Sensors and Materials, Vol. 35, No. 12 (2023) 4337–4348
MYU Tokyo

S & M 3484

A Study of User Satisfaction with and Acceptance of a Hydrology and Stratum Subsidence Monitoring System

Yu-Sheng Su,[1,2*] Yun-Chin Wu,[2] Ching-Teng Lo,[2] and Po-Ting Chen[2]

[1]Department of Computer Science and Information Engineering, National Chung Cheng University, Chiayi 621301, Taiwan
[2]Department of Computer Science and Information Engineering, National Taiwan Ocean University, Keelung 202301, Taiwan

(Received April 30, 2023; accepted October 17, 2023)

Keywords: land subsidence, groundwater level monitoring and management, technology acceptance model, user satisfaction

Land subsidence is a serious issue primarily caused by the human over-extraction of groundwater, excluding natural factors. To achieve a balance between supply and demand, the real-time monitoring and management of groundwater resources are currently implemented using sensors. However, many developed management platforms often overlook the actual usage and experience of the users, potentially resulting in a poor user experience. In this study, we applied the Technology Acceptance Model to explore users' acceptance of and satisfaction with a groundwater management platform. We found that the proposed management platform obtained higher levels of user acceptance and satisfaction, and can be practically applied to the monitoring and management of groundwater resources.

1. Introduction

Land subsidence has always been a crucial focus of attention in various countries, and the disasters caused by this problem have had a serious impact on nature and human life.[1] In previous studies that have explored the causes of and solutions to ground subsidence,[2,3] it was found that other than natural factors such as earthquakes that cause soil loosening and deformation, the main cause is an over-dependence on groundwater and its extraction, which leads to the problem of ground subsidence. These studies concluded that there is a need to strengthen the monitoring and management of groundwater resources, as well as to promote the utilization of water resources in order to curb and mitigate the rate and damage of ground subsidence.

The development of cloud computing has spurred related research on edge computing,[4–6] which has also enabled subsequent groundwater studies to utilize Internet of Things (IoT) technology for monitoring and visualizing data related to groundwater resources.[7,8]

Kombo *et al.* used IoT technology to perform the real-time detection of groundwater levels and visually displayed them on the platform, effectively reducing hardware deployment costs

*Corresponding author: e-mail: ccucssu@gmail.com
https://doi.org/10.18494/SAM4484

ISSN 0914-4935
https://myukk.org/

and power consumption.[7] Su and Hu utilized cloud computing and IoT technology to develop a hydrological and subsidence monitoring platform, providing a visualized approach to manage hydrological and subsidence data.[8] Unfortunately, the former management platform was very monotonous in design and did not explain how to effectively accommodate data from other monitoring stations. On the other hand, the latter management platform is more complete. However, it does not describe how to preprocess the data collected by the sensors. Furthermore, Davis argued that a new information system lacking the consideration of users' perceptions and feedback would result in difficulties in promotion and utilization.[9] Therefore, this issue had to be taken into account in order to improve the platform.

On the basis of previous findings, it is important to monitor, assess, and predict the accuracy and effectiveness of land subsidence for disaster prevention and mitigation, land planning, and administration.[1–3] Therefore, in this study, we aimed to develop an integrated monitoring and analysis platform on the basis of the above findings in order to provide accurate monitoring and analytical assessments, which in turn provide effective references for stratigraphic subsidence hazard management. To consider the users' experience and feedback in using the management platform, we drew on the Technology Acceptance Model (TAM) and incorporated two external dimensions, Interface Design and Interactive Experience, to explore user satisfaction with and acceptance of using this platform.[10]

2 Literature Review

2.1 Research on interface design

According to Eighmey, a successful website is achieved through the conveyance of information and the enjoyment of interaction with users, and the design of the website interface along with a well-planned workflow is highly relevant to users' willingness to use it.[11] In related studies, the interface has been shown to affect users' willingness to use a website.[12,13]

Hausman and Siekpe found that a well-structured design enhances the attractiveness and perceived usefulness of a platform by discussing the effects of interface features on users' purchase intentions.[12] Schenkman and Jönsson conducted a survey and performed preference analysis on users' first impressions of a platform, and found that aesthetic design and users' preferences can enhance perceived ease of use.[13]

From the aforementioned studies, it is evident that a well-designed interface can significantly enhance readability and operability, thereby increasing perceived usefulness and ease of use, which in turn affects users' behavioral intentions. Therefore, we aimed to investigate the relationship between interface design and other dimensions, taking into account their impact on users' behavioral intentions.

2.2 Research on interactive experience

Lascu and Clow found that users' interactions with technology evoke positive or negative emotional responses, suggesting that the interactive experience has a direct impact on users'

emotions.[14] Previous research on interactive experiences has shown that such experiences have a strong effect on users' intentions to use the technology.[15,16]

Constantinides studied how good user experience can affect users' purchasing decisions and found that usability, good interactive elements, and aesthetic design effectively improve the user experience.[15] Novak *et al.* found that improving the ease of use navigation experience can increase users' attention and improve their motivation.[16]

Through the aforementioned studies, it was found that excellent user experience enhances user engagement and attractiveness, thereby affecting users' behavioral intentions. Therefore, we explored the relationship between interactive experience and other factors.

2.3 TAM

TAM was proposed by Davis in 1989.[10] It has become the most widely used model for explaining users' acceptance of new information technology. The model defines the pattern of users' behavioral intentions when they encounter new information technology and can be used to explain the interaction between various influencing factors. For units and companies promoting new information technology, TAM can help to quickly understand users' acceptance and improve the technology based on influencing factors, effectively reducing investment costs.

TAM suggests that the intention to use a technology is not only affected by perceived usefulness and attitude towards its use, but also by user satisfaction. Baker and Crompton used structural equation modeling to investigate the relationship between satisfaction and behavioral intention, and the results showed a clear mutual effect between the two.[17] Chang found that enhancing user satisfaction can strengthen users' intentions.[18] Therefore, we included user satisfaction as a research hypothesis to explore its relationship with behavioral intention to use. On the basis of the above literature review, we designed a framework to explore the correlations between the factors. The model proposed in this study is shown in Figure 1.

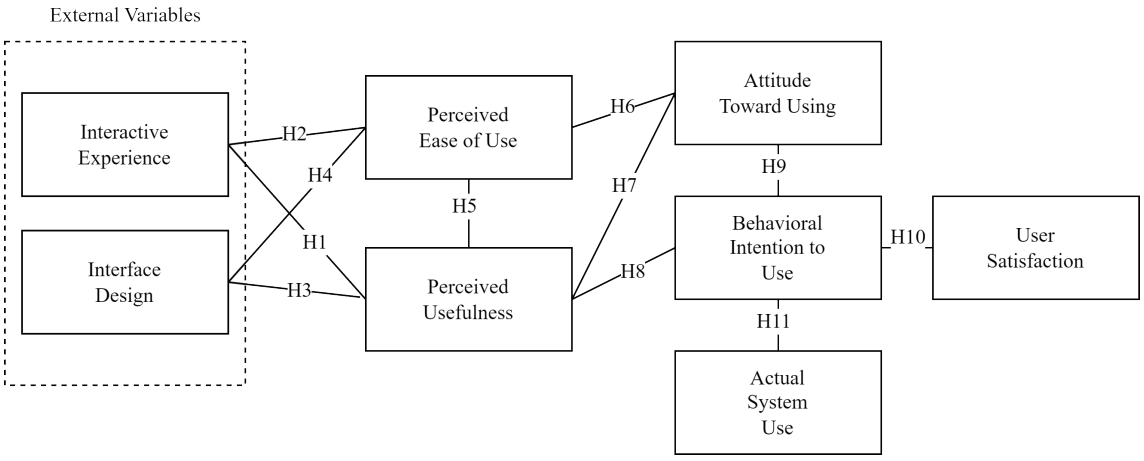

Fig. 1. Proposed model.

3. Hydrology and Stratum Subsidence Monitoring System

The main function of this platform is to analyze layer and time-series data. The layer data allow users to view the coordinates and detailed information of different groundwater monitoring stations on the map, addressing the lack of information display issue on Kombo's platform.[7] Figure 2 shows all the groundwater monitoring stations within the Choshui River Alluvial Fan area in Taiwan, while the information box shows all the details of the Tianzhong station. The time-series data allow users to view the numerical variations of groundwater levels and pumping stations at different time periods using the menu. This feature allows for the preprocessing of the data collected from sensors, addressing abnormal periods by filling them in with nearby normal data using the inverse distance weighting (IDW) technique.[20] It improves the shortcomings in the observation data processing of Su and Hu's platform.[8] Figure 3 shows the groundwater level data of the Tianzhong station, where green represents the original data and red represents the processed and corrected data.

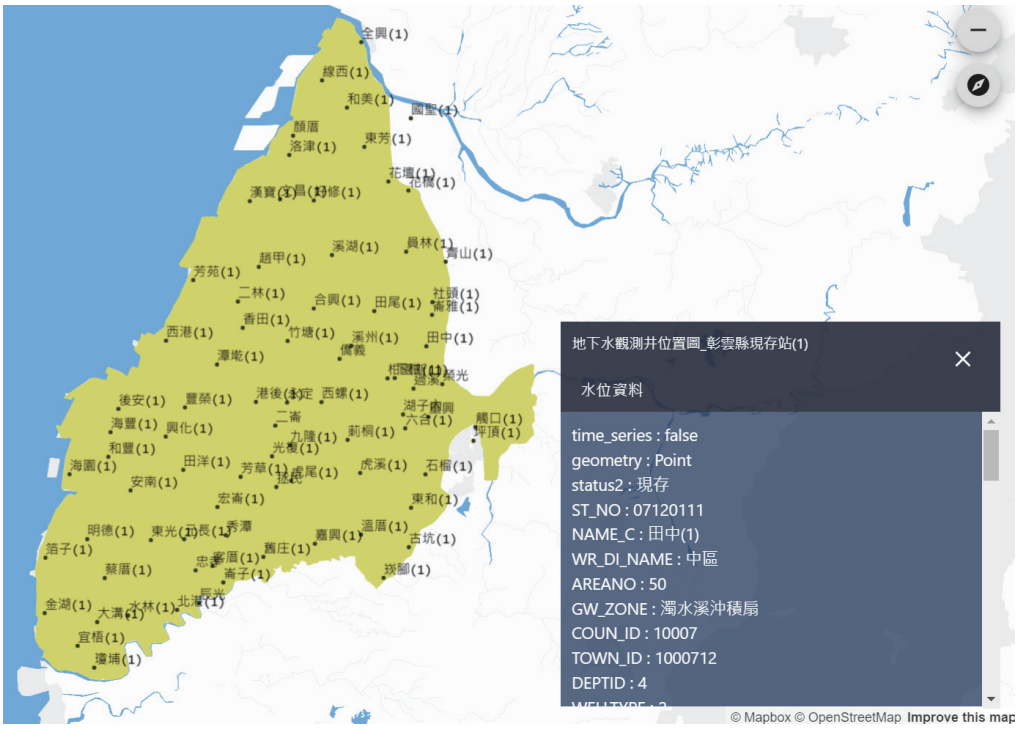

Fig. 2. (Color online) All the groundwater monitoring stations on the map.

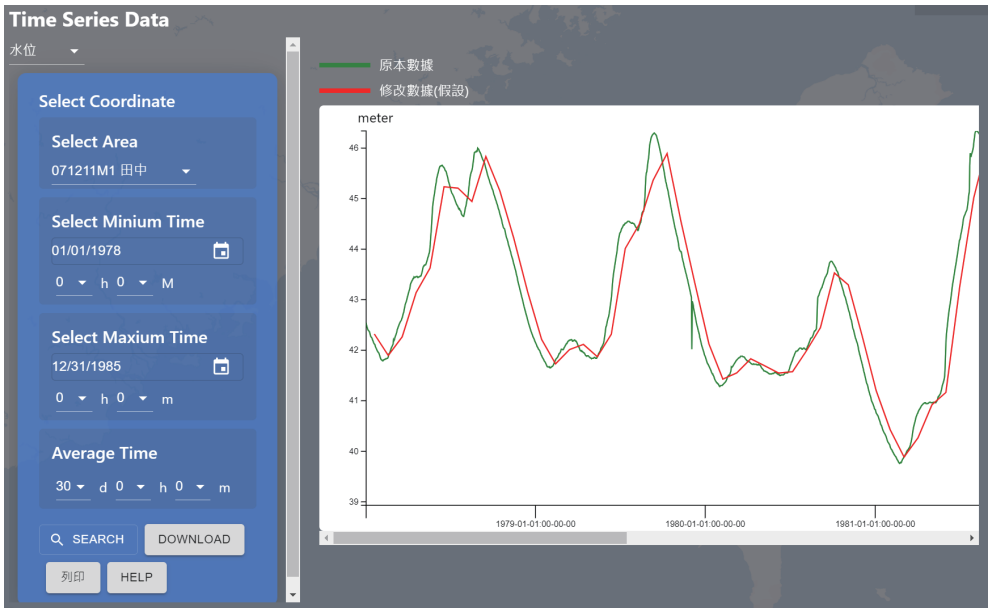

Fig. 3. (Color online) Groundwater level data of Tianzhong station.

4. Methodology

4.1 Data collection

In this study, we incorporated TAM and Zardari's research to design a questionnaire scale.[21] The questionnaire consisted of a total of 45 items. The options utilized the Likert scale, which is a psychological response scale that allows users to clearly indicate their level of agreement with the items.[22] All questionnaires were filled out during the introduction events. Prior to conducting the survey, we introduced the advantages of the proposed platform to the users and provided them with a certain amount of time to interact with it.

4.2 Instruments

4.2.1 Descriptive statistics

We used descriptive statistics to illustrate the distribution of users by gender, age, and education level.

4.2.2 Reliability analysis

We used Cronbach's alpha coefficient to judge the content stability and consistency of the questionnaire. DeVellis and Thorpe proposed that an alpha coefficient of 0.7 or higher indicates good performance. If the alpha coefficient is below 0.6, it is necessary to evaluate whether modifications to the questionnaire content are needed.[23]

4.2.3 Validity analysis

We utilized Kaiser-Meyer-Olkin (KMO), Bartlett's test, and factor analysis to assess whether the questionnaire results measured the intended analytical objectives. Kaiser proposed that a KMO sampling value of 0.6 or higher is an acceptable range. Bartlett's *p*-value is used to determine whether it is appropriate to conduct factor analysis, with a value less than 0.05 indicating suitability.[24] Factor analysis is a statistical method that mainly seeks to identify factors to explain the observed covariance and to understand whether the expected analysis objectives have been measured.

4.2.4 Analysis of variance

We utilized the analysis of variance (ANOVA) to test the research hypotheses by decomposing the total variance into variance between groups and variance within groups, to evaluate whether the differences among groups were statistically significant.

4.2.5 Correlation analysis

We employed correlation analysis to investigate the significant degree of association and the direction of change concerning the research hypotheses. This method utilizes the correlation coefficient as the indicator. The coefficient ranges from 1 to −1, with the sign representing the slope. A coefficient closer to 1 indicates a stronger correlation, whereas that closer to 0 implies no correlation.

4.2.6 Regression analysis

Regression analysis is characterized by a linear relationship that can be used to test the causal relationship between independent and dependent variables, thereby exploring the strength of effect of each research hypothesis. This study is based on the research of Baron and Kenney and uses regression analysis for validation.[25]

5. Results

5.1 Descriptive statistics

A total of 63 users completed the questionnaire and 63 valid responses were obtained. The result shows that the majority of the respondents were male, accounting for more than 80% of the total number of samples, while females accounted for lesss than 20% of the total number of samples. Regarding age, the majority of the respondents were in the 21–30 age group, accounting for 94%, while the 1–20 and 31–40 age groups accounted for a total of 6%. The education level of respondents was predominantly bachelor's degree, up to 84%, while those with a master's degree account for 14%.

5.2 Reliability analysis

Cronbach's alpha coefficients for each dimension of the questionnaire in this study are shown in Table 1, which demonstrates that Cronbach's alpha of the questionnaire in this study was close to 0.8. Moreover, even when each dimension was deleted one by one, Cronbach's alpha remained above 0.7, indicating a high level of stability for each dimension. The reliability analysis confirmed that the questionnaire exhibited reliability and internal consistency across all dimensions.

5.3 Validity analysis

The KMO value of the questionnaire in this study was 0.715 and Bartlett's p-value was less than 0.001, indicating good sample adequacy. Therefore, the questionnaire in this study was suitable for exploratory factor analysis (EFA). Table 2 presents the EFA results, where three primary factors explained 70% of the total variance extracted on the basis of the criterion of eigenvalues greater than 1. The factor loadings for each factor were all above 0.6, indicating a high correlation between the items and their corresponding factors, reflecting the explanatory power of the factors on the items.

Table 1
Results of reliability analysis.

Variable	Questions	Cronbach's Alpha	Alpha If Items Deleted
P.U.	7	0.775	0.734
P.E.U.	7		0.738
A.T.	7		0.748
B.I.	7		0.742
U.S.	7		0.733
I.E.	2		0.766
I.D.	2		0.772
A.U.	6		0.771

Table 2
EFA results.

Variable	Factor		
	1	2	3
P.U.	0.839		
P.E.U.	0.809		
A.T.	0.675		
U.S.	0.726		
I.E.		0.849	
I.D.		0.859	
B.I.			0.618
A.U.			0.894

5.4 Analysis of variance

In this study, ANOVA with Scheffe's post hoc test was used to test the hypotheses. Table 3 shows the results of ANOVA. Among the 11 research hypotheses, the *p*-values for H5 to H11 were all less than 0.001, indicating a significant positive correlation in line with the dimensions of TAM and confirmed by the relationship between user satisfaction and behavioral intention. Although the *p*-values for H1 to H4 were not less than 0.001, they still showed the characteristic of a significant effect. This shows that the external dimensions proposed in this study effectively affected users' perceptions of usefulness and ease of use.

5.5 Correlation analysis

We employed the Spearman correlation coefficient to explore the relationships between different dimensions. Table 4 shows the results of the correlation analysis. Perceived ease of use, perceived usefulness, and actual usage were significantly correlated with all dimensions. Except

Table 3
ANOVA results.

Hypothesis	*SS*	*df*	*MS*	*F*	*p*
H1	3.311	2	1.655	5.128	0.008**
H2	3.964	2	1.982	3.961	0.022*
H3	3.401	2	1.701	5.284	0.007**
H4	6.800	2	3.400	7.236	0.001**
H5	16.253	3	5.418	29.180	0.000***
H6	7.403	3	2.468	9.425	0.000***
H7	6.036	2	3.018	11.028	0.000***
H8	7.074	2	3.537	11.509	0.000***
H9	11.012	2	5.506	20.777	0.000***
H10	11.262	3	3.754	14.157	0.000***
H11	7.477	3	2.492	7.903	0.000***

Note: *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

Table 4
Results of correlation analysis.

	P.U.	P.E.U.	A.T.	B.I.	U.S.	I.E.	I.D.	A.U.
P.U.								
P.E.U.	0.702**							
A.T.	0.434**	0.445**						
B.I.	0.441**	0.434**	0.536**					
U.S.	0.457**	0.441**	0.724**	0.539**				
I.E.	0.334**	0.303**	0.089	0.064	0.195			
I.D.	0.293**	0.306**	0.155	0.115	0.180	0.607**		
A.U.	0.263**	0.214*	0.216*	0.474**	0.270**	0.282**	0.202*	

Note: *Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

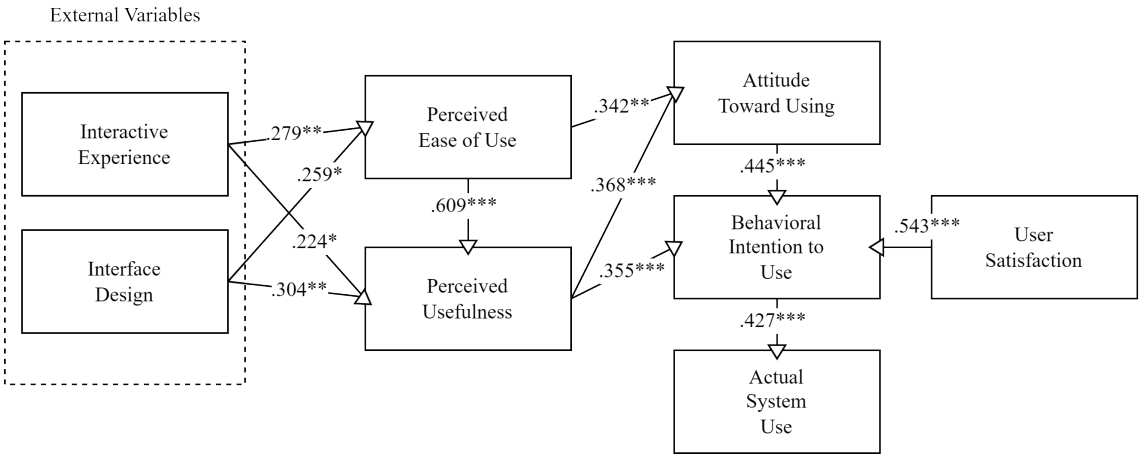

Fig. 4. Corresponding results of the proposed model.

for the two external dimensions, the other dimensions showed significant correlations, aligning with the proposed framework's concept of interrelatedness.

5.6 Regression analysis

We determined the standardized regression coefficients for each research hypothesis. From the results of the regression analysis, Fig. 4 shows the corresponding results of the proposed model. From the standardized regression coefficients of each research hypothesis, it can be observed that H5 had the highest impact, indicating that users perceived that a user-friendly and easy-to-use management platform effectively enhanced their usage experience. H10 had the second highest impact, suggesting that if users were satisfied with the management platform, it could positively affect their intention to use it, in line with previous research definitions.[17,18] H6, H7, H8, H9, and H11 were all significant, in line with the definitions of TAM.[10] H1 to H4 were also significant but had relatively lower coefficients than the other research hypotheses. It can be concluded that users generally considered usefulness and ease of use as the primary influencing factors, while interface design and interactive experience were perceived as additional positive aspects.

6. Conclusions

In this study, we developed an integrated monitoring and analysis platform that enables the precise monitoring and evaluation of groundwater levels, addressing the shortcomings of previous platforms such as insufficient information display and unprocessed sensor data. It provides an effective reference for mitigating land subsidence disasters. Furthermore, by combining TAM, two external variables (i.e., interface design and interactive experience), and user satisfaction, we provide insights for the development of future scientific application platforms.

In this study, we observed a significant relationship in H1 and H2, indicating that users perceived the platform in this study to enhance convenience and work efficiency in terms of operational experience, which is consistent with previous research findings.[14–16] We also observed a significant relationship in H3 and H4, suggesting that users perceived the platform in this study to enhance convenience and work efficiency in terms of design, which is consistent with previous research findings.[11–13] On the basis of these findings, we emphasize the design aesthetics and interactivity of the platform, focusing on transitions between functions and color schemes for the display, as these details can effectively enhance users' willingness to use the platform.

In this study, we observed a significant relationship between perceived ease of use and perceived usefulness in H5, indicating that users perceive that a simple and user-friendly management platform can improve work efficiency, which is consistent with the dimensions of TAM.[10] Therefore, we believe that the design of the management platform should aim to simplify operations and improve the smoothness of user interactions. Additionally, we also observed significant relationships in H6 and H7, suggesting that improving the perceived ease of use and perceived usefulness of the management platform can effectively improve users' evaluations of the platform.

In this study, we observed significant relationships in H8, H9, and H10, indicating that perceived usefulness, attitude towards use, and user satisfaction all affect users' intention to use the management platform, which is consistent with the dimensions of TAM.[10] We recommend not only developing comprehensive functionality but also understanding users' perspectives through online surveys and implementing iterative improvements to continuously enhance users' willingness to use the platform. Additionally, we also observed a significant relationship in H11, suggesting that users who have the intention to use the platform actually utilize it for queries and functions related to land subsidence research.

In conclusion, the management platform proposed in this study exhibits characteristics of ease of learning and use, effectively enhancing users' work efficiency, and demonstrating high acceptance and satisfaction levels, thereby encouraging users to utilize the platform. Despite conducting the experiment rigorously, this study still has certain limitations. One limitation is the relatively small number of participants, with only 63 individuals in total, warranting a larger sample size to support the findings. Additionally, there was a lack of opinions from female users, as the gender ratio in this study was 9:1, highlighting the need to include more female perspectives in the research. Furthermore, since the users involved were general public participants, the study lacks input from relevant domain experts. Strengthening this aspect could have a more impactful effect on the development of management platforms.

Acknowledgments

This research was partially supported by the National Science and Technology Council, the Republic of China, under grants NSTC 111-MOEA-M-008-001, NSTC 112-MOEA-M-008-001, and NSTC 111-2410-H-019-006-MY3. The authors thank the Water Resource Agency (WRA) and the Central Geological Survey (CGS) of Taiwan for providing the hydrological and geological data.

References

1 M. O. E. A. Water Resources Agency: The Project for Annual Work Plan of Land-Subsidence Prevention and Reclamation in 2021 (2021) 25.
2 C. H. Liu, Y. W. Pan, J. J. Liao, C. T. Huang, and S. Ouyang: Environ. Geol. **45** (2004) 1154. https://doi.org/10.1007/s00254-004-0983-6
3 P. Teatini, M. Ferronato, G. Gambolati, W. Bertoni, and M. Gonella: Environ. Geol. **47** (2005) 831. https://doi.org/10.1007/s00254-004-1215-9
4 C. Dai, X. Liu, Z. Li, and M. Y. Chen: Appl. Soft Comput. **101** (2021) 107051. https://doi.org/10.1016/j.asoc.2020.107051
5 C. Dai, H. Cheng, and X. Liu: Proc. In 2020 IEEE 22nd International Conference on High-Performance Computing and Communications; IEEE 18th International Conference on Smart City; IEEE 6th International Conference on Data Science and Systems (HPCC/SmartCity/DSS) (IEEE, 2020) 507–512. https://doi.org/10.1109/HPCC-SmartCity-DSS50907.2020.00062
6 C. Dai, Y. Huang, and W. C. Chien: Future Gener. Comput. Syst. **143** (2023) 51. https://doi.org/10.1016/j.future.2022.12.043
7 O. H. Kombo, S. Kumaran, and A. Bovim: IEEE Access. **9** (2021) 128417. https://doi.org/10.1016/j.future.2022.12.043
8 Y. S. Su and Y. C. Hu: Sens. Mater. **34** (2022) 1313. https://doi.org/10.18494/SAM3508
9 F. D. Davis: Int. J. Man Mach. Stud. **38** (1993) 475. https://doi.org/10.1006/imms.1993.1022
10 F. D. Davis: MIS Quarterly **13** (1989) 319. https://doi.org/10.2307/249008
11 J. Eighmey: J. Advertising Res. **37** (1997) 59.
12 A. V. Hausman and J. S. Siekpe: J. Bus. Res. **62** (2009) 5. https://doi.org/10.1016/j.jbusres.2008.01.018
13 B. N. Schenkman and F. U. Jönsson: Behav. Inf. Technol. **19** (2000) 367. https://doi.org/10.1080/014492900750000063
14 D. N. Lascu and K. E. Clow: J. Internet Commerce **7** (2008) 359. https://doi.org/10.1080/15332860802250476
15 E. Constantinides: Internet Res. **14** (2004) 111. https://doi.org/10.1108/10662240410530835
16 T. P. Novak, D. L. Hoffman, and Y. F. Yung: Marketing Sci. **19** (2000) 22. https://doi.org/10.1287/mksc.19.1.22.15184
17 D. A. Baker and J. L. Crompton: Annals Tourism Res. **27** (2000) 785. https://doi.org/10.1016/S0160-7383(99)00108-5
18 C. C. Chang: Library Management **34** (2013) 40. https://doi.org/10.1108/01435121311298261
19 A. Acharya and M. Raje: In USENIX Security Symposium (2000) 1. http://www.usenix.org/events/sec2000/full_papers/acharya/acharya.pdf
20 P. M. Bartier and C. P. Keller: Comput. Geosci. **22** (1996) 795. https://doi.org/10.1016/0098-3004(96)00021-0
21 B. A. Zardari, Z. Hussain, A. A. Arain, W. H. Rizvi, and M. S. Vighio: Sustainability **13** (2021) 6201. https://doi.org/10.3390/su13116201
22 A Joshi, S. Kale, S. Chandel, and D. K. Pal: Bri. J. Appl. Sci. Technol. **7** (2015) 396. https://doi.org/10.9734/BJAST/2015/14975
23 R. F. DeVellis and C. T. Thorpe: Scale development: Theory and applications (Sage Publications, 2021) Chap. 4.
24 H. F. Kaiser: Psychometrika **39** (1974) 31. https://doi.org/10.1007/BF02291575
25 R. M. Baron and D. A. Kenny: J. Personality Social Psychol. **51** (1986) 1173. https://doi.org/10.1037/0022-3514.51.6.1173

About the Authors

Yu-Sheng Su is currently an associate professor in the Department of Computer Science and Information Engineering at National Chung Cheng University, Taiwan. His research interests include social media mining, IoT, cloud computing, big data analysis, extended reality, machine learning/deep learning, and computational thinking. (ccucssu@gmail.com)

Yun-Chin Wu is a master's degree student in the Department of Computer Science and Engineering at National Taiwan Ocean University, Taiwan. His research interests include IoT, cloud computing, big data analysis, and machine learning/deep learning. (junior055365@gmail.com)

Ching-Teng Lo is a master's degree student in the Department of Computer Science and Engineering at National Taiwan Ocean University, Taiwan. His research interests include IoT, cloud computing, big data analysis, and machine learning/deep learning. (cs6363663@gmail.com)

Po-Ting Chen is a bachelor's degree student in the Department of Computer Science and Engineering at National Taiwan Ocean University, Taiwan. His research interests include IoT, cloud computing, big data analysis, and machine learning/deep learning. (timchen0719@gmail.com)