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Decision Support for Peri-Urban Sustainability: An AHP–EWM Based Livability Vulnerability Assessment

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Abstract

In Korea, rural regions increasingly function as peri-urban zones integrated into urban systems. To assess vulnerabilities in these transitional areas characterized by mixed land use and uneven access to infrastructure, this study developed a three-tiered peri-urban livability vulnerability framework by integrating the analytic hierarchy process and the entropy weight method. The results indicated that medical facilities, childcare and education centers, and village communities consistently emerged as key indicators, linking peri-urban livability directly to the stability of settlement environments and the quality of life of residents. Contrastingly, expert evaluations and data-driven outcomes related to road networks and agricultural infrastructure displayed substantial discrepancies, revealing gaps between perceived importance and actual provision levels. Such differences highlight the risk of underestimating infrastructure-related vulnerabilities when subjective assessments are employed exclusively. By synthesizing subjective and objective weights, this study advances urban and environmental analysis and supports evidence-based decision-making for policy prioritization. The findings demonstrate that peri-urban vulnerability is shaped less by productive capacity than by social infrastructure and community stability. This conclusion offers crucial insights for enhancing livability and guiding urban planning strategies.

Keywords: peri-urban livability; AHP–EWM; vulnerability assessment; planning support system

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1. Introduction

Rural and peri-urban regions worldwide have undergone accelerating structural decline, not because of temporary demographic fluctuations but rather because of the cumulative effects of urban expansion, industrial restructuring, weakened agricultural bases, and rapid population aging [1]. Among the most prominent cases is Korea, which became a super-aged society in only seven years, while youth outmigration and limited employment opportunities have likely intensified the risks of depopulation [2]. These dynamics are not unique to Korea; similar trends have been documented in East Asia, Latin America, and parts of Europe, where peri-urban zones have functioned as transitional yet vulnerable spaces at the rural–urban interface. The application of the rural depopulation risk index has indicated that 726 of 1404 towns (51.7%) have been categorized as at risk of extinction, thereby revealing structurally embedded decline. Beyond population loss, vulnerabilities in healthcare, welfare, childcare, and housing directly threaten the

quality of life—conceptualized as livability—of rural residents [3–6]. Livability has been defined not as the mere convenience of daily life but rather as the comprehensive condition that enables residents to live in healthy, safe, and sustainable environments. It integrates social infrastructure, environmental sustainability, and community stability, all of which directly influence the well-being of residents [3,4]. Internationally, peri-urban areas have been conceptualized as hybrid and transitional spaces that combine both urban and rural characteristics, functioning as autonomous spatial units that require multidimensional governance [7–10]. Rather than being defined solely by administrative boundaries or distance from urban centers, peri-urban spaces are characterized by functional linkages—such as commuting patterns, service dependencies, and land use interactions—between urban and rural systems. These areas often experience rapid land use change, uneven infrastructure provision, and governance challenges stemming from overlapping jurisdictions, making them particularly vulnerable to structural pressures and policy blind spots. In the Korean context, most municipalities outside major metropolitan cores can be understood as peri-urban spaces. Although administratively designated as rural, these areas are functionally and spatially integrated with nearby urban centers through transportation networks, service provision systems, and daily commuting flows. Korea's rural regions exhibit peri-urban characteristics—close physical proximity to cities, strong functional integration, and transitional socio-economic structures—which justify their treatment as peri-urban spaces within the global conceptual framework. Situating Korean municipalities within this international peri-urban discourse allows for a more accurate interpretation of their livability vulnerabilities and policy challenges. In recognition of these challenges, the Korean government has enacted the Special Act on the Improvement of the Quality of Life of Farmers and Fishers and, more recently, the Rural Space Restructuring Act (2024). These measures mandated comprehensive surveys and sector-specific plans across healthcare, welfare, education, and housing. However, despite these legislative advances, significant limitations persist. Central government-led initiatives have tended to overlook local needs, implementation capacities among municipalities have remained uneven, and most importantly, the characteristics of peri-urban spaces that are functionally linked to urban systems yet rural in form have not been sufficiently considered in policy design and evaluation [2,11–13]. Consequently, complex vulnerabilities and livability challenges at the urban–rural interface have remained insufficiently captured [14,15]. Against this backdrop, the establishment of a systematic framework for diagnosing livability vulnerabilities and scientifically prioritizing policy resources is required. Previous studies have proposed various approaches to rural vulnerability assessment, such as village-level landscape indices [13], functional diagnostic systems distinguishing living, production, leisure, and community domains [16], and composite indices integrating social welfare and environmental factors [17]. However, these frameworks have primarily relied either on subjective methods, such as the analytic hierarchy process (AHP) and Delphi, or on objective statistical techniques, such as the entropy weight method (EWM) and principal component analysis. When applied in isolation, AHP is constrained by the subjectivity and inconsistency of expert judgments, whereas EWM, although mathematically rigorous, entails the risk of overlooking contextual and policy relevance because of its exclusive dependence on statistical variation. Even in integrative applications, insufficient attention has been given to interpreting discrepancies between qualitative and quantitative results. Moreover, few frameworks explicitly reflect the spatial and functional realities of peri-urban contexts, which are neither entirely urban nor entirely rural but are instead shaped by hybrid and transitional characteristics. Internationally, peri-urban areas have been increasingly conceptualized as autonomous and complex spaces. In China, metropolitan expansion has underscored the necessity of planned land conversion management, as unregulated transitions have been shown to accelerate farmland loss and

weaken rural collectives [18]. In India, peri-urban regions have been defined as multidimensional spaces, and the introduction of multi-level governance arrangements has been emphasized to resolve conflicts associated with land acquisition and resource distribution [8,10]. In Europe, regulatory tools such as greenbelts and zoning have been regarded as effective only when combined with strategic spatial planning, thereby linking ecological preservation with the containment of urban expansion [9]. In Latin America, evidence from Mexico City has highlighted that informal settlements and infrastructural deficiencies must be addressed by recognizing peri-urban regions as independent policy units requiring integrated management strategies [7]. Collectively, these cases suggest a convergent tendency to treat peri-urban areas as hybrid and autonomous policy spaces. However, despite such policy-oriented advances, empirical research explicitly evaluating livability and vulnerability in peri-urban contexts remains extremely limited, necessitating further theoretical and methodological contributions. Therefore, this study sought to overcome the limitations of single-method approaches by integrating the AHP and EWM within a unified framework for assessing peri-urban livability vulnerability. This framework provides a scientific basis for prioritizing policy resources by incorporating subjective judgments and objective variations. It also advances theoretical discussions by examining how subjective and objective assessments may converge or diverge when shaping our understanding of livability in transitional rural–urban contexts. Figure 1 illustrates the research process.

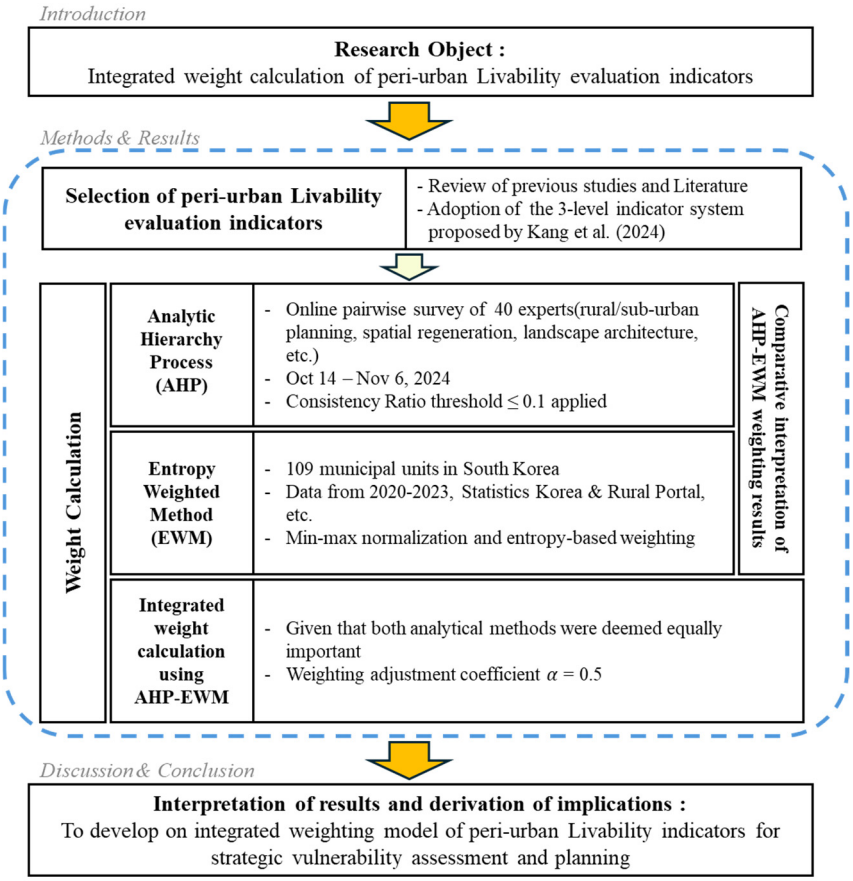


Figure 1. Flow chart of the research process [16].

2. Materials and Methods

2.1. Study Area and Indicator Framework

This study adopted the vulnerability assessment framework Kang et al. [16] proposed as the basis for the AHP–EWM analysis. The framework classifies rural spaces into four domains—living, production, leisure, and community—operationalized into 40 indicators

(Table 1). On the first tier, the living domain comprises health, welfare, and childcare services; the production domain considers agricultural infrastructure and employment conditions; the leisure domain reflects cultural and recreational facilities; and the community domain addresses demographic stability and social cohesion.

Table 1. Vulnerability diagnostic indicators [12].

Category	Detailed Indicator	Symbol	Indicator Formula
Services and Welfare (Living area)			
Settlement Environment	Old Houses Rate	S1	Houses over 20 years old/Total number of houses × 100
	Vacant Houses Rate	S2	No. of vacant houses/Total number of houses × 100
	Commercial Facilities	S3	No. of commercial facilities/Population × 100
	Financial Facilities	S4	No. of financial institutions/Population × 100
Local Economy and Production (Production area)			
Financial	GRDP	E1	Gross regional domestic product (GRDP)
	Fiscal Independence Rate	E2	Financial independence rate
Cultural Amenity and Leisure (Rest area)			
Culture and Sport	Cultural Facilities	A1	No. of cultural facilities/Population × 100
	Library Supply Rate	A2	No. of libraries/Population × 100
	Tourist Attractions	A3	No. of historical and cultural spaces/Population × 100
	Professional Sports Facilities	A4	No. of professional sports facilities/Population × 100
	Public Sports Facilities	A5	No. of public sports facilities/Population × 100
Community and Demographic Stability (Community area)			
Population	Population Density	C1	Population/Area × 100
	Population Growth Rate	C2	Population growth rate
	Elderly Population Rate	C3	Population over age 65 years/Total population × 100

Note. Additional indicators are listed in Appendix A.

The indicator system is regarded as valid, not because it measures facility provision rates but rather because it captures multidimensional aspects of livability, including social infrastructure, demographic structure, and local community integration. Its empirical application in Jinan County has further verified the capacity of the framework to differentiate vulnerability factors across spatial contexts, thereby confirming its practical utility in field settings.

In addition, this study selected 109 municipalities under the jurisdiction of the Ministry of Agriculture, Food and Rural Affairs (MAFRA) as the target areas for assessing peri-urban livability vulnerability. These municipalities represent the core target areas of the Act on Support for Rural Spatial Restructuring and Regeneration (2024), which aims to address long-term regional decline and improve residents' quality of life through the establishment

of spatial plans and revitalization strategies. Accordingly, these 109 municipalities are considered a suitable sample for applying and validating a national peri-urban livability vulnerability assessment framework

2.2. AHP

The AHP, which Saaty [19] introduced, is a multi-criteria decision-making method that operates according to three principles: constructing a hierarchical structure, assigning relative importance, and maintaining logical consistency. By decomposing complex problems into multiple levels, AHP derives indicator weights from pairwise comparisons of expert judgments. Although the method effectively incorporates expert knowledge, it is constrained by subjectivity and difficulty maintaining consistency, particularly as the number of comparison items increases [20–22].

In this study, the AHP analysis comprised four steps. First, a three-tiered hierarchical framework of evaluation indicators was established (Figure 2). Second, a pairwise comparison survey with responses rated on a 9-point scale (Table 2) was designed and distributed to 40 experts, including rural scholars, practitioners, and researchers associated with the Digital-Based Rural Space Regeneration Technology Development Project. The survey was administered online over 24 days from October 14 to 6 November 2024.

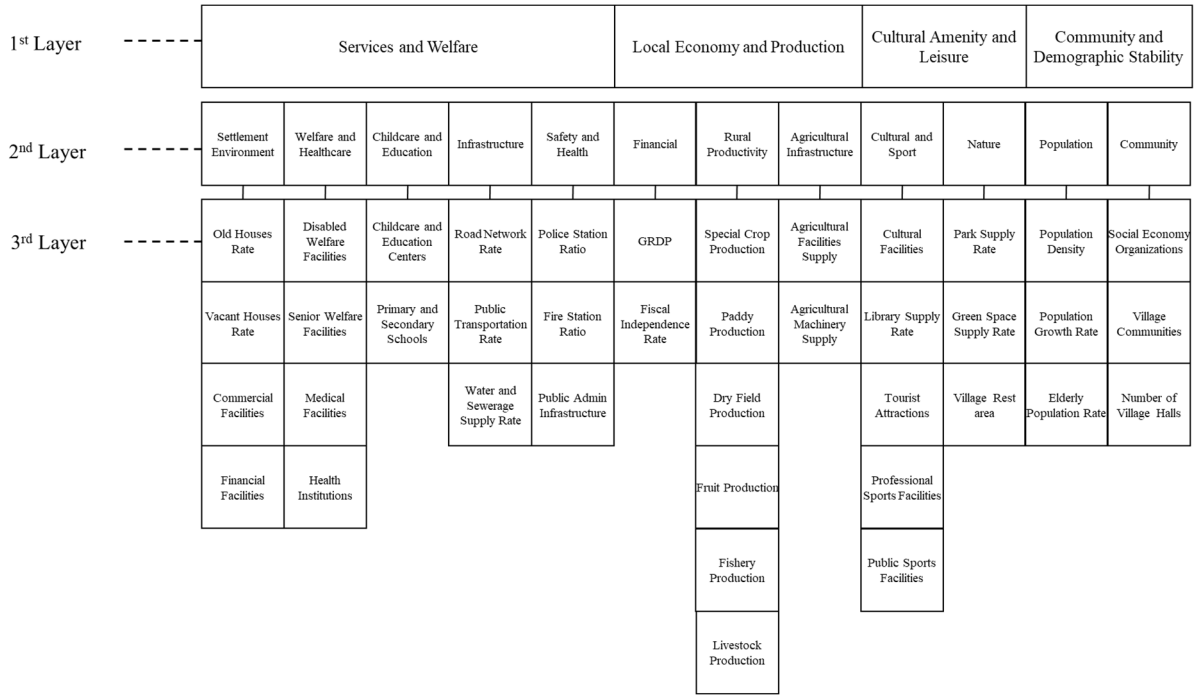


Figure 2. Hierarchy model of the AHP.

Table 2. Comparison scale for the AHP [19].

Scale	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Absolute importance
2, 4, 6, 8	Midpoint between the above scales

Third, the responses were translated into pairwise comparison matrices, and weights were derived using the eigenvalue method (Equations (1) and (2)).

$$A = \begin{bmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & 1 \end{bmatrix} \quad (1)$$

$$w = \lambda_{max} \cdot w \quad (2)$$

Fourth, the consistency of the responses was verified by calculating the consistency index (CI) and consistency ratio (CR; Equation (3)). Responses with a CR of 0.1 or lower are generally considered reliable; thus, only inputs that satisfied this threshold were retained for the analysis.

$$CI = \frac{\lambda_{max} - n}{n - 1}, \quad CR = \frac{CI}{RI} \quad (3)$$

2.3. EWM

The EWM, which is rooted in information theory [23], evaluates the importance of indicators based on the variability of their data distributions. Indicators that exhibit greater variability are assumed to convey more information and are thus assigned higher weights, whereas those with uniform values across regions receive lower weights [24]. This approach is advantageous because it eliminates reliance on subjective judgments and ensures reproducible results from identical datasets. However, the EWM has limitations; it may overlook the substantive or policy relevance of variables, it fails to account for inter-indicator interactions, and it provides limited rank discrimination [25,26].

In this study, primary data for 40 indicators (Table 1) were compiled from the Rural Spatial Information System, Statistics Korea, and the Korea Rural Community Corporation. The data cover the most recent records for the period 2020–2023 and pertain to 109 peri-urban cities and counties designated by the Ministry of Agriculture, Food, and Rural Affairs. Since measurement units varied, all indicators were normalized on a 0–100 scale (Equation (4)).

$$Y_{ij} = \frac{X_{ij} - \min(X_i)}{\max(X_i) - \min(X_i)} \times 100 \quad (4)$$

Entropy values were then calculated to assess the informational contribution of each indicator (Equation (5)), with lower entropy implying greater variability and higher informational value.

$$E_i = -\frac{1}{\ln(n)} \sum_{j=1}^{n} P_{ij} \ln P_{ij} \quad (5)$$

Finally, indicator weights were derived using Equation (6). The process ensured that the resulting values reflected objective variability across spatial units.

$$W_i = \frac{1 - E_i}{k - \sum_{i=1}^{k} E_i} \quad (6)$$

2.4. AHP–EWM

The AHP–EWM approach is a multi-criteria decision-making method that integrates expert knowledge with quantitative data to support decision-making [27,28]. The hybrid approach of combining the AHP, which reflects expert experience and judgment to enable realistic decision-making, with the EWM, which derives objective weights from data variability, allows for more balanced and objective weight estimation while reducing potential biases arising from subjective opinions [27,29].

Accordingly, this study adopted the AHP–EWM to minimize the limitations that may arise when each technique is used independently and to thus derive more reliable and precise final weights. Through this integration, this study enhances the reliability and objectivity of peri-urban livability vulnerability indicators, thereby contributing to the establishment of scientific criteria that can be effectively applied to practical policymaking.

The combined AHP–EWM weighting scheme can be expressed as follows [27]:

$$W_{final,i} = \alpha W_{AHP,i} + (1 - \alpha) W_{EWM,i} \quad (7)$$

In Equation (7), $\alpha (0 \leq \alpha \leq 1)$ denotes the weight adjustment coefficient. As α approaches 1, the influence of subjective evaluation (AHP) increases, whereas as α approaches 0, the influence of objective evaluation (EWM) becomes dominant. In previous studies adopting the AHP–EWM integrated approach, the weight adjustment coefficient (α) has been commonly set to 0.5 as a standard practice, ensuring a balanced consideration between subjective judgments and objective data, without favoring one method over the other [27,30–32]. Similarly, in this study, the importance of the two weighting techniques was regarded as equal; therefore, the adjustment coefficient α was set to 0.5 for the calculation. By setting α to 0.5, this study ensured that neither subjective judgments nor statistical variability disproportionately dominated the final results. This balanced weighting increases the transparency of the interpretation process, as the rationale for integrating expert knowledge and data-driven evidence is made explicit. It also strengthens the robustness of the analysis, since the outcomes remain stable and credible rather than being overly sensitive to one methodological perspective. Consequently, the adopted weighting scheme provides a fair and replicable basis for assessing rural vulnerabilities and enhances confidence in the reliability of policy implications derived from the results.

3. Results

3.1. Results of AHP Analysis

The AHP analysis results presented in Table 3 indicated that all CRs were below 0.1, thus ensuring the reliability of the expert responses. On the first tier, Services and Welfare received the highest weight, followed by Community and Demographic Stability, Local Economy and Production, and Cultural Amenity and Leisure. These rankings suggest that the experts perceived the services directly linked to the daily lives of residents as the most critical dimension of peri-urban livability, whereas leisure-related elements were evaluated as supplementary factors rather than as core determinants.

Table 3. AHP results.

1st Layer	2nd Layer	Weight	Rank	3rd Layer	Weight	Rank
Services and Welfare (0.4515)	Settlement Environment	0.1574	1	S1	0.0350	11
				S2	0.0466	4
				S3	0.0494	2
				S4	0.0264	17
	Welfare and Healthcare	0.1173	3	S5	0.0091	38
				S6	0.0243	18
				S7	0.0451	5
				S8	0.0388	7

Table 3. *Cont.*

1st Layer	2nd Layer	Weight	Rank	3rd Layer	Weight	Rank
Services and Welfare (0.4515)	Childcare and Education	0.0748	6	S9	0.0369	10
				S10	0.0379	9
	Infrastructure	0.0559	10	S11	0.0140	31
				S12	0.0242	19
				S13	0.0178	24
	Safety and Health	0.0460	11	S14	0.0147	28
				S15	0.0140	30
				S16	0.0173	25
Local Economy and Production (0.1863)	Financial	0.0585	9	E1	0.0309	13
				E2	0.0275	14
	Rural Productivity	0.0653	7	E3	0.0148	27
				E4	0.0095	37
				E5	0.0103	34
				E6	0.0103	35
				E7	0.0064	40
				E8	0.0139	32
	Agricultural Infrastructure	0.0625	8	E9	0.0423	6
				E10	0.0202	22
Cultural Amenity and Leisure (0.1378)	Culture and Sport	0.0940	5	A1	0.0268	16
				A2	0.0153	26
				A3	0.0144	29
				A4	0.0101	36
				A5	0.0274	15
	Nature	0.0438	12	A6	0.0122	33
				A7	0.0080	39
				A8	0.0236	20
Community and Demographic Stability (0.2244)	Population	0.1068	4	C1	0.0225	21
				C2	0.0494	3
				C3	0.0349	12
	Community	0.1177	2	C4	0.0381	8
				C5	0.0599	1
				C6	0.0197	23

On the second tier, indicators under Services and Welfare, such as Settlement Environment, Welfare and Healthcare, and Childcare and Education, were prioritized, reflecting the importance of physical living conditions and social safety nets. Similarly, the prioritization of Community and Demographic Stability emphasized the significance of community networks and resident participation, whereas that of Local Economy and Production highlighted agricultural productivity as a key but secondary driver of regional vitality.

On the third tier, indicators such as Village Communities, Commercial Facilities, Vacant Houses Rate, Medical Facilities, and Childcare and Education Centers consistently appeared at the top. These outcomes indicate that the experts emphasized the stability of settlement environments and the presence of robust community networks as central to assessing vulnerability. Contrastingly, indicators including Fishery, Green Space Supply Rate, Disabled Welfare Facilities, and Road Network Rate occupied the lowest ranks. The divergence between top- and bottom-ranked indicators suggests that social infrastructure and community stability were regarded as core dimensions of livability, whereas economic and physical production-based elements were considered supportive rather than decisive.

3.2. Results of EWM Analysis

The EWM analysis results presented in Table 4 revealed that on the first tier, Services and Welfare received the highest weight, indicating substantial disparities in basic infrastructure such as welfare, education, and settlement environment. The second-highest weight was assigned to Community and Demographic Stability, reflecting pronounced regional differences in demographic structure, aging rate, and population growth. Contrastingly, Cultural Amenity and Leisure and Local Economy and Production were assigned lower weights, suggesting that leisure- and production-related indicators exhibited relatively uniform distributions and therefore contributed less to regional differentiation.

Table 4. EWM results.

1st Layer	2nd Layer	Weight	Rank	3rd Layer	Weight	Rank
Services and Welfare (0.6257)	Settlement Environment	0.1716	1	S1	0.0640	2
				S2	0.0377	8
				S3	0.0348	10
				S4	0.0351	9
	Welfare and Healthcare	0.1519	2	S5	0.0289	15
				S6	0.0315	11
				S7	0.0658	1
				S8	0.0257	18
	Childcare and Education	0.0849	5	S9	0.0559	4
				S10	0.0290	14
	Infrastructure	0.1291	3	S11	0.0558	5
				S12	0.0102	31
				S13	0.0630	3
	Safety and Health	0.0882	4	S14	0.0299	13
				S15	0.0303	12
				S16	0.0280	17
Local Economy and Production (0.1051)	Financial	0.0165	12	E1	0.0040	39
				E2	0.0125	29

Table 4. *Cont.*

1st Layer	2nd Layer	Weight	Rank	3rd Layer	Weight	Rank
Local Economy and Production (0.1051)	Rural Productivity	0.0529	9	E3	0.0041	38
				E4	0.0144	26
				E5	0.0066	35
				E6	0.0114	30
				E7	0.0012	40
				E8	0.0153	24
	Agricultural Infrastructure	0.0358	10	E9	0.0074	34
				E10	0.0284	16
Cultural Amenity and Leisure (0.1113)	Culture and Sport	0.0822	6	A1	0.0224	19
				A2	0.0059	37
				A3	0.0216	20
				A4	0.0140	27
				A5	0.0182	23
	Nature	0.0290	11	A6	0.0094	32
				A7	0.0135	28
				A8	0.0061	36
Community and Demographic Stability (0.1579)	Population	0.0782	8	C1	0.0092	33
				C2	0.0216	21
				C3	0.0475	6
	Community	0.0796	7	C4	0.0147	25
				C5	0.0463	7
				C6	0.0186	22

On the second tier, within Services and Welfare, Settlement Environment had the highest weight, followed by Welfare and Healthcare, Infrastructure, Safety and Health, and Childcare and Education. This pattern underscores regional disparities in settlement conditions and welfare services, whereas education and childcare facilities showed more even distributions, partly due to national policy interventions. Within Community and Demographic Stability, Community and Population recorded nearly identical weights, suggesting the even distribution of both social networks and demographic structures, without sharp interregional gaps. Regarding Cultural Amenity and Leisure, Culture and Sports outweighed Nature, which is consistent with the geographical advantage of peri-urban areas, where natural resources are broadly available. In Local Economy and Production, Rural Productivity showed greater variability than the Agricultural or Financial indicators, reflecting regional distinctions in productive capacity.

The analysis of the third tier identified Medical Facilities, Old Houses Rate, Water and Sewerage Supply Rate, Childcare and Education Centers, Road Network Rate, and Elderly Population Rate as heavily weighted indicators, highlighting significant disparities in essential services and settlement conditions. Conversely, indicators such as Fishery Production, Gross Regional Domestic Product (GRDP), Special Crop Production, and Public Transportation Rate were assigned the lowest weights. Thus, the indicators that were confined to specific regions or secured at broadly similar levels across most areas exhibited

limited discriminating power. Consequently, although they captured local particularities, their contribution to explaining overall peri-urban vulnerability remained low.

3.3. Comparison of the AHP and EWM Weighting Results

Among the top ten indicators derived from the EWM and AHP analyses, all but Agricultural Facilities in the AHP results belonged to the first-tier domains of Services and Welfare and Community and Demographic Stability. This indicates that, in peri-urban areas, regional data variability is the greatest for these two domains, and experts have similarly considered them to be core elements in vulnerability assessment. Notably, Medical Facilities ranked first in EWM and fifth in AHP, whereas Vacant Houses Rate (eighth in EWM and fourth in AHP) and Childcare and Education Centers (fourth in EWM and tenth in AHP) appeared consistently among the top indicators in both methods. These findings reflect a convergence between expert judgment and data-driven variability, suggesting that healthcare, childcare, and housing-related facilities are fundamental to ensuring residential stability and improving quality of life in peri-urban areas.

Contrastingly, Old Houses Rate, Road Network Rate, and Financial Facilities ranked second, fifth, and ninth, respectively, in the EWM analysis but did not appear among the top ten in the AHP results. This suggests that the experts did not regard these indicators as central to vulnerability assessment. However, in practice, significant regional disparities and high variability elevated their importance in the data-driven analysis. Conversely, Village Communities, Social Economy Organizations, and Population Growth Rate ranked first, eighth, and third, respectively, in the AHP results but were absent from the top ten in the EWM results. This indicates that the experts considered social networks and demographic dynamics to be essential for rural sustainability, but the relatively small regional differences in these indicators resulted in lower weights in the data-based analysis.

3.4. Final Weighting Results of AHP–EWM

The final weights derived from the integrated AHP–EWM approach are presented in Table 5 and represent the synthesis of expert judgment, captured by the AHP, and data-driven variability, captured by the EWM. In this process, the indicators in both methods identified as being important received consistently high weights, whereas those rated highly by one method and rated low by the other tended to be averaged, resulting in moderate final weights.

Table 5. AHP–EWM results.

1st Layer	2nd Layer	Weight	Rank	3rd Layer	Weight	Rank
Services and Welfare	Settlement Environment	0.1645	1	S1	0.0495	3
				S2	0.0421	5
				S3	0.0421	6
				S4	0.0308	13
	Welfare and Healthcare	0.1346	2	S5	0.0190	25
				S6	0.0279	14
				S7	0.0554	1
				S8	0.0323	12
	Childcare and Education	0.0799	7	S9	0.0464	4
				S10	0.0335	11

Table 5. *Cont.*

1st Layer	2nd Layer	Weight	Rank	3rd Layer	Weight	Rank
Services and Welfare	Infrastructure	0.0925	5	S11	0.0349	10
				S12	0.0172	28
				S13	0.0404	8
	Safety and Health	0.0671	8	S14	0.0223	21
				S15	0.0222	22
				S16	0.0226	20
Local Economy and Production	Financial	0.0375	11	E1	0.0175	27
				E2	0.0200	23
	Rural Productivity	0.0591	9	E3	0.0095	38
				E4	0.0119	33
				E5	0.0085	39
				E6	0.0108	34
				E7	0.0038	40
				E8	0.0146	31
	Agricultural Infrastructure	0.0491	10	E9	0.0248	16
				E10	0.0243	18
Cultural Amenity and Leisure	Culture and Sport	0.0881	6	A1	0.0246	17
				A2	0.0106	37
				A3	0.0180	26
				A4	0.0121	32
				A5	0.0228	19
	Nature	0.0364	12	A6	0.0108	35
				A7	0.0107	36
				A8	0.0149	30
Community and Demographic Stability	Population	0.0925	4	C1	0.0158	29
				C2	0.0355	9
				C3	0.0412	7
	Community	0.0987	3	C4	0.0264	15
				C5	0.0531	2
				C6	0.0192	24

On the first tier, Services and Welfare recorded the highest weight, followed by Community and Demographic Stability, Cultural Amenity and Leisure, and Local Economy and Production. This outcome reflects the convergence of two perspectives: expert evaluations that emphasized the importance of the settlement environment and community revitalization, and data characteristics that showed high variability in Services and Welfare and Community and Demographic Stability but lower variability in Local Economy and Production, Cultural Amenity and Leisure.

On the second tier, the highest weights were assigned to Settlement Environment, Community, Financial, and Culture and Sports. These results integrated expert assess-

ments highlighting settlement conditions and community engagement as central to rural vulnerability evaluations with EWM findings showing substantial regional disparities in financial accessibility and cultural and sports infrastructure. Contrastingly, indicators such as Nature, Agricultural Infrastructure, and Rural Productivity received lower final weights, reflecting both the relatively lower importance experts assigned to them and the limited variability in the data.

On the third tier, Medical Facilities was identified as the most important indicator, followed by Village Communities, Old Houses Rate, Childcare and Education Centers, Vacant Houses Rate, Commercial Facilities, Elderly Population Rate, Water and Sewerage Supply Rate, Population Growth Rate, and Road Network Rate. Among these, indicators such as Medical Facilities, Old Houses Rate, Water and Sewerage Supply Rate, and Childcare and Education Centers consistently ranked high in both the AHP and EWM, reinforcing their significance in the final weighting. These results emphasized that improving settlement conditions and supporting community capacity are central to peri-urban livability because they directly influence the quality of life of residents and simultaneously exhibit substantial regional disparities.

The lowest-ranked indicator was Fishery Production, followed by Dry Field Production, Special Crop Production, Library Supply Rate, Green Space Supply Rate, Park Supply Rate, Fruit Production, Paddy Production, Professional Sports Facilities, Livestock Production, and Village Rest Area. These lower-ranked indicators were concentrated in the first-tier domains of Local Economy and Production and Cultural Amenity and Leisure. The integration of expert judgment and data-based weighting thus indicates that in peri-urban livability vulnerability assessment, production-oriented and leisure-related factors are considered less critical than the settlement environment and community-related dimensions, which are directly tied to the quality of life of residents.

Accordingly, to allocate limited policy resources efficiently, priority should be given to improving residential conditions and community-based services and facilities rather than to investing in production infrastructure or leisure facilities.

3.5. Application of Final AHP–EWM Weights

Vulnerability indices for the 109 cities and counties included in the evaluation were calculated by applying the final weights to the derived indicator values. To facilitate comparative interpretation, the resulting indices were classified into five categories using equal interval ranking, with approximately 22 units assigned to each group. This procedure ensured a balanced distribution across the full range of scores and allowed for the relative positioning of regions according to their vulnerability levels. In Figure 3, higher ranks correspond to areas with lower vulnerability, and lower ranks denote areas with higher vulnerability.

Application of the final AHP–EWM weights revealed that regions such as Gokseong in Jeollanam-do, Yongin in Gyeonggi-do, and Pohang in Gyeongsangbuk-do ranked highly, reflecting relatively low vulnerability. Contrastingly, Asan in Chungcheongnam-do, Hongseong in Chungcheongbuk-do, and Changnyeong in Gyeongsangnam-do occupied lower positions, indicating higher levels of vulnerability. These lower-ranked areas, characterized by heightened vulnerability, provide empirical evidence supporting the need for national policies on balanced development and regional regeneration. High-vulnerability areas should be prioritized in policy implementation, particularly in initiatives aimed at improving residential environments, reinforcing healthcare and welfare infrastructure, and ensuring the provision of tailored forms of support for vulnerable peri-urban communities.

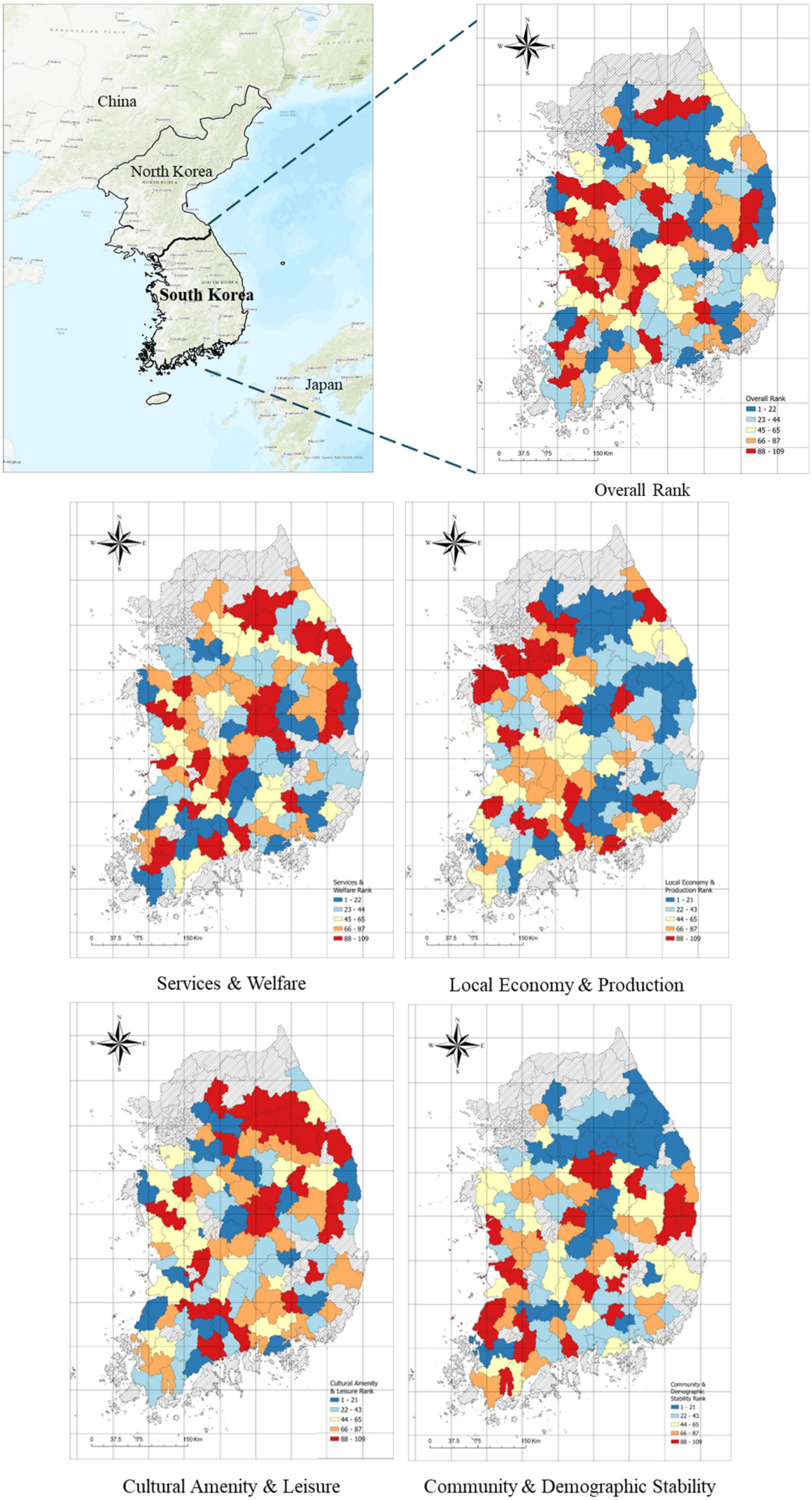


Figure 3. Spatial distribution of peri-urban livability vulnerability based on final AHP–EWM weights.

4. Discussion

4.1. Indicators Showing Differences Between the AHP and EWM

The weighting analysis revealed that the most significant discrepancies between methods were observed regarding indicators such as Disabled Welfare Facilities, Road Network Rate, Water and Sewerage Supply Rate, GRDP, and Agricultural Facilities (Table 6). These indicators showed substantial gaps in ranking between the AHP and EWM results, reflecting differences between expert perceptions and data-driven variability. Generally, such indicators were either regarded as important by experts but exhibited low variability in the data, or conversely, they displayed high variability but were assigned lower importance in expert judgment. Consequently, they were averaged in the integrated weighting scheme and appeared in the mid-range of the final weights. Together, these discrepancies illustrate the complementary nature of the AHP–EWM framework. This suggests that if either subjective or objective methods were applied in isolation, the importance of certain indicators could have been either overstated or understated, leading to biased and extreme evaluations. By integrating both approaches, the analysis achieves a more balanced weighting scheme that simultaneously reflects expert perceptions and data-driven variability.

Table 6. Comparison of the top ten indicators in AHP versus EWM analysis.

Rank	AHP		EWM	
	Indicator	**Weight**	**Indicator**	**Weight**
1	Village communities	0.0599	Medical Facilities	0.0658
2	Commercial Facilities	0.0494	Old Houses Rate	0.0640
3	Population Growth Rate	0.0494	Water and Sewerage Supply Rate	0.0630
4	Vacant Houses Rate	0.0466	Childcare and Education Centers	0.0559
5	Medical Facilities	0.0451	Road Network Rate	0.0558
6	Agricultural Facilities Supply	0.0423	Elderly Population Rate	0.0475
7	Health Institutions	0.0388	Village communities	0.0463
8	Social Economy Organizations	0.0381	Vacant Houses Rate	0.0377
9	Primary and Secondary Schools	0.0379	Financial Facilities	0.0351
10	Childcare and Education Centers	0.0369	Commercial Facilities	0.0348

The Disabled Welfare Facilities indicator ranked 38th in the AHP and 15th in the EWM, showing a substantial divergence. The experts assigned relatively low importance to this indicator, likely perceiving it as a secondary component of social welfare or as a supporting element within the broader healthcare infrastructure. Contrastingly, the EWM revealed significant regional disparities in the provision of disability welfare facilities, leading to higher weights based on entropy analysis. Given the hybrid urban–rural characteristic of peri-urban areas, where welfare services are often unevenly distributed, this indicator may exacerbate regional disparities in accessibility, inclusivity, and social integration. Therefore, future policy design should incorporate both the spatial distribution of the disabled population and regional accessibility to develop tailored strategies that address welfare infrastructure gaps more effectively [33,34].

Similarly, Road Network Rate ranked 31st in the AHP and 5th in the EWM. Experts tended to view road infrastructure as a precondition rather than a differentiating factor of rural vulnerability, resulting in lower subjective weights. However, the data analysis

highlighted pronounced disparities in road conditions, particularly in county-level and development-lagging regions where road density and pavement rates remained below average. This pattern may reflect structural limitations in regions with slower development or geographical constraints, but at the same time, it underscores the need to reinterpret road infrastructure as a key element in shaping peri-urban vulnerability. Roads serve not only as transportation channels but also as essential routes for the flow of services and resources. In geographically disadvantaged or underdeveloped areas, these infrastructural disparities play a particularly critical role in determining accessibility to social services, emergency response systems, and overall spatial equity [35–37].

Water and Sewerage Supply Rate ranked 24th in the AHP and 3rd in the EWM, again reflecting the gap between expert perceptions and data-based variability. Experts regarded this indicator as a largely resolved infrastructure problem given nationwide improvements in supply coverage. However, the EWM results highlighted persistent disparities, particularly in peri-urban regions characterized by fragmented settlement structures, low population density, aging housing, and fiscal constraints. These factors impose structural limitations on the provision of water infrastructure and exacerbate vulnerabilities [38–40]. Therefore, although water and sewerage infrastructure tends to be treated as a basic facility that has already been sufficiently secured through nationwide expansion, unequal accessibility persists across regions. In areas with low population density and dispersed settlements, infrastructure expansion is structurally constrained by aging housing stock and fiscal limitations. These disparities can have long-term impacts on overall living environments, underscoring the need for policy responses that explicitly reflect data-based evaluations rather than relying solely on generalized assumptions about infrastructure coverage.

Contrastingly, GRDP ranked 13th in the AHP and 39th in the EWM. Experts perceived GRDP as a critical indicator of regional autonomy and resilience and assigned it high importance. However, the EWM results showed low variability across regions, reflecting a homogenized fiscal structure and high dependence of the central government on Korean localities. Although the GRDP may not serve as a discriminating factor in data-driven analyses, it remains crucial for policy decision-making because it signals limitations in local fiscal autonomy and adaptability [41,42]. This discrepancy highlights the symbolic meaning of fiscal indicators relative to their empirical distribution. While GRDP may not provide strong discriminatory power in data-driven analysis, it remains a critical policy indicator, signaling constraints in local fiscal autonomy and adaptive capacity. Consequently, the interpretation and use of fiscal indicators require a more nuanced and policy-sensitive approach.

Finally, Agricultural Facilities ranked 6th in AHP and 34th in EWM, thus emerging as one of the most divergent indicators. Peri-urban agriculture refers to agricultural practices occurring in peri-urban areas—zones that exhibit both urban and rural characteristics. Recent studies have increasingly highlighted the potential of urban and peri-urban agriculture and forestry in poverty alleviation and mitigating vulnerabilities associated with climate change. Experts emphasized the critical role of agricultural infrastructure in enhancing the resilience of urban peripheries and linked it to productivity, resource security, and long-term sustainability. Conversely, the EWM assigned it a lower weight owing to reduced variability stemming from nationwide policy initiatives such as farm equipment subsidies and mechanization programs that have mitigated regional disparities. Moreover, the increasingly diversified economic base of peri-urban areas has reduced reliance on agricultural infrastructure as the sole determinant of vulnerability [10,28,40–42]. This finding suggests that traditional agriculture-centered policy approaches may no longer be sufficient for effectively explaining or mitigating peri-urban vulnerabilities. As economic

bases diversify and infrastructural disparities shrink, policy design must be reoriented to address new functional roles and multilayered demands within peri-urban areas.

Together, these discrepancies illustrate the complementary nature of the components of the AHP–EWM framework. Although the experts emphasized structural and functional elements as central to long-term sustainability, the data-driven analysis revealed acute disparities in basic infrastructure and service provision. Integrating both perspectives ensures a more balanced and comprehensive assessment of peri-urban vulnerability.

4.2. Indicators Consistently Ranked as Important in AHP and EWM

The final weighting results indicated that Medical Facilities, Old Houses Rate, Childcare and Education Centers, Water and Sewerage Supply Rate, and Village Communities consistently ranked among the top indicators that were assigned high weights in both the AHP and EWM analyses. This outcome reflects the convergence of expert perceptions that emphasized the fundamental importance of the settlement environment for the quality of life of residents and highlighted empirical evidence of large disparities in distribution across regions.

Between 2015 and 2022, the number of medical institutions located in rural areas (Rural Living Infrastructure Supply Rate) steadily increased, according to Statistics Korea [43]. Nevertheless, You et al. [44] found that the distribution of medical facilities within Jeollabuk-do varied significantly, and such disparities were strongly correlated with the inflow and settlement of young populations (r = 0.903, $p < 0.05$) [44]. These regional disparities in healthcare facilities likely influenced the entropy-based weighting outcomes. Access to medical infrastructure in peri-urban areas has been empirically confirmed as a key determinant of health status [45]. The experts who participated in this study recognized healthcare access as a core component of vulnerability; consequently, the AHP analysis assigned high importance to this indicator, resulting in Medical Facilities consistently ranking at the top of the final weighting.

Experts have also emphasized that social networks and levels of community participation constitute essential elements of local resilience and are often perceived as more effective at mitigating outmigration than physical infrastructure [46–48]. Reflecting this view, the Korean government has supported various initiatives such as the Village-Making Project, the Rural Pact, and the Rural Center Revitalization Program, which promote community-based development driven by resident participation. However, challenges such as the absence of capable operating bodies, lack of organizational capacity, and concentration of responsibility on a small number of activists have often led to the underutilization of facilities and symbolic participation [49]. The data used in this study captured these disparities in the level of community engagement, which contributed to the variability reflected in the weighting of the outcomes.

In peri-urban areas, ongoing population decline and demographic aging have intensified the prevalence of old and vacant housing, which is emerging as a pressing social issue. Vacant houses are directly associated with sanitation, safety, and landscape concerns. Additionally, they increase the risk of crime, fire, and structural collapse, thereby undermining local identity and accelerating depopulation [50]. Experts have recognized that failure to address vacant housing could rapidly deteriorate local livability. Consequently, they assigned high weights to the Vacant Houses Rate in the AHP analysis. In response, the Ministry of Health and Welfare and the central government introduced initiatives such as the Old Housing Renovation Project and the Vacant House Regeneration Program, alongside the enactment of the Rural Space Restructuring Act and the mobilization of policy loans to support rural resettlement. Nevertheless, substantial regional disparities

persist owing to differences in geographic location and levels of economic activity, which were subsequently reflected in data variability [51].

Commercial facilities are essential nodes for improving the convenience residents enjoy, strengthening local economic capacity, and providing key service infrastructure. In the rural context, they also function as crucial social spaces for mitigating isolation among the aging population [52,53]. Previous studies have highlighted the close linkage of the accessibility and qualitative improvement of commercial facilities with life satisfaction among residents [52]. Consequently, the experts who participated in this study identified Commercial Facilities as a core factor in peri-urban livability assessments. However, unlike urban centers, rural and peri-urban areas often lack systematic standards for land use and spatial allocation, leading to an unbalanced distribution of essential amenities such as commercial infrastructure [54]. This spatial imbalance was reflected in the quantitative analysis, in which data variability resulted in high weights for Commercial Facilities within the EWM framework.

Childcare and education centers were also found to be directly associated with the stability of settlement environments, with their absence significantly contributing to out-migration and the long-term risk of regional extinction [55,56]. Empirical studies have reported that children in rural areas demonstrate lower levels of language development than their urban counterparts, highlighting the urgent need for both quantitative and qualitative improvements in childcare and educational services [57]. Accessibility has been identified as the most critical factor in parental decision-making, and surveys have consistently found lower satisfaction with childcare environments and a greater burden placed on rural parents [58]. Thus, experts have come to regard Childcare and Education Centers as indispensable for strengthening settlement bases and sustaining population levels in peri-urban regions. Despite initiatives such as the Rural Childcare Service Program and the Rural Childcare Support Project, which the Ministry of Agriculture, Food, and Rural Affairs has implemented, recent findings have indicated that disparities between urban and rural childcare environments are widening, even with quantitative increases in public childcare facilities [59].

4.3. International Comparison and Policy Implications

Findings reveal that peri-urban areas emerge as transitional yet vulnerable spaces where structural decline is shaped less by constraints on production or economic activity than by deficiencies in social infrastructure, housing stability, and community cohesion, including the availability of healthcare facilities and childcare and educational services, existence of village communities, and prevalence of aging housing. These results are not confined to the Korean context but resonate internationally. Previous studies on peri-urban regions in Iran have similarly revealed that livability is primarily determined by health, education, housing-related services, and community-based resilience rather than by purely economic factors [60–62]. Additionally, expert assessments of peri-urban viability and resilience in Kazakhstan identified social infrastructure—such as transport and service accessibility—and demographic structures as critical determinants, in close alignment with the findings of this study [63]. Together, these international cases have consistently demonstrated that social infrastructure factors, including healthcare, education, housing, and community stability, govern peri-urban vulnerability. In this regard, the present study complements existing research by addressing methodological gaps through a comprehensive evaluation of peri-urban vulnerabilities from objective and subjective perspectives. Moreover, the results suggest that the analytical framework can be extended beyond the Korean context to serve as a universally applicable tool for prioritizing policy interventions and validating their appropriateness.

5. Conclusions

Peri-urban areas, which account for over half of the administrative units in Korea, continue to face persistent vulnerabilities driven by population aging, youth outmigration, and unequal access to essential services. This study aimed to diagnose vulnerabilities and establish a scientifically grounded framework for policy prioritization by integrating the AHP with EWM. The study sought to evaluate its applicability at the national scale and contribute to advancing theoretical discussions about how subjective and objective assessments converge or diverge when shaping our understanding of peri-urban livability. The analysis revealed that medical facilities, childcare and education centers, village communities, and the old houses rate consistently ranked highly across both methods, thereby confirming their role as the core determinants of peri-urban vulnerability. This outcome suggests that social infrastructure and community stability rather than production- or economy-oriented factors play a central role in shaping peri-urban living conditions and regional sustainability. At the aggregate level, services and welfare emerged as the most critical domain, followed by community and demographic stability, local economy and production, and cultural amenity and leisure. Beyond peri-urban livability vulnerability assessment, the integrated AHP–EWM framework proposed in this study has broader methodological and practical applicability. For example, it can be utilized to integrate expert and user perspectives with empirical data in various fields such as urban design, ecosystem service evaluation, and disaster risk assessment. Moreover, by combining residents' perceptions with administrative statistics, this framework can be applied as a tool for verifying the real-world impacts of policies after implementation, demonstrating its potential as a versatile decision-support mechanism across different spatial and policy contexts.

Nevertheless, this study had several limitations. Indicators that exhibited large discrepancies between methods were averaged in the final weighting process, which may have obscured policy implications by diluting the distinctive outcomes of the subjective and objective approaches. Furthermore, some indicators that the experts perceived as highly important may have already been improved through policy interventions, thereby exposing a gap between expert judgment and on-the-ground realities. Importantly, the analysis relied primarily on static data, not because dynamic information was unavailable but because national-scale panel data remain limited; consequently, temporal changes could not be sufficiently reflected. Future research may adopt time-series analyses to capture long-term trajectories and cyclical variations, thus allowing for more adaptive and forward-looking policy responses. Moreover, because this study set the weighting adjustment coefficient (α) at 0.5 to equally balance the subjective and objective approaches for analytical simplicity rather than to achieve empirical validation, future work should explicitly test the sensitivity of results to varying α values to improve methodological robustness and ensure that policy implications are not unduly shaped by an arbitrary coefficient. Additionally, this study incorporated spatial and geographical factors—such as topographical variation and the spatial distribution patterns of urban and rural settlements—to a limited extent. This limitation may influence the applicability of the proposed framework to guiding region-specific policy implementation and prioritization. To address this gap, future research could explore how geographically specific factors can be systematically integrated into regional policy planning. The alignment of policy responses with the physical and socio-spatial characteristics of local areas would complement national-level assessment and support the conceptualization of more nuanced, context-sensitive strategies for enhancing peri-urban resilience and sustainability.

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Abbreviations

The following abbreviations are used in this manuscript:

AHP	Analytic hierarchy process
CI	Consistency index
CR	Consistency ratio
EWM	Entropy weight method
GRDP	Gross regional domestic product

Appendix A

Table A1. Vulnerability diagnostic indicators.

Category	Detailed Indicator	Symbol	Indicator Formula
Services and Welfare (Living area)			
Settlement Environment	Old Houses Rate	S1	Houses over 20 years old/Total number of houses × 100
	Vacant Houses Rate	S2	No. of vacant houses/Total number of houses × 100
	Commercial Facilities	S3	No. of commercial facilities/Population × 100
	Financial Facilities	S4	No. of financial institutions/Population × 100
Welfare and Healthcare	Disabled Welfare Facilities	S5	No. of facilities for people with disabilities/Population with disabilities × 100
	Senior Welfare Facilities	S6	No. of senior welfare facilities/Population over 65 × 100
	Medical Facilities	S7	No. of hospitals, clinics, emergency medical facilities/Population × 100
	Health Institutions	S8	No. of health institutions/Population × 100
Childcare and Education	Childcare and Education Centers	S9	No. of childcare and education institutions/Child population × 100
	Primary and Secondary Schools	S10	No. of primary and secondary schools/Student population × 100
Infrastructure	Road Network Rate	S11	Road extension/Area × 100
	Public Transportation Rate	S12	No. of bus stops/Area × 100
	Water and Sewerage Supply Rate	S13	Water and sewerage supply rate
Safety and Health	Police Station Ratio	S14	No. of police stations/Population × 100
	Fire Station Ratio	S15	No. of fire stations/Population × 100
	Public Administrative Infrastructure	S16	No. of public servants/Population × 100
Local Economy and Production (Production area)			
Financial	GRDP	E1	GRDP
	Fiscal Independence Rate	E2	Financial independence rate

Table A1. *Cont.*

Category	Detailed Indicator	Symbol	Indicator Formula
Rural Productivity	Special Crop Production	E3	Special crop production/Area × 100
	Paddy Production	E4	Paddy production/Area × 100
	Dry Field Production	E5	Dry field production/Area × 100
	Fruit Production	E6	Fruit production/Area × 100
	Fishery Production	E7	Fishery production/Area × 100
	Livestock Production	E8	Livestock production/Area × 100
Agricultural Infrastructure	Agricultural Facilities Supply	E9	Benefited area of agricultural production facilities/Agricultural area × 100
	Agricultural Machinery Supply	E10	Households with agricultural machinery/No. of agricultural households × 100
Cultural Amenity and Leisure (Rest area)			
Culture and Sport	Cultural Facilities	A1	No. of cultural facilities/Population × 100
	Library Supply Rate	A2	No. of libraries/Population × 100
	Tourist Attractions	A3	No. of historical and cultural spaces/Population × 100
	Professional Sports Facilities	A4	No. of professional sports facilities/Population × 100
	Public Sports Facilities	A5	No. of public sports facilities/Population × 100
Nature	Park Supply Rate	A6	Park area/Population × 100
	Green Space Supply Rate	A7	Green space area/Population × 100
	Village Rest Area	A8	No. of walking paths village + rest area/Population × 100
Community and Demographic Stability (Community area)			
Population	Population Density	D1	Population/Area × 100
	Population Growth Rate	D2	Population growth rate
	Elderly Population Rate	D3	Population over 65 years/Total population × 100
Community	Social Economy Organizations	D4	No. of villages, social enterprises, and cooperatives × 100
	Village Communities	D5	No. of villages with community activities/Total administrative villages × 100
	Number of Village Halls	D6	No. of village halls/Population × 100

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