (CCVA) in this study was conducted based on the administrative district information provided by the National Geographic Information Institute and data was converted into raster images.

2. Data collection and analysis processing

A flow chart of the process used to determine the CCVA in cool-season grasslands is shown in Fig. 1. The evaluation index related to the CCVA in cool-season grasslands was selected based on expert opinion and related research papers. The criteria and sources of the indicators are presented in Table 1. The importance of each index was analyzed through the AHP after pre-processing of data for standardization. The weightages assigned to the indicators are listed in Table 2. A digital map was prepared at a grid resolution of 1 km for average monthly maximum air temperature in August (MTA) using data obtained from the National Institute of Horticultural and Herbal Science (Fig. 2)

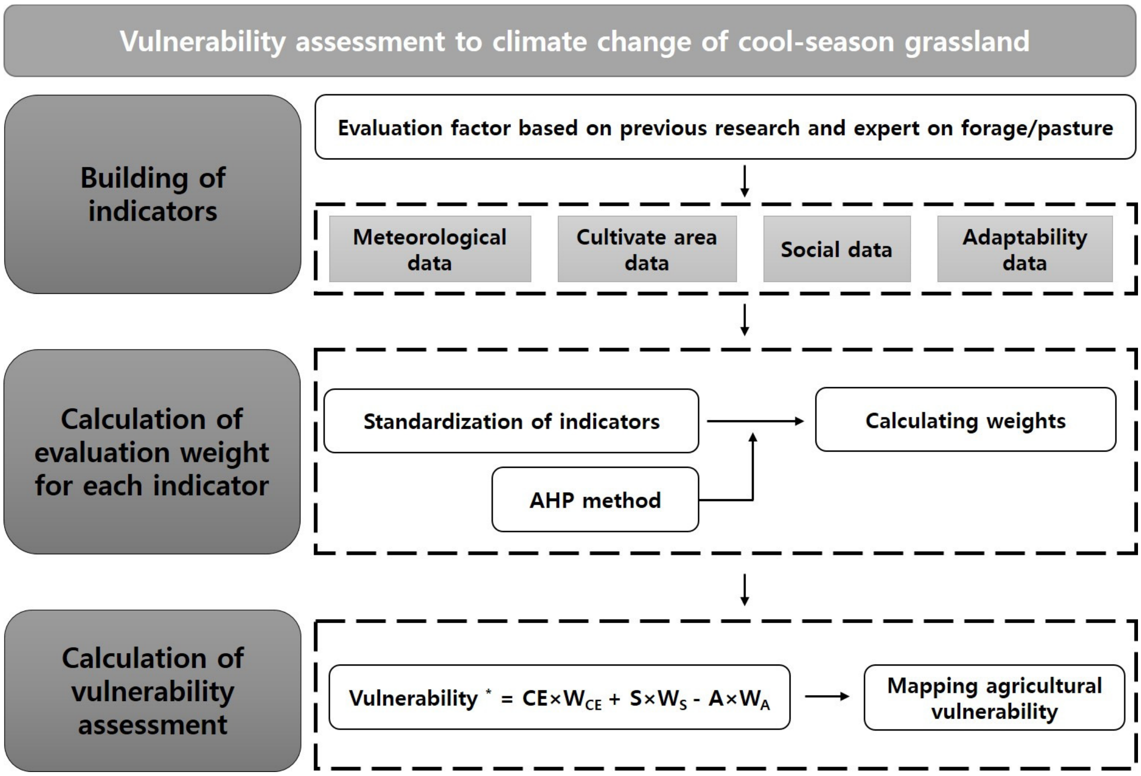

Fig. 1. Flow chart of the process used to determine the vulnerability assessment model of climate change in cool-season grasslands.

* CE: climate exposure; S: sensitivity; A: adaptive capacity; W: weight of the indicator

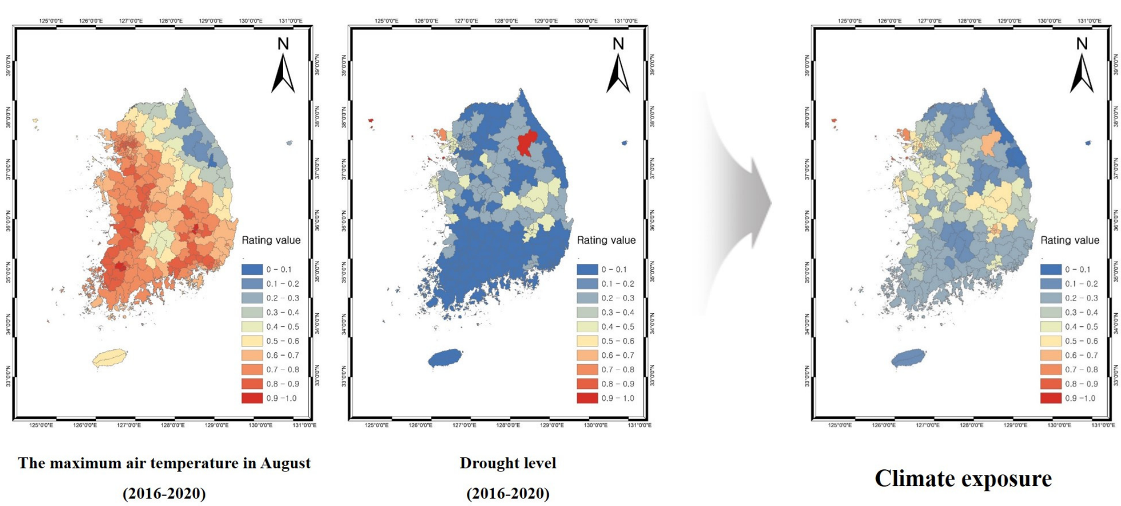

Fig. 2. Climate exposure calculated for the Republic of Korea based on distribution maps of the maximum air temperature in August and drought levels.

and was classified into four classes (best suitable, suitable, possible, and low productivity) based on the criteria range in Table 1. Precipitation data were collected from the nearest weather station and drought classes were determined based on yearly precipitation (2016~2020) by region. Grassland area and unused grassland area were obtained from reports of the current state and utilization of grasslands in 2021 (MAFRA, 2021). The number of farms using grasslands and cultivation area under forage crops was collected from the national statistics for 2021 from KOSTAT (Statistics Korea). The digital map for grassland compatibility was obtained from the Korean Soil Information System (NAS in Korea; http://soil.rda.go.kr), and regions were classified into two classes based on the criteria range listed in Table 1.

3. Standardization of the evaluation index

After determining the vulnerability evaluation index (sensitivity, exposure, and adaptation), a standardization process was performed to eliminate the effect of different dimensions. As the dimensions

Table 1. Indicators, criteria range, and source for assesment of climate change vulnerabilities of cool-season grasslands

<table>
<tr><th>Categories</th><th>Indicator</th><th colspan="5">Criteria range</th><th>Source</th></tr>
<tr><td rowspan="14">Climate exposure</td><td rowspan="5">The average maximum air Temperature in August (MTA)</td><td colspan="5">Suitability classes based on MTA (2016-2020)</td><td rowspan="5">Kim et al. (1997)</td></tr>
<tr><td colspan="2">Best suitable</td><td colspan="3">MTA ≤ 25℃</td></tr>
<tr><td colspan="2">Suitable</td><td colspan="3">25℃ < MTA ≤ 28℃</td></tr>
<tr><td colspan="2">Possible</td><td colspan="3">28℃< MTA ≤ 31℃</td></tr>
<tr><td colspan="2">Low productivity</td><td colspan="3">MTA >31℃</td></tr>
<tr><td rowspan="9">Drought level</td><td colspan="5">Drought classes based on yearly precipitation (2016-2020)</td><td rowspan="9">Agricultural Weather Information Service (RDA, 2021)</td></tr>
<tr><td colspan="2">Class</td><td colspan="3">Criteria range</td></tr>
<tr><td colspan="2">5</td><td colspan="3">Less than 60% of 40 year average precipitation</td></tr>
<tr><td colspan="2">4</td><td colspan="3">60%–70% of 40 year average precipitation</td></tr>
<tr><td colspan="2">3</td><td colspan="3">70%–80% of 40 year average precipitation</td></tr>
<tr><td colspan="2">2</td><td colspan="3">80%–90% of 40 year average precipitation</td></tr>
<tr><td colspan="2">1</td><td colspan="3">90%–100% of 40 year average precipitation</td></tr>
<tr><td colspan="2">0</td><td colspan="3">More than 100% of 40 year-average precipitation</td></tr>
<tr><td rowspan="2">Sensitivity</td><td>Grassland area</td><td colspan="5">Domestic grassland area statistics for 2020</td><td>MAFRA (2021)</td></tr>
<tr><td>Unused grassland area</td><td colspan="5">Domestic unused grassland area statistics for 2020</td><td>MAFRA (2021)</td></tr>
<tr><td rowspan="10">Adaptive capacity</td><td rowspan="8">Grassland compatibility</td><td colspan="5">Suitable level of soil condition for grassland</td><td rowspan="8">Kim et al. (1997)</td></tr>
<tr><td rowspan="2">Item</td><td colspan="4">Grade</td></tr>
<tr><td>1st</td><td>2nd</td><td>3rd</td><td>4th</td></tr>
<tr><td>Soil drainage</td><td>Good–Fair</td><td>Excellent–poor</td><td>Excellent–very bad</td><td>Excellent–very bad</td></tr>
<tr><td>Soil texture</td><td>Clayey, Clay loam, Silty clay loam, Coarse Loamy, coarse silty over</td><td>Clayey, Clay loam, Silty clay loam, Coarse Loamy, coarse silty over, Sandy</td><td>Clayey, Clay loam, Silty clay loam, Coarse Loamy</td><td>Clayey, Clay loam, Silty clay loam, Coarse Loamy</td></tr>
<tr><td>Effective depth of soil (cm)</td><td>>100</td><td>>100</td><td>100–50</td><td>100–50</td></tr>
<tr><td>Gravel content</td><td>Not detected</td><td>Not detected–Slightly present</td><td>Slightly present</td><td>Present</td></tr>
<tr><td>Slope (%)</td><td>< 2</td><td>2–7</td><td>< 15</td><td>< 15</td></tr>
<tr><td>Number of farms using grassland</td><td colspan="5">The number of farms with grassland in 2020 in the Republic of Korea
Range (No.): 0–1,105</td><td>KOSTAT (2021)</td></tr>
<tr><td>Cultivation area under forage crops</td><td colspan="5">Cultivation area under forage crops by region in 2020
range (hectare): 0–47,446</td><td>[OSTAT (2021)</td></tr>
</table>

of each evaluation index are not unified, comparisons are not possible. Therefore data were standardized for analysis using the following equation:

$$D_i^t = \frac{X_i^t - X_i^{max}}{X_i^{max} - X_i^{min}}$$

where X_i^t is an original value, D_i^t is the standard value (range from 0 to 1); X_i^{max} is the maximum value of an indicator; X_i^{min} is the minimum value of an indicator (Shao et al., 2016). The higher the value, the higher the vulnerability, and the reduced vulnerability index was converted inversely.

4. AHP method for weight calculation of indicators

The weight of each indicator for performing the CCVA in cool-season grasslands was determined. The AHP is an effective multi-criteria decision-making method that can be used to set a systematic approach for evaluating and integrating the impacts of different indicators (Saaty, 1980). AHP analysis can determine a weight vector that is most likely to cause the associated pairwise comparison matrix (Hashimoto, 1994, Lee et al., 2018). In this study, the weight for vulnerability assessment factors was determined through a questionnaire and the AHP method used by 11 experts in forage research. Individual experts' experiences are utilized to estimate the relative weights of factors through pair-wise comparisons. The relative weights of the factors using the AHP method are listed in Table 2. The CCVA comprised seven indices subdivided into three categories based on vulnerability determining factors, (i) climate exposure, (ii) sensitivity, and (iii) adaptive capacity, which were used for the relative importance grading of pairwise elements. The inconsistency rate (IR) value was used as an index for assessing the departure of the matrix from uniformity. The IR should be < 0.1; otherwise, it is essential to check for subjective judgments and recalculate the weights (Saaty and Vargas, 2001).

5. Spatial distribution map

The overall vulnerability assessment was performed using the spatial analyst tool in ArcGIS 10.8 for mapping the spatial distribution of vulnerability.

Ⅲ. RESULTS AND DISCUSSION

1. Calculation of the evaluation weight for each indicator

1.1. Climate exposure

In the AHP analysis, climate exposure showed a very high impact (0.575) on the vulnerability assessment (Table 2). Two indicators, MTA and drought level, were determined as influencing climate exposure; drought level showed a higher weight than MTA. Drought stress is an important factor limiting the productivity of plants, and high temperatures can cause physiological damage and affect crop yield (Boyer, 1982). In many situations, heat and drought stress occur simultaneously, and the impact of the interaction between the two on plant physiology is extremely complex (Buttlar et al., 2018). Zhu et al. (2021) reported that the impact of drought on plant

Table 2. Indicators and weights for assesment of climate change vulnerabilities of cool season grasslands

Categories	Indicator	Details	Weight of indicator	Weight of criteria
Climate exposure	The average maximum air temperature in August	Evaluating the effect of high temperature on cool-season grasslands	0.343	0.575
	Drought level	Evaluating the effect of yearly precipitation	0.657	
Sensitivity	Grassland area	Domestic grassland area statistics	0.487	0.141
	Unused grassland area	Domestic grassland area statistics	0.513	
Adaptive capacity	Grassland compatibility	Suitability for grassland (soil drainage, soil texture, effective depth of soil, soil profile, soil erosion, and slope)	0.616	0.283
	Number of farms using grasslands	The number of farms with grasslands in the Republic of Korea	0.156	
	Cultivation area under forage crops	Cultivation area under forage crops by region	0.228	

productivity was greater than that of heat, and complex effects were greater than the impact of individual stress factors. In the current study, the impact of drought stress indicators on the productivity of cool-season grasslands was greater than that of MTA (Table 2). The results of the climate risk assessments are presented in Fig. 2. Regarding MTA, Daegu, Gwangju, and Jeonju City showed a high score ranging from 0.92 to 1. Regarding drought level, the regions with the highest indices were Ongjin-gun (1), Pyeongchang-gun (1), and Ganghwa-gun (0.75). For climate exposure, the higher the index value, the greater is the influence of climate (Yoo et al., 2013). Overall, the average climate exposure index was 0.34, and the average of the top 30% values was as high as 0.51 (Fig. 2).

1.2. Sensitivity

Sensitivity is the degree to which a system is affected by climate change, including both negative and positive effects (Koh et al., 2010). The indicators that best represent the degree to which cool-season grasslands are affected by climate change are grassland area and unused grassland area. Sensitivity showed a low impact (0.141) on the vulnerability assessment (Table 2). Two indicators, grassland area and unused grassland area in 2020, were identified. The grassland area rating value was low in Jeju-do and Gangwon-do Province, which had a large grassland area and was high in Gyeonggi-do and Gyeongsangnam-do Province, where the grassland area was small. As a result, the sensitivity index was higher in Chungcheongbuk-do Province than in other regions and was relatively low in Jeju-do and Gangwon-do Province (Fig. 3).

1.3. Adaptive capacity

Adaptive capacity is the ability of a framer to adopt an adaption strategy to reduce the adverse effects of climate change on crop production (Nantui et al., 2012, McCarthy et al., 2001). Adaptive capacity showed a medium impact (0.283) on the vulnerability assessment. Three indicators, grassland compatibility, number of farms using grasslands, and cultivation area under forage crops, were identified for adaptive capacity. Grassland compatibility was calculated as the area ratio of grades 1 and 2 based on a suitable level of soil conditions for grassland (Table 1). Grassland compatibility in Gangwon-do and Chungcheongbuk-do Province, which have extensive mountainous regions, was found to be low (Fig. 4). Jeju-do and Jeollanam-do Province showed a high rating value for the number of farms using grasslands. There were extensive cultivation areas under forage crops in Jeollanam-do Province (Fig. 4). As a result, the adaptation index was higher in Jeollanam-do Province than in other regions and was relatively low in Gangwon-do Province (Fig. 4).

2. Calculation of the CCVA of cool-season grasslands

The distribution map of vulnerability of the cool-season grasslands for the Republic of Korea is shown in Fig. 5. The vulnerability of Jeju-do Province was lower than that of other regions, whereas it was higher in Gyeongsangbuk-do Province than in the other regions (Fig 5).

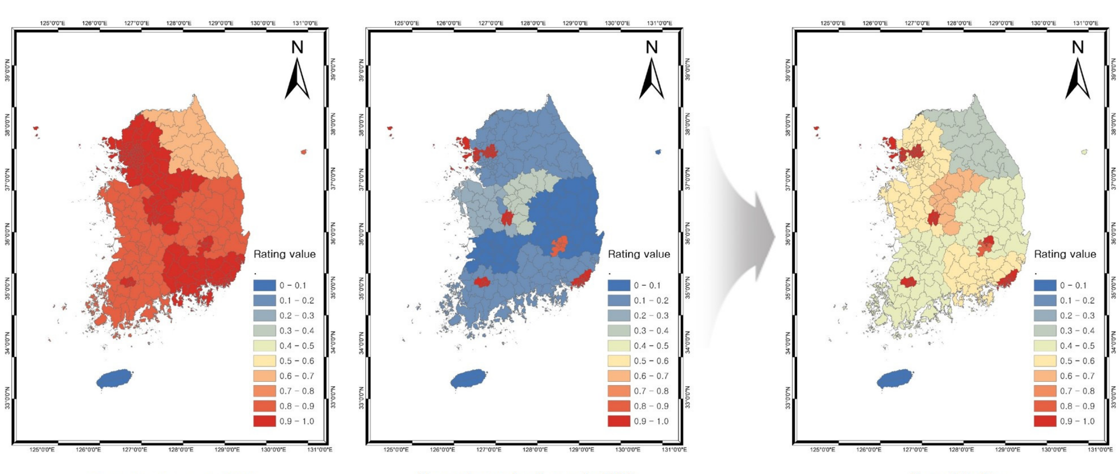

Fig. 3. Sensitivity calculated for the Republic of Korea using distribution maps of grassland area and unused grassland area.

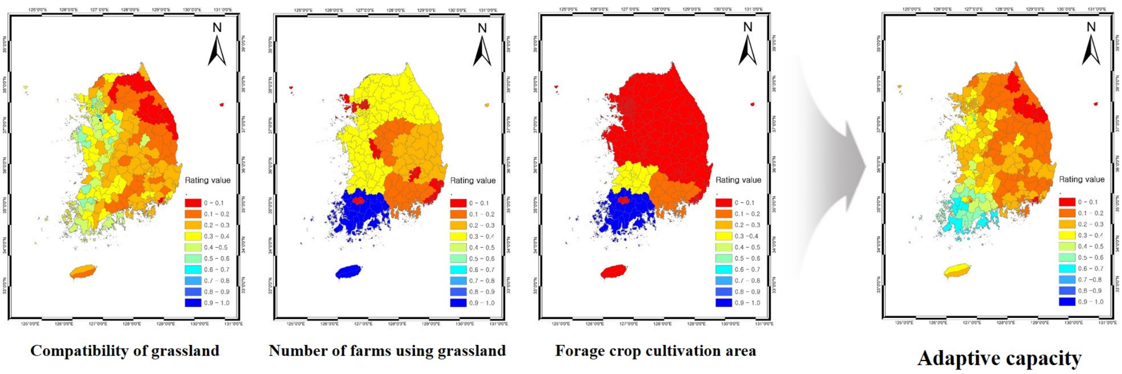

Fig. 4. Adaptive capacity calculated for the Republic of Korea using distribution maps of grassland compatibility, number of farms using grasslands, and cultivation area under forage crops.

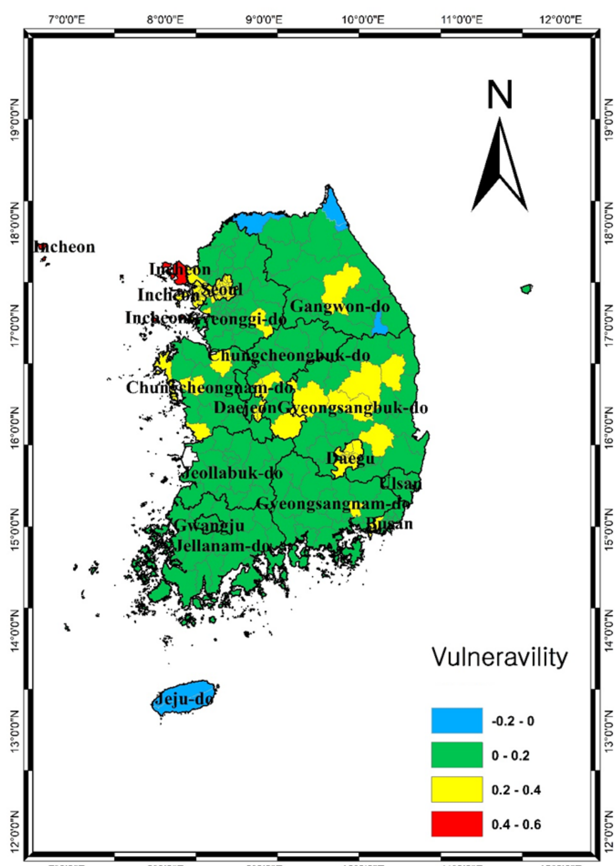

Fig. 5. Distribution map of vulnerability of cool-season grasslands in the Republic of Korea.

Ⅳ. CONCLUSION

The objective of this study was to perform CCVA in cool-season grasslands based on the AHP method to contribute toward effective decisions to reduce grassland damage owing to climate change and extreme weather conditions. Based on the AHP analysis, vulnerability was found to be influenced in the order of climate exposure (0.575), adaptive capacity (0.283), and sensitivity (0.141). Regarding climate exposure, the influence of drought (0.657) was higher than the effect on temperature (MTA: 0.343). The climate exposure rating value was low in Jeju-do Province and high in Daegu (0.36–0.39) and Incheon (0.33–0.5). The adaptive capacity showed that grassland compatibility (0.616) is more important than other indicators. The adaptation index was higher in Jeollanam-do Province than in other regions and relatively low in Gangwon-do Province. In terms of sensitivity, grassland area and unused grassland area influence were found to affect sensitivity the most with values of 0.487 and 0.513, respectively. The grassland area rating value was low in Jeju-do and Gangwon-do Province, which had a large grassland areas. In terms of vulnerability, that of Jeju-do Province was lower and of Gyeongsangbuk-do Province was higher than of other regions. Our approach identified cool-season grasslands that are vulnerable to climate change or extreme weather conditions. Specifically, we highlighted that Gyeongsangbuk-do Province, Daegu, Incheon, and Pyeongchang-gun are regions where appropriate conservation management strategies and actions must be implemented as a priority as these regions are highly vulnerable to climate change. These results suggest that integrating the three aspects of vulnerability (climate exposure, sensitivity, and adaptive capacity) may offer comprehensive and spatially explicit adaptation plans to reduce the impacts of climate change on the cool-season grasslands of South Korea. Continuing to improve our understanding of the climate exposure, sensitivity, and adaptive capacity of cool-season grasslands in South Korea will inform adaptation plans that help preserve grassland productivity, economics, and food security.

Ⅴ. ACKNOWLEDGMENTS

This work was conducted with the support of the Cooperative Research Program for Agriculture Science & Technology Development (Project title: Establishment of a database for analysis of productivity change and assessing impact and vulnerability of forage, Project No. PJ01507901), Rural Development Administration, Republic of Korea.

This study was supported by 2021 the RDA Fellowship Program of National Institute of Animal Science, Rural Development Administration, Republic of Korea.

Ⅵ. CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported

Ⅶ. REFERENCES

Boyer, J.S. 1982. Plant productivity and environment. Science. 218(4571): 443-448. doi: 10.1126/science.218.4571.443

Buttlar, J., Zscheischler, J., Rammig, A., Sippel, S., Reichstein, M., Knohl, A., Jung, M., Menzer, O., Arain, M.A. and Buchmann, N. 2018. Impacts of droughts and extreme-temperature events on gross primary production and ecosystem respiration: a systematic assessment across ecosystems and climate zones. Biogeosciences. 15(5):1293-1318. doi:10.5194/bg-15-1293-2018

Choi, G.J., Jung, J.S., Choi, K.C., Hwang, T.Y., Kim, J.H., Kim, W.H., Lee, E.J., Sung, K.I. and Lee, K.W. 2020. Impact of different environmental conditions and management techniques on productivity of grassland in central and southern area of korea. Journal of the Korean Society of Grassland and Forage Science. 40(2):87-97. doi:10.5333/KGFS.2020.40.2.87

De Boeck, H.J., Hiltbrunner, E., Verlinden, M., Bassin, S. and Zeiter, M. 2018. Legacy effects of climate extremes in alpine grassland. Frontiers in Plant Science. 9:1586. doi:10.3389/fpls.2018.01586

Emadodin, I., Corral, D.E.F., Reinsch, T., Kluß, C. and Taube, F. 2021. Climate change effects on temperate grassland and its implication for forage production: A case study from Northern Germany. Agriculture. 11(3):232. doi:10.3390/agriculture11030232

Glick, P., Stein, B.A. and Edelson, N.A. 2011. Scanning the conservation horizon: A guide to climate change vulnerability assessment. Washington, DC: National Wildlife Federation. p. 168.

Hashimoto, A. 1994. A note on deriving weights from pairwise comparison ratio matrices. European Journal of Operational Research. 73(1):144-149. doi:10.1016/0377-2217(94)90153-8

Hopkins, A. and Del Prado, A. 2007. Implications of climate change for grassland in Europe: Impacts, adaptations and mitigation options: A review. Grass and Forage Science. 62(2):118-126. doi:10.1111/j.1365-2494.2007.00575.x

Hunt, H., Trlica, M., Redente, E., Moore, J., Detling, J., Kittel, T., Walter, D., Fowler, M., Klein, D. and Elliott, E. 1991. Simulation model for the effects of climate change on temperate grassland ecosystems. Ecological Modelling. 53:205-246. doi:10.1016/0304-3800(91)90157-V

IPCC 2001. 2001. Third assessment report-Summary for policy makers.

Jung, J.S., Choi, K.C., Kim, W.H., Kim, H.S. and Choi, G.J. 2019. The effects of shifting seeding dates on botanical composition and productivity under the climate change in oversown mixed pasture, middle region of South Korea. Journal of the Korean Society of Grassland and Forage Science. 39(1):24-30. doi:10.5333/KGFS.2019.39.1.24

Jung, J.S., Kim, J.G., Kim, H.S., Park, H.S., Choi, K.C., Ji, H.J., Choi, G.J. and Oh, S.M. 2018. The effects of seeding rate of seed mixture on productivity and botanical composition in oversown hilly pasture. Journal of the Korean Society of Grassland and Forage Science. 38(1):30-38. doi:10.5333/KGFS.2018.38.1.30

Jung, J.S., Kim, J.G., Park, H.S., Lee, S.H., Kim, H.S., Kim, W.H., Kim, Y.J. and Choi, G.J. 2016. The effects of improvement of botanical composition technology application on botanical composition and dry matter productivity in Rumex acetosella dominated hilly pasture. Journal of the Korean Society of Grassland and Forage Science. 36(2):81-88. doi:10.5333/KGFS.2016.36.2.81

Kawanabe, S. 1985. Present situation and future prospects for grassland farming in Japan. In: International Symposium on Pastures in the Tropics and Subtropics: Proceedings of a Symposium on Tropical Agriculture Research, Tsukuba, October 2-6, 1984. p. 87.

Kim, D.A., Kwon, C.H., Kim, B.H., Kim, C.J., Kim, D.J., Kim, M.C., Bae, D.H., Seo, S., An, K.S., Lee, I.D., Lee, H.W., Jeon, B.T., Jeon, W.B., Jung, J.R., Jo, M.H., Jo, J.G. and Hur, S.N. 1997. Grassland science. Sunjin, Republic of Korea. p. 4.

Kim, M.H., Kim, M.J., Lee, S.R. and Lee, S.H. 2011. The relationship between climate and major forage crop productivity in Daegwallyeong and Suwon sites. The Geographical Journal of Korea. 45(1):137-147.

Koh, J. and Kim, H. 2010. A study on local vulnerability assessment to climate change-The case of municipalities of Gyeonggi-Do. J. Environ. Policy Adm 18:79-105. doi: 10.1007/978-94-007-0785-6_42

KOSTAT. 2021. Agricultural area and crop production survey. Statistics Korea. Available from: http://kostat.go.kr/portal/eng/surveyOutline/1/1/index.static. Accessed Sep. 1, 2021.

Kurukulasuriya, P. and Rosenthal, S. 2013. Climate change and agriculture: A review of impacts and adaptations. http://hdl.handle.net/10986/16616

Leclerc, C., Courchamp, F. and Bellard, C. 2020. Future climate change vulnerability of endemic island mammals. Nature Communications. 11(1):1-9. doi:10.1038/s41467-020-18740-x

Lee, I.D., Lee, H.S. and Kim, S.K. 2000. Comparative studies on the DM yield and quality before and after pasture renovation of summer depression damaged pasture. Journal of the Korean Society of Grassland Science. 20(3):215-220.

Lee, S.J., Song, J.D., Jang, T.I., Sul, D.M. and Son, J.K. 2018. A study on the derivation of the user-oriented agricultural drought assessment criteria using the AHP technique. Journal of Korean Society of Rural Planning. 24(4):47-55. doi:10.7851/Ksrp.2018.24.4.047

Lei, T., Pang, Z., Wang, X., Li, L., Fu, J., Kan, G., Zhang, X., Ding, L., Li, J. and Huang, S. 2016. Drought and carbon cycling of grassland ecosystems under global change: A review. Water. 8(10):460. doi:10.3390/w8100460

MAFRA. 2021. The report of current state and utilization of grassland. Ministry of Agriculture, Food and Rural Affairs.

Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C. and Pidcock, R. 2018. Global warming of 1.5 C. An IPCC Special Report on the Impacts of Global Warming of. IPCC. 1(5).

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. 2001. Climate change 2001: Impacts, adaptation, and vulnerability: Contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Nandintsetseg, B., Boldgiv, B., Chang, J., Ciais, P., Davaanyam, E., Batbold, A., Bat-Oyun, T. and Stenseth, N.C. 2021. Risk and vulnerability of Mongolian grasslands under climate change. Environmental Research Letters. 16(3):034035. doi:10.1088/1748-9326/abdb5b

Nantui, M.F., Bruce, S.D. and Yaw, O.A. 2012. Adaptive capacities of farmers to climate change adaptation strategies and their effects on rice production in the northern region of Ghana. Russian Journal of Agricultural and Socio-Economic Sciences. 11(11).

Oh, S.M., Kim, M., Peng, J., Lee, B.H., Kim, J.Y., Chemere, B., Kim, S.C., Kim, K.D., Kim, B.W. and Jo, M.H. 2018. The relationships between dry matter yield and days of summer depression in different regions with mixed pasture. Journal of the Korean Society of Grassland and Forage Science. 38(1):53-60. doi:10.5333/KGFS.2018.38.1.53

Parry, M., Parry, M.L., Canziani, O., Palutikof, J., Van der Linden, P. and Hanson, C. 2007. Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC. Cambridge University Press.

RDA. 2021. Agricultural weather information service. Rural Development Administration. Available from: http://weather.rda.go.kr. Accessed Sep. 1, 2021.

Riahi, K., Rao, S., Krey, V., Cho, C., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N. and Rafaj, P. 2011. RCP 8.5-A scenario of comparatively high greenhouse gas emissions. Climatic Change. 109(1):33-57. doi: 10.1007/s10584-011-0149-y

Saaty, T.L. 1988. The analytic hierarchy process (AHP). Springer, Berlin, Heidelberg. doi: 10.1007/978-3-642-83555-1_5

Saaty, T.L. and Vargas, L.G. 2001. Models, methods, concepts & applications of the analytic hierarchy process. Kluwer Academic Publishers, Boston. doi:10.1007/978-1-4614-3597-6

Shao, H., Sun, X., Wang, H., Zhang, X., Xiang, Z., Tan, R., Chen, X., Xian, W. and Qi, J. 2016. A method to the impact assessment of the returning grazing land to grassland project on regional eco-environmental vulnerability. Environmental Impact Assessment Review. 56:155-167. doi:10.1016/j.eiar.2015.10.006

Thorne, J.H., Choe, H., Stine, P.A., Chambers, J.C., Holguin, A., Kerr, A.C. and Schwartz, M.W. 2018. Climate change vulnerability assessment of forests in the Southwest USA. Climatic Change. 148(3):387-402. doi: 10.1007/s10584-017-2010-4

Yan, Y., Liu, X., Wen, Y. and Ou, J. 2019. Quantitative analysis of the contributions of climatic and human factors to grassland productivity in northern China. Ecological Indicators. 103:542-553. doi: 10.1016/j.ecolind.2019.04.020

Yoo, S.M., Lee, W.K., Chae, Y.R., Kwak, H.B., Kim, M.I. and Jung, R.S. 2013. The influence of weighing value derived by the regression equation on the result of vulnerability assessment. The Korean Society of Climate Change Research. 4(4):331-348.

Zhu, X., Zhang, S., Liu, T. and Liu, Y. 2021. Impacts of heat and drought on gross primary productivity in China. Remote Sensing. 13(3):378.

(Received : September 13, 2021 | Revised : September 23, 2021 | Accepted : September 24, 2021)