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Research Article

Analysis of the Potential for a Hillside Collapse for a Community in Changhua County, Taiwan

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To create communities that are resistant to disasters, public disaster prevention and response must be reinforced by promoting disaster prevention and knowledge and technology to ensure an adequate response through public participation. Promoting disaster prevention measures reduces the number of factors in communities that pertain to disasters. Changhua County contains 589 villages, 81 of which are prone to hillsides (including protected forest). In addition to original potential debris flow torrent communities, disaster-resistant communities have been established under the guidance of Soil and Water Conservation Bureau (SWCB), Council of Agriculture in Taiwan; Changhua County Government also plans to establish disaster-resistant communities in other hillside communities. This study proposes an expert questionnaire to determine the potential for a hillside disaster and uses an analytical hierarchy process (AHP) and an analytical network process (ANP) to determine the weights of factors that pertain to potential disasters in hillside communities so that these communities can become resistant to disasters.

1. Introduction

Disaster-resistant communities have been actively promoted in various countries, with an emphasis on residents' interaction and participation to encourage disaster prevention with the aim of promoting a national disaster prevention program. Disaster-resistant communities have been promoted with top-down project guidance and budgetary and talent input or disaster risk information. The evaluation of the practices that are required for a disaster-resistant community project or the cost and benefit analysis in terms of input and output is a matter for continued study. The evaluation criteria for the effectiveness of a disaster-resistant community are determined in this study. Hillside communities with a disaster resistance policy are studied. Using governmental education and disaster prevention wargaming, villages with potential hazards in Changhua County, Taiwan, are classified in terms of awareness of disaster prevention and the response to disasters.

A disaster-resistant community integrates government and community resources to establish a community disaster prevention system [1]. Communities also utilize existing resources to increase their ability to help themselves after disasters, using disaster reduction and prevention methods to reduce the impact of disasters on their communities. The Taiwanese government has a strategy to "practice the community disaster prevention system, promoting community disaster prevention, guiding communities to establish disaster prevention concepts, and organizing civil rescue teams to cultivate the disaster emergency response ability" in the interests of community security.

In addition to relevant theories and literature [2–6], a questionnaire survey and a case study are used. Using theory and practice, the results on disaster potential, historical experience with disasters, community vitality, and residents' willingness to cooperate are used to determine the factors that affect disasters in various regions. An overlay map of hillside areas (Figure 1) that are under Soil and Water

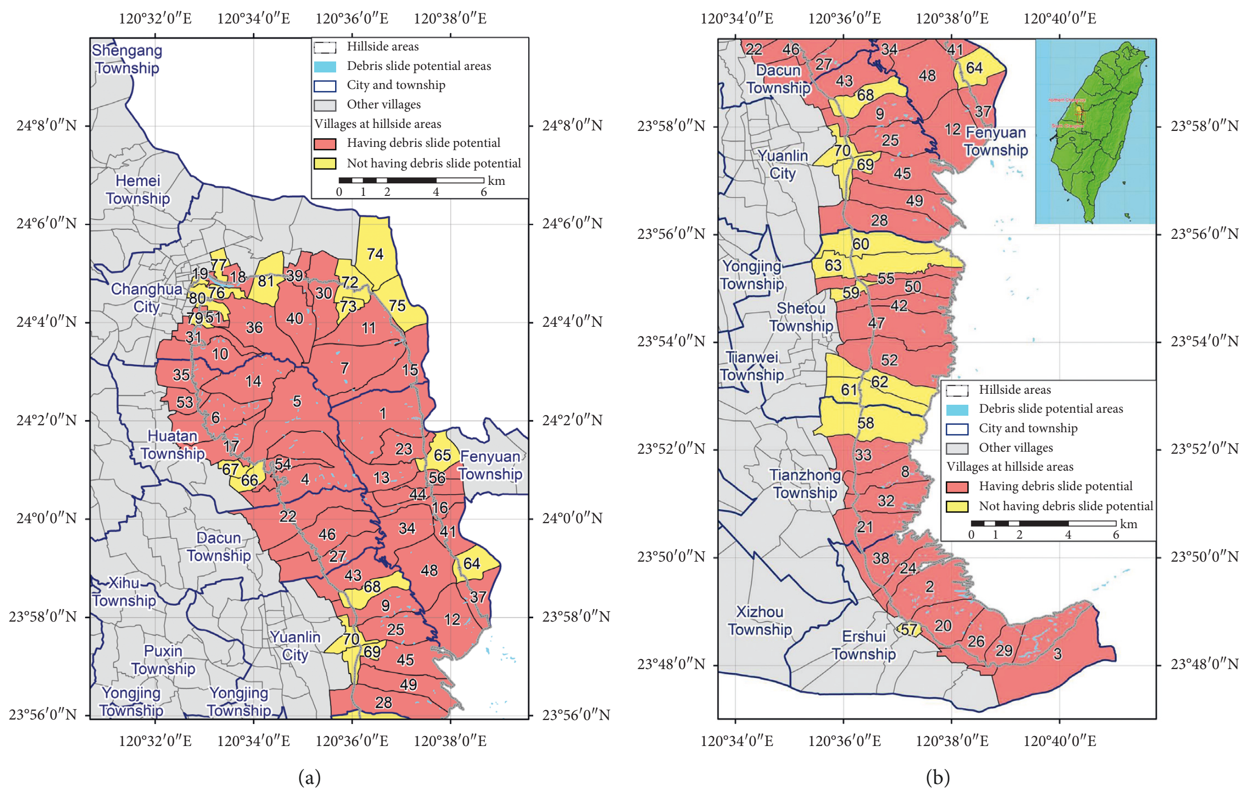


Figure 1: Distribution map for hillside villages in Changhua County: (a) northern Changhua; (b) southern Changhua.

Conservation Bureau's jurisdiction and Changhua County administrative areas shows that 81 of 589 villages in Changhua County are prone to hillsides (including protected forest) [7]. The map for potential hillside disasters from the National Science and Technology Center for Disaster Reduction (NCDR) [8] shows that four types of hillside disasters are possible: rock fall, debris slide, rock slide, and dip gradient. The results show that only debris slide is relevant to Changhua County.

Using an expert questionnaire survey, the evaluation items and factors for hillside communities are classified, and "potential," "hazard," and "vulnerability" are the key elements that are used to determine the disaster potential for a community. For hillside villages with hillside disaster potential, the locations where there is potential for a hillside disaster, and roads and built-up areas (including public facilities) that have a potential for a disaster, the factors are identified and their weights are summed [9, 10] to determine the potential for a hillside disaster. The disaster potentials are used to determine the hillside communities that are disaster resistant. This allows the Changhua County Government to establish hillside disaster-resistant communities.

2. Research Methods

Using data collection and an analysis of the relevant literature [4, 11–16], the evaluation factors are ranked after the interview. An analytical hierarchy process (AHP) and an analytical network process (ANP) are used to determine the weights for disaster potential for disaster-resistant communities on hillsides. The ANP, which is an extension of the AHP, adds feedback to the AHP to predict the internal relationships between all criteria, objectives, and projects using ratio scales, to allow robust decision-making processes [2, 17–20].

2.1. Analytical Hierarchy Process (AHP). The AHP was developed by Saaty [21, 22] to allow decisions involving several evaluation criteria and simplify complex problems. It is used to determine priority, in terms of resource planning, allocation, prediction, and investment. The theory of the AHP is clear and simple and uses the opinions of several experts and decision-makers. It is broadly used in academia and in practical applications [10, 23–27].

2.2. Analytical Network Process (ANP). The ANP is a decision-making method that uses a nondependent hierarchical structure, as proposed by Professor Saaty of the University of Pittsburgh in 1996 [28]. It is a decision-making method that uses an AHP. It incorporates dependency and feedback (including intracluster and intercluster interaction and feedback) into the ANP. The ANP adds feedback to the AHP and uses a hypermatrix to calculate dependent effects. The ANP is also a multiobjective decision-making method that is used in economic, social, and management sciences. It gives decision-makers a deep understanding of issues using several evaluation factors to resolve complicated decision-making problems [15, 20, 29–33].

2.3. Design of the Expert Questionnaire. Disasters in hillside communities include rock fall, debris slide, rock slide, and dip gradient. Several factors are analyzed, and literature examples [7, 8] are used to design an expert questionnaire to determine the potential for disasters in hillside disaster-resistant communities.

The disasters in hillside communities are classified as “potential,” “hazard,” and “vulnerability,” where “potential” refers to the possibility of a disaster, “hazard” refers to the scale of a disaster, and “vulnerability” represents the possibility of secured objects suffering from disasters. The evaluation factors for hillside disaster potentials are shown in Table 1, and the hierarchical structure is shown in Table 2.

3. Results and Discussion

3.1. Results of the Expert Questionnaire Survey. The questionnaire survey was divided into two stages for clarifying the relationship among the factors in Table 2. In the first stage, the expert questionnaire determines the relative importance of evaluation factors for hillside disaster potential analysis. A scale of 0–10 is used; a higher score represents greater importance. The results could become the reference for expert evaluations in the second stage. The relative importance of evaluation items is evaluated to determine the hierarchical structure matrix for the AHP and ANP.

Nine questionnaires were returned from experts and village leaders. The background of the experts is shown in Table 3. One teaches in an academic institution, five are technicians or architects, one serves in a private enterprise, and two are local village leaders.

In the second stage, the experts compared the relative importance of the paired factors for the comparison matrices in various hierarchies, as shown in Table 4. Other comparison matrices are similarly designed using the same structure (see Table 4) for their questionnaire. According to the AHP, the pair comparison should satisfy the transitivity of preference and strength. Nevertheless, the actual evaluation could hardly satisfy such a hypothesis. Saaty [21, 22] therefore considered consistency tests for pair evaluation, including the steps of calculating Consistency Index (CI) and Consistency Ratio (CR). Saaty [21] regarded the comparison being randomly generated when CR approached 1 and the consistency being higher when CR approached 0. In general, $CR \leq 0.1$ was considered acceptable, while $CR > 0.1$ showed the inconsistency that they had to be recompared. After calculating the weight among factors in the hierarchies, the weight of the overall hierarchy should also be calculated.

The results of the expert questionnaire are used to compare the relative importance of paired factors to produce a comparison matrix, which is shown in Tables 5–8. The relative weights for “potential,” “hazard,” and “vulnerability” in Hierarchy 2 are compared to allow the experts to determine the relative importance, and then the geometric mean is calculated.

The relative weights for the evaluation items in Hierarchy 2 are multiplied by the relative weights of factors in Hierarchy 3 in Tables 6–8 to determine the weights of the factors. This information is shown in Table 9. Tables 6–8 show that an average hillside has the highest weight for “potential,” “potential debris flow torrent coverage” has the highest weight for “hazard,” and “disaster prevention education or practice” has the highest weight for “vulnerability.” In this case, the hierarchical analysis of the expert questionnaire, in terms of the weights, is used to select major evaluation items for the analysis of the potential for disasters for a hillside disaster-resistant community and to compare with the average importance of factors for experts. The AHP is then used to produce the weight (see Table 9).

Table 1: Evaluation items for hillside disaster-resistant communities.

Item	Description
A: potential	Possibility of disaster occurrence
B: hazard	Scale of disasters
C: vulnerability	Possibility of secured objects suffering from disasters

Since the calculations for the ANP are complicated, Super Decisions software is used in this study to produce an unweighted hypermatrix and a weighted hypermatrix. These two matrices are multiplied by the dependent convergence to determine the relative weight between factors. The result of the ANP is shown in Table 9. The comparison with the AHP is shown in Figure 2. The comparison between the AHP and the ANP shows that both are similar. However, the average difference between the AHP and the ANP is less than 2%. The difference may be caused by the ANP which considers the connection of Hierarchy 2 such as A: potential and B: hazard. Since the ANP is an expansion of the AHP, it more accurately reflects the real weights of factors, so the ANP is considered a better choice for the overlay analysis of the geographic information system (GIS) [34–36].

In this study, three aspects “potential,” “hazard,” and “vulnerability” are proposed for the disasters in hillside communities. It is expected that “potential” refers to the possibility of a disaster, “hazard” refers to the scale of a disaster, and “vulnerability” represents the possibility of secured objects suffering from disasters. AHP results showed that the weights of “potential,” “hazard,” and “vulnerability” are 29.98%, 36.99%, and 33.03%, respectively. “Hazard” is the most important factor according to the experts’ decision, and “vulnerability” is the second. However, they are all very close, so it is also indicated that the assumption of these three aspects is reasonable and they are almost equally important. Based on these three aspects, the next step of analysis will not cause any bias nor focus on specific items of the assessment.

3.2. GIS Overlay. The sources of basic GIS data, including the terrain and administrative area boundary, come from the open data platform of the Ministry of the Interior, Taiwan. The debris slide map was provided by the NCDR [8], and it offered the detailed information on rock fall, debris slide, rock slide, and dip gradient. The debris flow potential and

Table 2: Hierarchical structure for hillside disaster-resistant communities.

Hierarchy 1: objective	Hierarchy 2: evaluation item	Hierarchy 3: factor
Hillside disaster-resistant community disaster potential analysis	A: potential[1]	A-1: average hillside gradient
		A-2: debris slide potentials
		A-3: potential debris flow torrent
	B: hazard[2]	B-1: major historical disasters
		B-2: total area of debris slide
		B-3: potential debris flow torrent coverage
	C: vulnerability[3]	C-1: type to affect secured objects
		C-2: establishment of the hillside disaster-resistant community
		C-3: disaster prevention education or practice

[1]To establish "evaluation factors for hillside disaster-resistant communities," factors for potential are explained: A-1: average gradient (%) for various villages; A-2: possibility of debris slide being weathered soil, detritus, colluvium, or soft and broken geological avalanche or sliding; A-3: possibility of debris flow surrounding rivers. [2]To establish "evaluation factors for hillside disaster-resistant communities," factors for hazards are explained: B-1: major disasters that occurred in the community in the past years; B-2: debris slide coverage in villages; B-3: debris flow coverage surrounding rivers. [3]To establish "evaluation factors for hillside disaster-resistant communities," factors for vulnerability are explained: C-1: type of disaster that affects local people; C-2: the establishment and operation of relevant hillside disaster-resistant communities; C-3: disaster prevention education or practice in communities.

Table 3: Background of the experts involved with the expert questionnaire.

No.	Specialty	Working department property	Seniority
Expert 1	Soil and water conservation	Technician or architect	More than 10 years
Expert 2	Civil and hydraulic engineering	Private enterprise	Within 2 years
Expert 3	Civil and hydraulic engineering	Technician or architect	More than 10 years
Expert 4	Soil and water conservation	Technician or architect	More than 10 years
Expert 5	Architecture	Technician or architect	More than 10 years
Expert 6	Architecture	Academic institution	More than 10 years
Expert 7	Urban plan, architecture, community development	Technician or architect	More than 10 years
Expert 8	Landscape, environment, community development	Village head	5~10 years
Expert 9	Landscape, environment	Village head	5~10 years

Table 4: Questionnaire example of pair comparison in the AHP.

More important in the left event	Importance									More important in the right event
	Absolutely important 9 : 1	Extremely important 7 : 1	Quite important 5 : 1	Slightly important 3 : 1	Equally important 1 : 1	Slightly important 1 : 3	Quite important 1 : 5	Extremely important 1 : 7	Absolutely important 1 : 9	
A: potential										B: hazard
A: potential										C: vulnerability
B: hazard										C: vulnerability

Table 5: Relative importance of the evaluation items.

Item	A: potential	B: hazard	C: vulnerability	Weight
A: potential	1	0.6861	1.0717	0.2998
B: hazard	1.4573	1	0.9479	0.3699
C: vulnerability	0.9330	1.0548	1	0.3303

Maximum eigenvalue = 3.0278; CI = 0.0139; CR = 0.0239.

influence areas including community residents and activities are from SWCB and Changhua County Government [7].

Figure 3(a) shows the average gradient (%) for each village. Each gradient is divided into a first-grade gradient (<5%), a second-grade gradient (5–10%), a third-grade gradient (10–15%), a fourth-grade gradient (15–20%), and a fifth-grade gradient (>20%). These, respectively, receive 2, 4, 6, 8, and 10 points.

Table 6: Relative importance of factors for "A: potential."

Factor	A-1: average hillside gradient	A-2: debris slide potential river	A-3: potential debris flow torrent	Weight
A-1: average hillside gradient	1	1.2406	1.2032	0.3752
A-2: debris slide potential river	0.8060	1	0.5834	0.2553
A-3: potential debris flow torrent	0.8310	1.7139	1	0.3695

Maximum eigenvalue = 3.0288; CI = 0.0144; CR = 0.0248.

Table 7: Relative importance of factors for "B: hazard."

Factor	B-1: major historical disaster	B-2: total debris slide area	B-3: potential debris flow torrent area	Weight
B-1: major historical disaster	1	1.7395	0.8378	0.321
B-2: total debris slide area	0.9049	1	0.6550	0.2767
B-3: potential debris flow torrent area	1.1935	1.5266	1	0.4023

Maximum eigenvalue = 3.0024; CI = 0.0012; CR = 0.0021.

Table 8: Relative importance of factors for "C: vulnerability."

Factor	C-1: affecting secured objects	C-2: establishment of the hillside disaster-resistant community	C-3: disaster prevention education or practice	Weight
C-1: affecting secured objects	1	1.4244	0.9049	0.3568
C-2: establishment of the hillside disaster-resistant community	0.7020	1	0.6550	0.253
C-3: disaster prevention education or practice	1.1050	1.5266	1	0.3902

Maximum eigenvalue = 3.0001; CI = $5.1981E-5$; CR = $8.9622E-5$.

Table 9: Weights of evaluation factors using the AHP and ANP.

Evaluation item	Evaluation factor	Weight	
		AHP (%)	ANP (%)
A: potential	A-1: average hillside gradient	11.24	9.42
	A-2: debris slide potential river	7.65	10.38
	A-3: potential debris flow torrent	11.07	13.39
B: hazard	B-1: major historical disaster	11.87	9.69
	B-2: total debris slide area	10.24	10.19
	B-3: potential debris flow torrent area	14.88	12.73
C: vulnerability	C-1: effect on secured objects	11.79	13.78
	C-2: establishment of the hillside disaster-resistant community	8.36	5.81
	C-3: disaster prevention education or practice	12.89	14.61

The debris slide map provided by the NCDR is used to analyze Figure 3(b). Among the 81 hillside villages in Changhua County, there are 56 villages with the potential slide areas. The maximum number in a village is 33, and the average of all is 7.07. Potential slide areas in villages are awarded 10 points for "the number of potential slide areas >15 in a village," 8 points for "the number between 11 and 14," 6 points for "the number between 8 and 10," 4 points for "the number between 4 and 7," 2 points for "the number between 1 and 3," and 0 for those without collapse.

In terms of the debris flow potential stream in Figure 3(c), 10 points are awarded for a high-potential debris flow in a village, 7 points for a medium-potential debris flow, and 4 points for a low-potential debris flow, according to the level of the debris flow potential that is evaluated by the Soil and Water Conservation Bureau (SWCB) in Taiwan. Those areas with potential debris flow score 0. A total of 7 villages have potential for debris flow, and they are at the same level by the classification of SWCB. In order to highlight the importance of debris flow disasters, this study gives 10 points for these 7 villages.

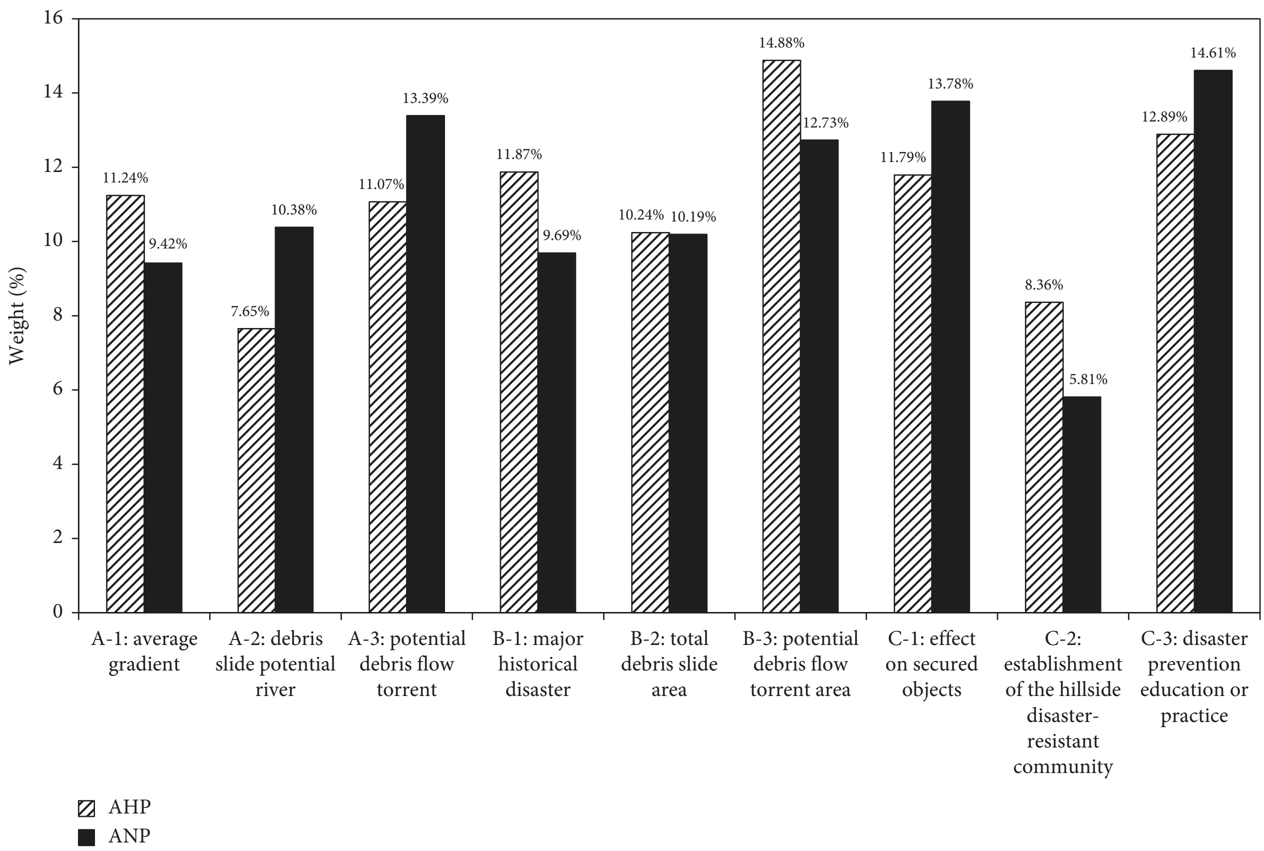
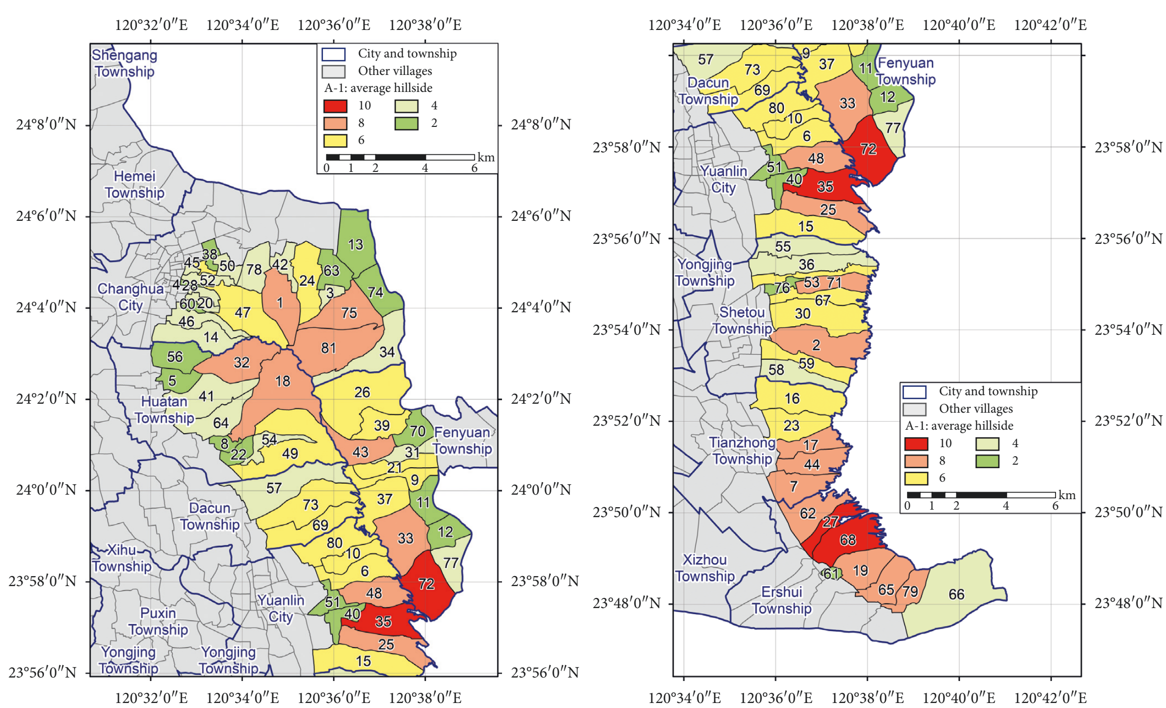
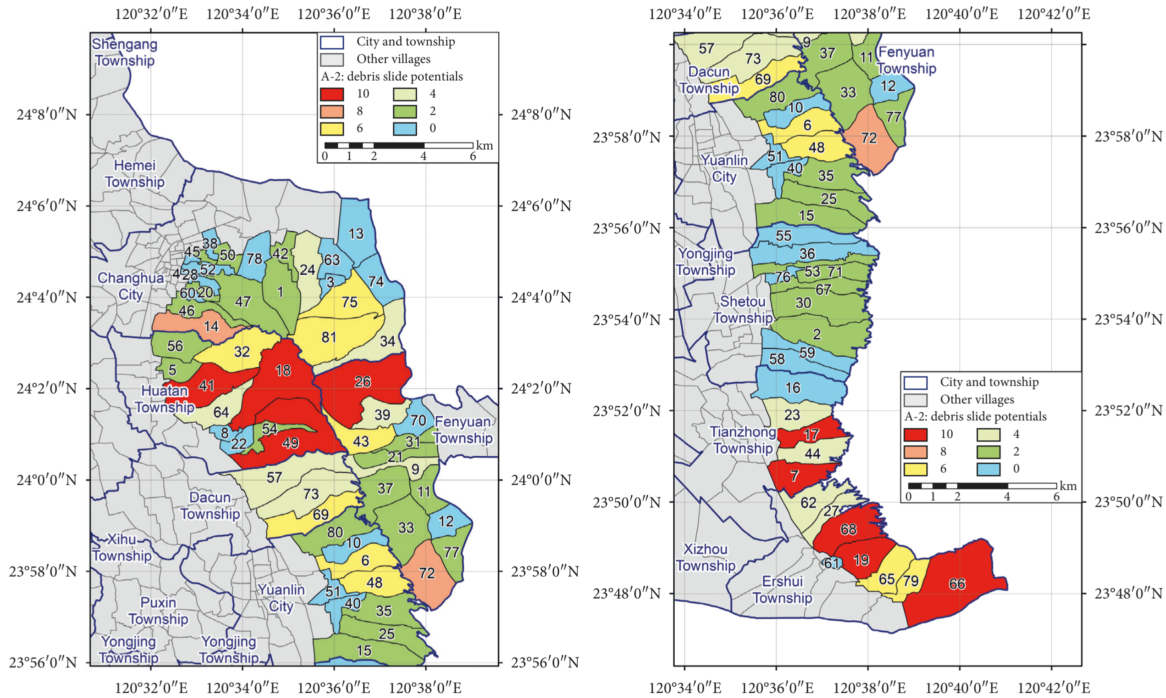


Figure 2: Comparison between the AHP and the ANP.



(a)

Figure 3: Continued.



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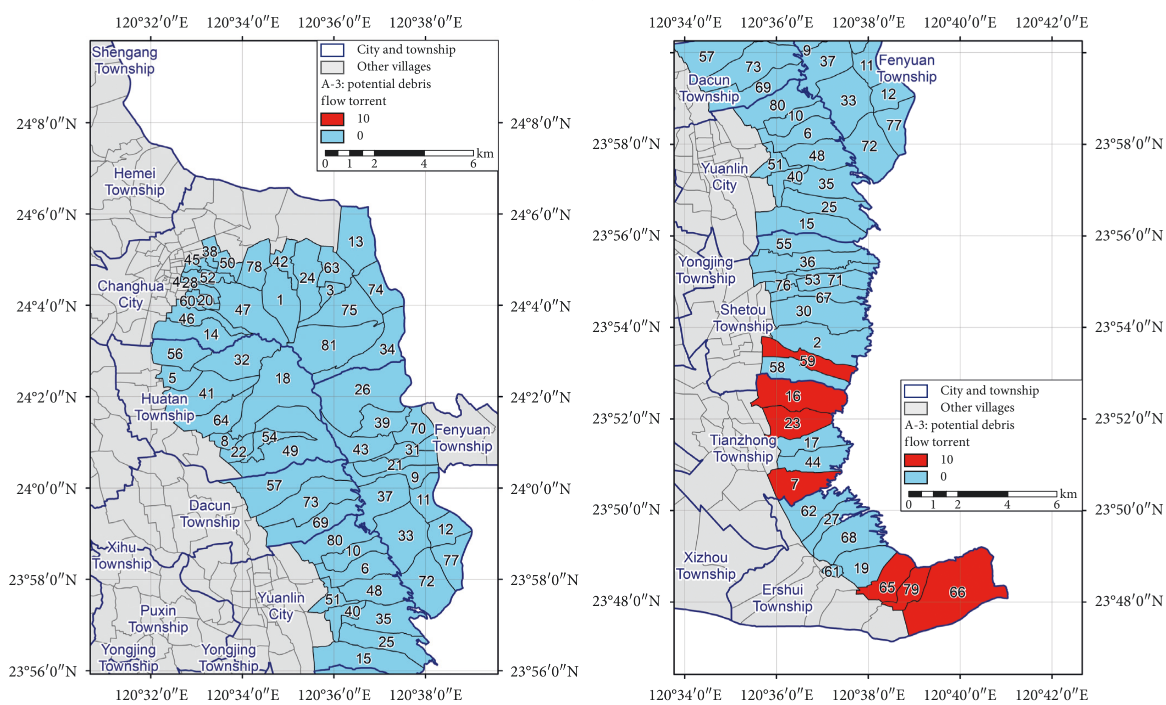
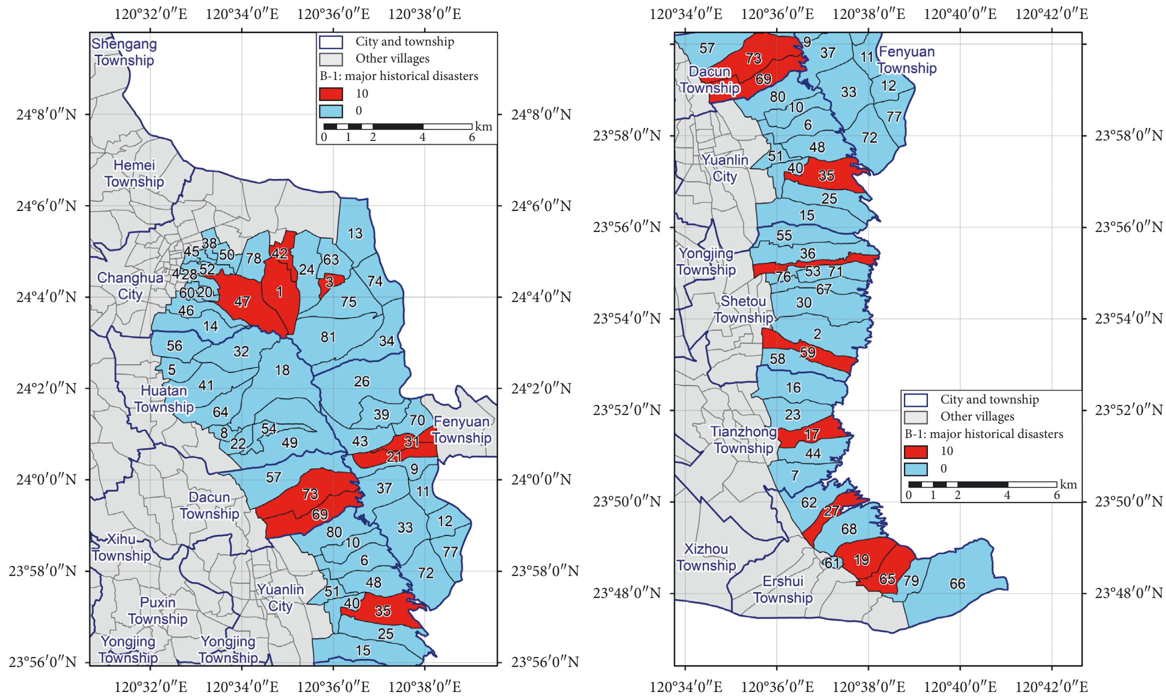
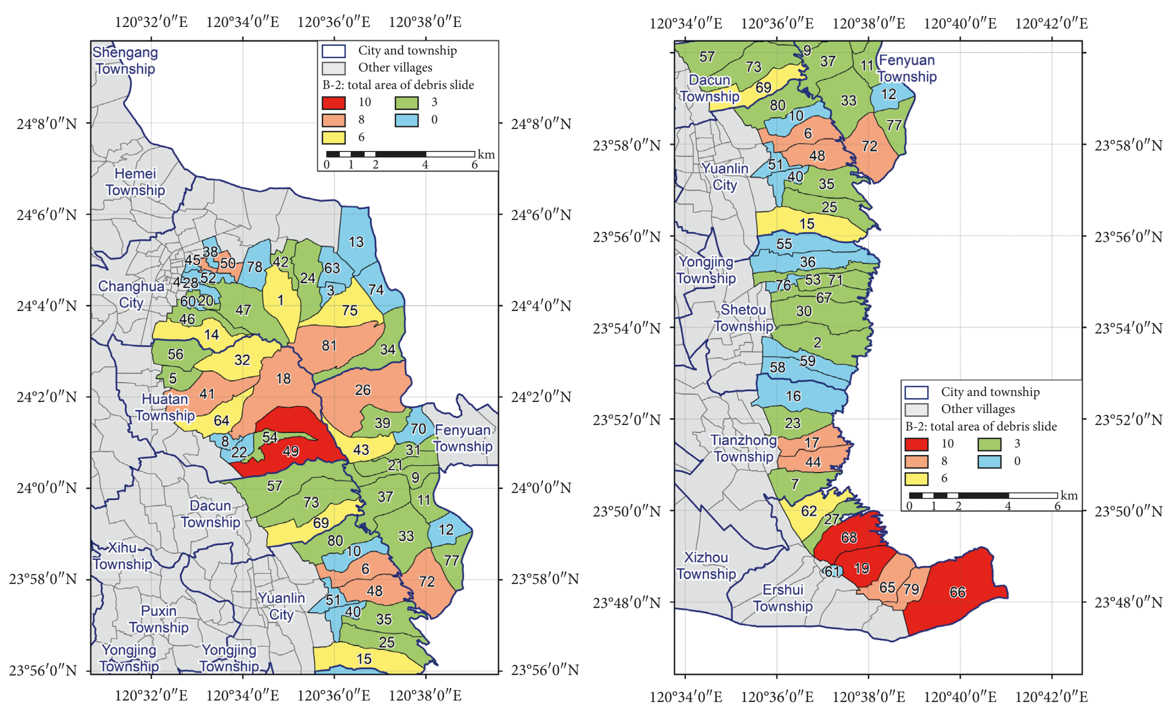


(c)

Figure 3: Continued.



(d)



(e)

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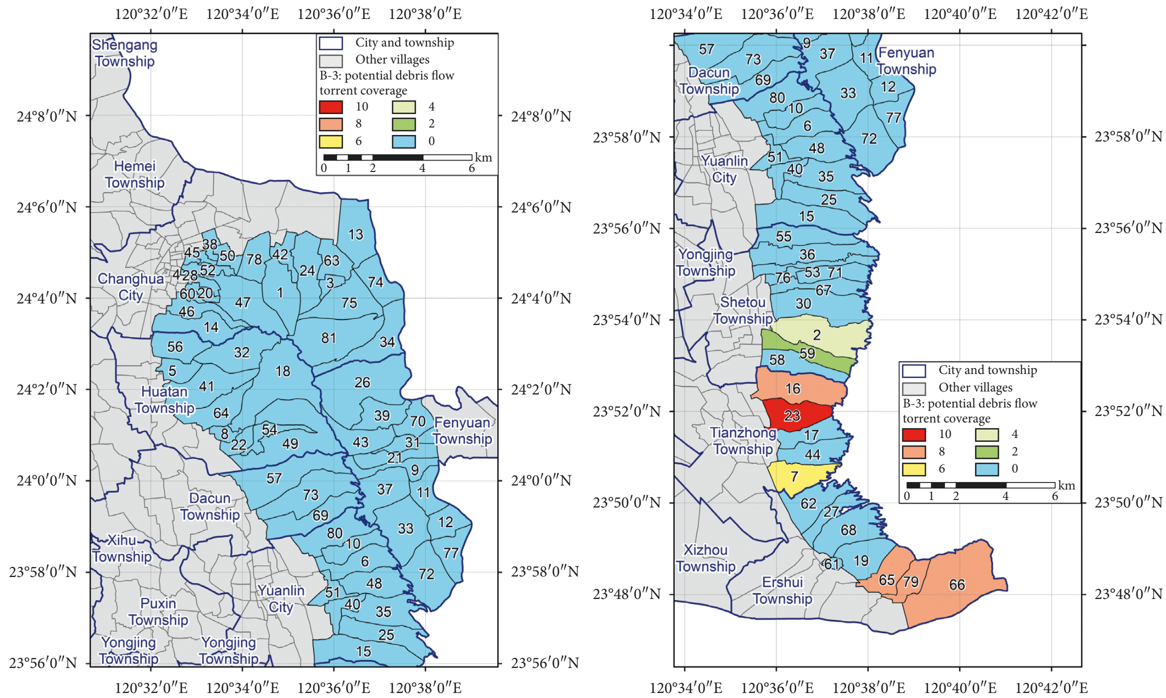
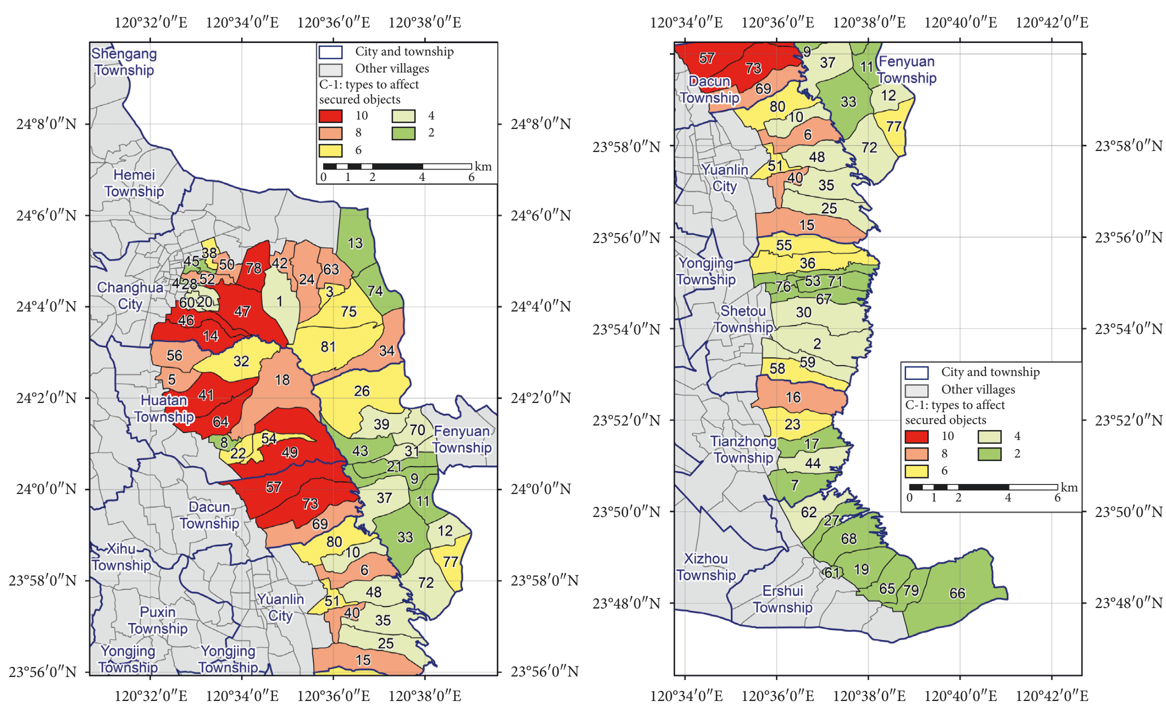
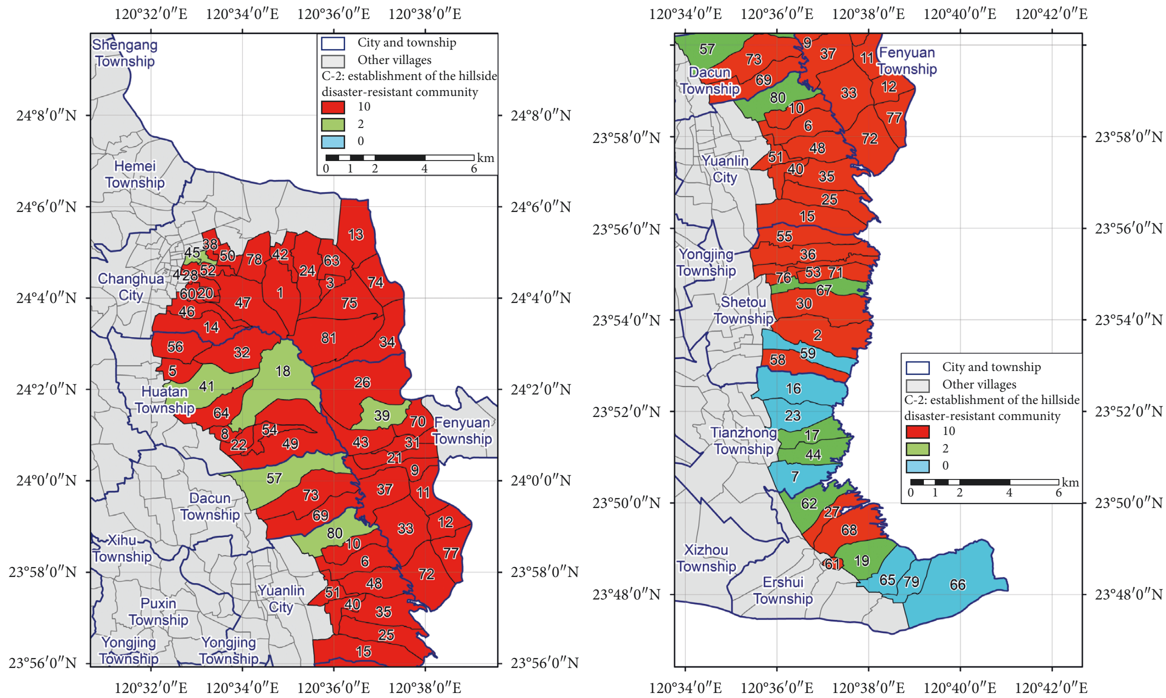


(f)

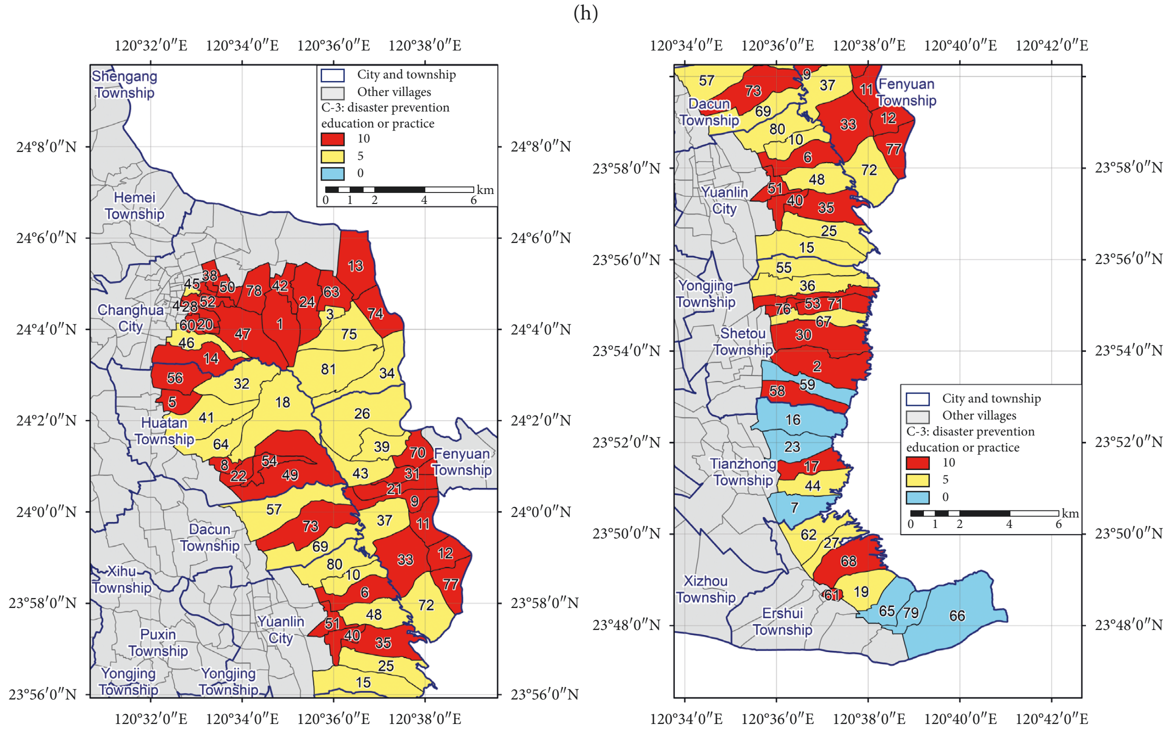


(g)

Figure 3: Continued.



(h)

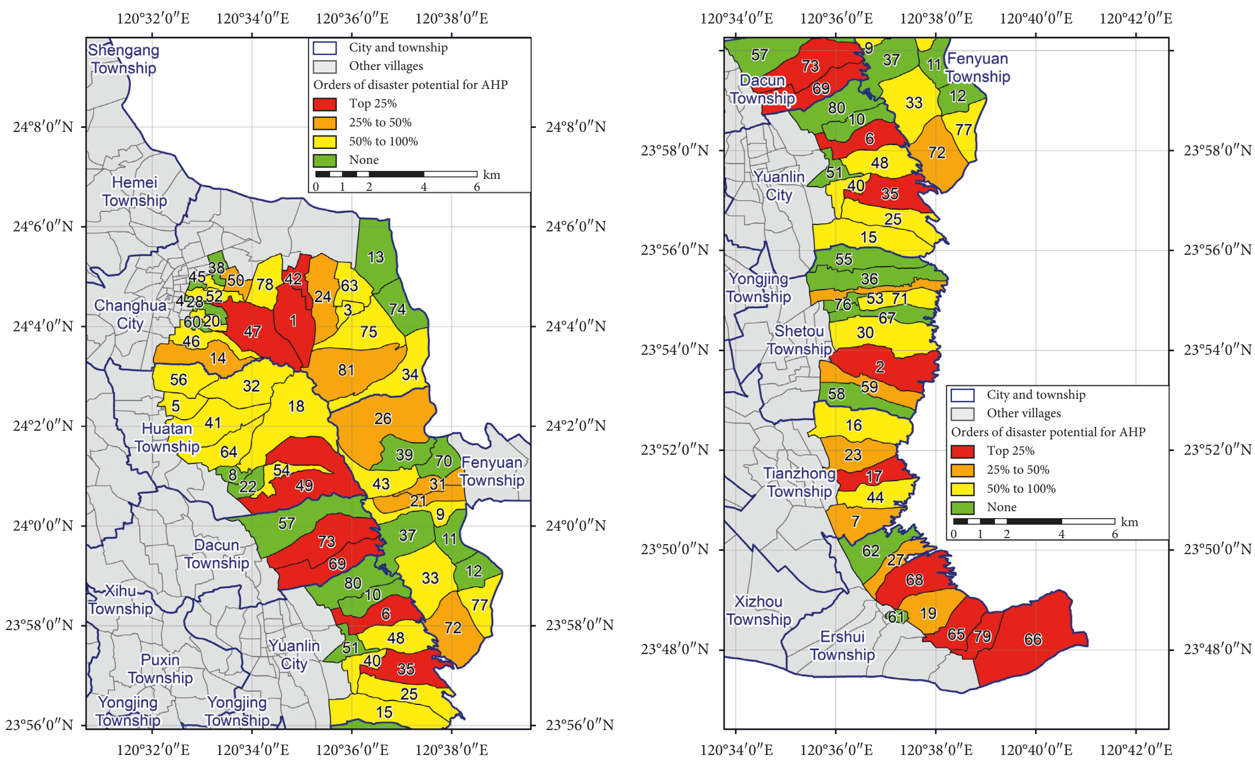


(i)

Figure 3: GIS maps for the evaluation factors used in overlay results. (a) Average gradient. (b) Debris slide potential river. (c) Potential debris flow torrent. (d) Major historical disaster. (e) Total debris slide area. (f) Potential debris flow torrent area. (g) Effect on secured objects. (h) Establishment of the hillside disaster-resistant community. (i) Disaster prevention education or practice.

In terms of "hazard," there are 17 historical disaster records in Changhua County according to the investigation of the NCDR. In Figure 3(d), 10 points are awarded for the villages with historical disaster events and 0 for those without record.

The total debris slide area of the debris slide in the village in Figure 3(e) uses the data provided by the NCDR. The largest area of the debris slide area is 10.94 hectares, and the potential debris slide areas are an average of 1.75 hectares among 56 villages. The debris slide area is 0 ha (0 points), less



(a) (b)

Figure 4: GIS overlay results by the AHP: (a) northern Changhua; (b) southern Changhua.

than 1 ha (3 points), 1 to 2 ha (6 points), 2 to 5 ha (8 points), and larger than 5 ha (10 points) as per the classification criteria in this study.

The range of influence of the debris flow is estimated using the total area of the debris flow potential as defined by SWCB that is affected and the area of the village. The influence area is less than 1 ha (2 points), 1–5 ha (4 points), 5–10 ha (6 points), 10–20 ha (8 points), larger than 20 ha (10 points), and 0 for those without debris flow, as shown in Figure 3(f).

The data about secured objects on the map that are affected are used to determine "vulnerability." The areas where there is slide potential in villages are awarded 10 points for "the area of buildings >50 ha," 8 points for "35–50 ha," 6 points for "25–35 ha," 4 points for "15–25 ha," 2 points for "<15 ha," and 0 for "null" (Figure 3(g)).

The factor pertaining to "establishment of the hillside disaster-resistant community" is divided into finance support from SWCB and Changhua County Government. Because of the perennial funds, the communities supported by SWCB and Changhua County Government receive 0 points and 2 points, respectively, and the others receive 10 points (Figure 3(h)).

As for "disaster prevention education or practice," 0 points are given to the communities with annual disaster prevention education lectures or drills, 5 points to those who have handled, and 10 points to those without experience, as shown in Figure 3(i).

These scores are multiplied by the weights and then summed to calculate the potential for a disaster for a village. The overlay results are shown in Figures 4 and 5 by the AHP and ANP, respectively. The red areas in Figures 4 and 5 represent the top 25% disaster potential analysis according to this overlay result. Orange areas are between 25% and 50%, and those ranked between 50% and 75% are yellow. The green areas show relatively low-risk villages. Although the weights of the AHP and ANP are similar, there are 11 villages with different results based on AHP and ANP analysis among the 81 villages in Figures 4 and 5. It indicates there is about 13.6% difference after GIS overlay analysis even though the results of the AHP and ANP are very close. Based on the assumptions of the AHP and ANP, the results of the ANP should be probably closer to the real situation.

The willingness of community residents is the key factor for a hillside disaster-resistant community, so the disaster risk from the GIS overlay is used to determine the willingness of villages to establish hillside disaster-resistant communities. When a suitable hillside disaster-resistant community is selected, the GIS data and site investigation (including current facilities in communities, shelters, and evacuation plan) are used. The disaster evacuation map is constructed, and a hillside disaster-resistant community workshop is conducted. There will be more information about "major historical disasters," "establishment of the hillside disaster-resistant community," and "disaster prevention education or practice" when these disaster-resistant communities have been established. More complete evaluation factors in Table 8 can be used to establish an evaluation

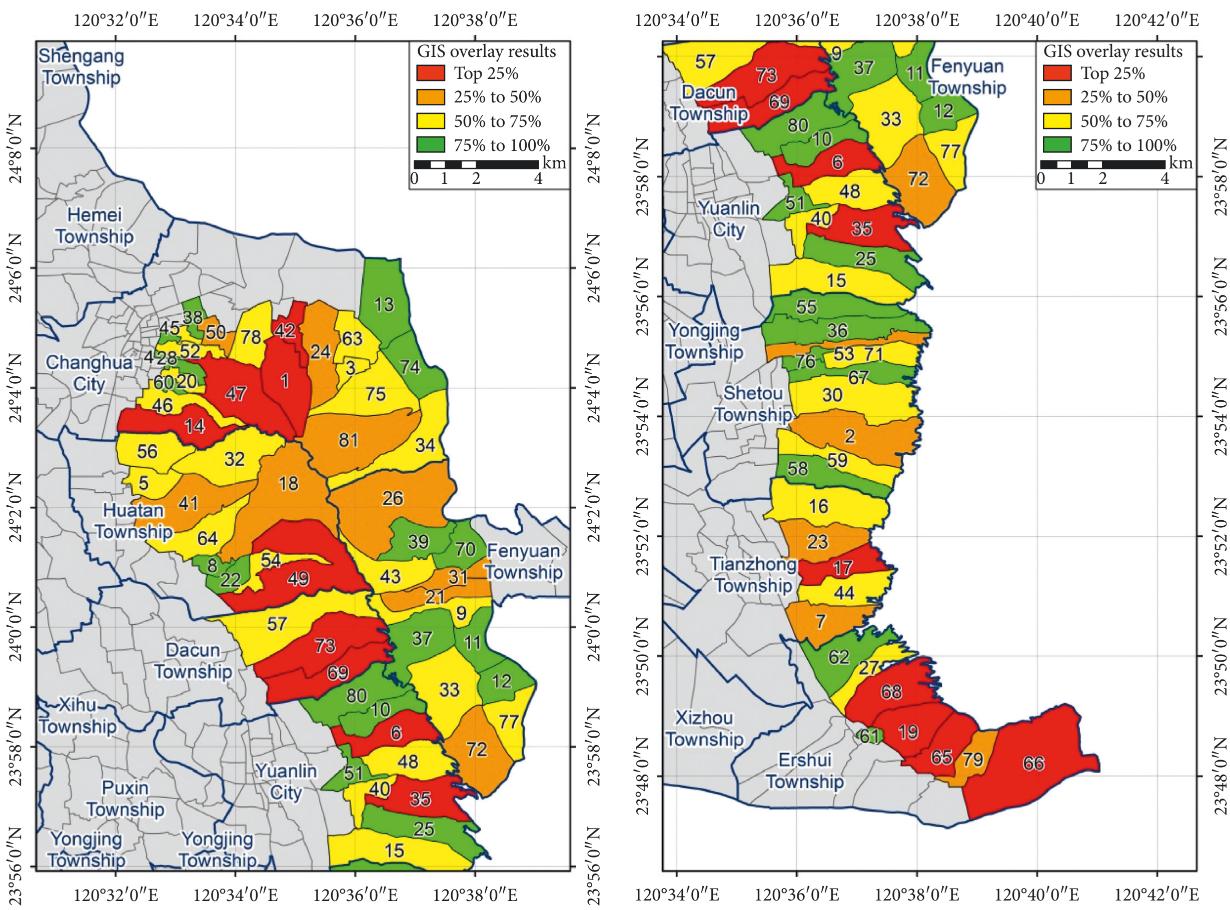


Figure 5: GIS overlay results by the ANP: (a) northern Changhua; (b) southern Changhua.

system for a hillside disaster-resistant community in the future.

4. Conclusions

This study pertains to communities with a potential for a hillside disaster and uses an expert questionnaire survey. The survey results are used to calculate the disaster potentials for hillside communities. The relationships between factors for a hillside disaster-resistant community are used to analyze the disaster potential. An analysis of the expert questionnaire is used to determine the weights of the evaluation factors, in order to establish a scientific and objective evaluation model. This has not been a factor of many studies.

To calculate the disaster potential for a hillside community, the weights of the evaluation factors for the disaster potential are used. The GIS overlay results are used to determine the priorities to allow a hillside community establishment to make disaster-resistant plans. In addition to establishing an evaluation system for hillside communities to resist disasters using the ANP, community disaster prevention education, war-gaming, and disaster prevention practice allow local residents to have better responses to disasters.

In this study, the weight of the factor "C-3: disaster prevention education or practice" is 12.89% (AHP) or 14.61% (ANP). Although Changhua County Government continues to handle disaster prevention education and training, the results are not completely documented and preserved. This study suggests that the hillside prevention community can be continuously established with reference to the priority of this study, and the disaster prevention education training and drill records will be returned to revise the factor weights in the future.

Data Availability

The GIS data used to support the findings of this study were supplied by NCDR, Taiwan, and so cannot be made freely available. Requests for access to these data should be made to NCDR, Taiwan, at https://www.ncdr.nat.gov.tw/.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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