

Establishing a Subsidence Warning System Due to Drought and Groundwater Exploitation: A Case Study at Ca Mau Peninsula, Vietnam

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Abstract

Nowadays, there are a lot of natural disasters such as flash floods and landslides, subsidence and riverbank erosion, droughts, etc. which have caused heavy losses in Vietnam and around the world. Natural disasters have increased due to the impact of climate change. Establishing subsidence early warning systems due to drought and groundwater exploitation is the technical solutions and disaster risk management to reduce human and property losses in Ca Mau Peninsula. The Ca Mau Peninsula is one of the areas with severe and frequent subsidence. The warning system is built based on the factor weighting method combined with GIS technology. This subsidence warning system due to drought and groundwater exploitation was applied for the dry season in 2024. Results show that subsidence locations from the system are relatively consistent with surveyed subsidence locations. The subsidence warning system will be an effective tool and will be transferred to the Ca Mau provincial hydrometeorological station for use in their work in the dry season in 2025. This system can be replicated in areas facing increasing subsidence.

Keywords

Subsidence Warning System, Drought, Groundwater Exploitation, Ca Mau Peninsula, Vietnam

1. Introduction

In recent years, natural disasters have occurred more and more frequently with increasingly strong impacts because of climate change. Faced with this situation, scientists are constantly researching and applying new technologies to improve the capacity to respond to natural disasters. With increasingly developed technology,

time-series and monitoring subsidence warning systems are increasingly in the world (Hu et al., 2019; Ochungo et al., 2019; Fadhillah et al., 2020; Franczyk et al., 2022; Song et al., 2023; Salameh et al., 2024; Jena et al., 2024). As a landslide warning system in India with four functional modules (Ghosh et al., 2010), the system provides warning information in the form of short messages with a maximum delay of 50 seconds and a minimum of 10 seconds. The landslide warning system in Bangladesh (Mallick & Parvin, 2019) includes two components: one part uses GIS tools to show changes in the shoreline and the second part is a household survey process with a number of pre-prepared question structures. Hemmelder et al. (2018) proposed a riverbank erosion warning system in France that built a map using multi-temporal imagery from unmanned aerial vehicles to assess river morphology and riverbank erosion in the Buëch River floodplain in the Hautes-Alpes province in southeastern France. The early warning system for subsidence in southwestern Iran (Pourmorad et al., 2021) made a subsidence risk map using an integrated hierarchical analysis method (AHP and FAHP) and programming in the MATLAB environment with the help of the Evalfs function. Gao et al. (2021) proposed a study on a subsidence warning system in China based on the application of GIS technology, combined with surface subsidence analysis, the values of surface subsidence, slope, curvature deformation values, horizontal displacement, and corresponding horizontal deformation formulas were comprehensively analyzed and studied. In order to visualize the surface deformation of the subsidence area, this study introduces a 3D visual settlement data analysis method and performs the corresponding regression visualization and calculation result analysis in the subsidence area depth prediction process. Ning et al. (2023) integrated multi-source monitoring, early warning technology, and multi-pronged prevention and control technology. It can monitor and control ground subsidence and early warning prevention in Beijing, Tianjin, and Hebei regions. Chen et al. (2024) employed PS-InSAR and SBAS-InSAR techniques to monitor the land subsidence along the Yangtze River in Nanjing, using a total of 42 Sentinel-1A images obtained between April 2015 and November 2021. The results obtained through PS-InSAR and SBAS-InSAR technologies revealed a high degree of consistency in monitoring outcomes, and the latter method exhibited superior monitoring accuracy than the former one in the Yangtze River.

In Vietnam, Minh et al. (2018) established an early warning system based on the global ASIS system. The ASIS system was independently developed for Ninh Thuan province. The system has produced highly accurate drought monitoring results consistent with historical drought events in Ninh Thuan. This system can help support decision-making in the optimal operation of the irrigation system in Ninh Thuan as well as overcoming problems caused by drought. The flood monitoring and warning system on the WebGIS platform (Phuong et al., 2022) has been built with three main components: 1) monitoring and surveillance system, 2) information storage, processing, and forecasting system, 3) information provision and emergency response support system and the drought monitoring and

warning system on the WebGIS platform has been built with the components: a) standardized rainfall index SPI, b) moisture deficit index SWDI, c) reservoir water level index. Quang et al. (2021) has presented the results of the research on building an early warning system for landslides and flash floods based on IoT and WSN technology. This system has provided a solution for monitoring and early warning of slope instability and measuring the movement of mudflows based on the latest technology integrating pore water pressure sensors, acoustic emission measurement, inertia, low-power wide area networks, artificial intelligence on super energy-saving microprocessors, etc., an effective approach to detect slope movements and mudflows and then notify/alarm users. The early warning system for landslides in the coastal area of the Mekong Delta (WRI, n.d.) includes a data center, rain gauge station, surveillance camera, vibration sensor, and radar water level meter. The technology applies a 24/7 monitoring system and is easy to operate. The sensor combined with the monitoring information platform is integrated with the flood forecasting system. Therefore, users can access data from computers or update data via mobile networks connected to the Internet. After analysis and processing, data will provide a natural disaster warning threshold and send it to management agencies to be more proactive in the early detection of risks and hazards, helping to reduce damage to property and people as well as protect natural resources and the environment.

Subsidence is a fairly common phenomenon in Vietnam, especially in the Ca Mau Peninsula where there is almost no exogenous flow to supply water. The Ca Mau Peninsula's main water supply uses underground water sources while the drought has increased and lasted for many years, leading to increasingly serious subsidence in this area. Nevertheless, it is evident that there is currently no early warning system for the risk of subsidence due to drought and groundwater exploitation. The increased subsidence has affected the socio-economic development in the area, so it is necessary to research and build a warning system for subsidence due to drought and groundwater exploitation.

2. Materials and Methods

2.1. Description of the Study Site

The Ca Mau Peninsula is in the southernmost part of the country, with geographical coordinates from 8° 34' to 9° 33' north and from 104° 43' to 105° 25' east, with three sides bordering the sea. The eastern region of the Ca Mau Peninsula borders the East Sea, the Western and Southern regions border the Gulf of Thailand, and the northern region borders Bac Lieu and Kien Giang provinces (Figure 1). The Ca Mau Peninsula has a natural area of 522,119 hectares, accounting for 13.13% of the Mekong Delta area and 1.58% of the country's area. The coastline is 254 km long; the west coast is 147 km long, and the east coast is 107 km long. Collapse and subsidence during the dry season are common in the freshwater region of Ca Mau Province. Therefore, this study focused on identifying the main factors influencing subsidence, using the AHP method to determine the weights of

influencing factors and applying GIS technology to compile maps of locations at risk of subsidence in Ca Mau province.



Figure 1. Study location map.

2.2. Data and Method

2.2.1. Data

The data used in the article include:

- Meteorological data of stations in the study area (Source: Information and Data Center, Vietnam Meteorological and Hydrological Administration).
- Data on groundwater exploitation flow (Source: National Center for Water Resources Planning and Investigation).
- Information on factors: 1) geology, 2) soil, 3) evaporation, 4) dry season flow, 5) land use and 6) groundwater exploitation (Source: Department of Survey,

Mapping and Geographic Information Viet Nam).

2.2.2. Methodology

a) Application of AHP method (Cheng et al., 2002; Saaty, 2008) to determine factor weights: The factors affecting subsidence due to drought and groundwater exploitation in the study area were selected are: 1) geological structure; 2) Soil documents; 3) Groundwater flow exploitation; 4) Water flow in the dry season; 5) Current land use status; 6) Evaporation in the dry season. This article used AHP to calculate the weights of factors affecting subsidence in the study area.

b) Applying GIS to overlay factor map layers to build a subsidence risk map: 1) GIS technology is applied to edit component map layers; 2) Overlay component map layers with corresponding weights to edit the subsidence map in the study area.

c) Applying Python and Dart programming languages to build a warning system: 1) Python programming language is used to calculate and process results to build a warning system for the risk of subsidence due to drought and groundwater exploitation in the study area; 2) Dart programming language is used to build the user interface and display results of drought subsidence warning systems and groundwater exploitation for the study area.

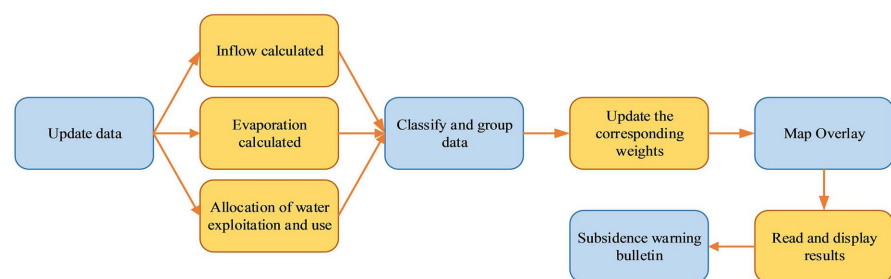


Figure 2. Structure of the subsidence risk warning system.

3. Results and Discussion

3.1. Results of AHP Application to Calculate Factor Weight

The paper selects 6 main factors affecting subsidence in the study area to evaluate the influence weight, the selected factors are presented in **Table 1**.

Table 1. Selected criteria for assessing the risk of land subsidence.

No.	Selection criteria	Data sources used
1	Geological structure	Geological map of the study area (scale 1:10,000)
2	Soil documents	National Center for Water Resources Planning and Investigation
3	Groundwater flow exploitation	National Center for Water Resources Planning and Investigation

Continued

4	Water flow in the dry season	Calculated according to SCS (Curve Number Method, 1964, 1972)
5	Current land use status	Land use map of the study area (scale 1:10,000)
6	Evaporation in the dry season	Calculated according to Penman-Monteith formula (Allen et al., 1998; FAO, 2000)

The weights of factors affecting subsidence in the Ca Mau Peninsula area are shown in **Table 2**.

Table 2. Weight matrix of evaluation factors.

Element	Land	Q _{dry}	Geological	Land use	ET _{dry}	Q _{exploit}	W _i
Land	0.033	0.125	0.012	0.014	0.012	0.024	0.036
Q _{dry}	0.100	0.375	0.110	0.293	0.261	0.639	0.296
Geological	0.100	0.125	0.037	0.011	0.017	0.024	0.052
Land use	0.233	0.125	0.329	0.098	0.012	0.071	0.145
ET _{dry}	0.233	0.125	0.183	0.293	0.087	0.030	0.159
Q _{exploit}	0.300	0.125	0.329	0.293	0.609	0.213	0.312

The result shows that CI = 0.101 and CR = 8.1%. As the CR value is less than 10%, the weight can be used.

The subsidence risk index of the study area is calculated according to the following formula:

$$\begin{aligned} \text{Risk of subsidence (C)} = & (\text{Land} \times 0.036) + (\text{Q}_{\text{dry}} \times 0.296) + (\text{Geological} \times 0.052) \\ & + (\text{Land use} \times 0.145) + (\text{ET}_{\text{dry}} \times 0.159) \\ & + (\text{Groundwater exploitation} \times 0.312) \end{aligned} \quad (1)$$

Formula (1) weighted with the influencing factors (land, Q_{dry}, geological, land use, ET_{dry}, groundwater exploitation) was applied to build a land subsidence risk zoning map, as shown in **Figure 2**. The study results are shown a subsidence risk zoning map that provides an intuitive and general overview of the areas with high subsidence risk and can be a document to help managers consult in the work of building a socio-economic development plan for the Ca Mau Peninsula region.

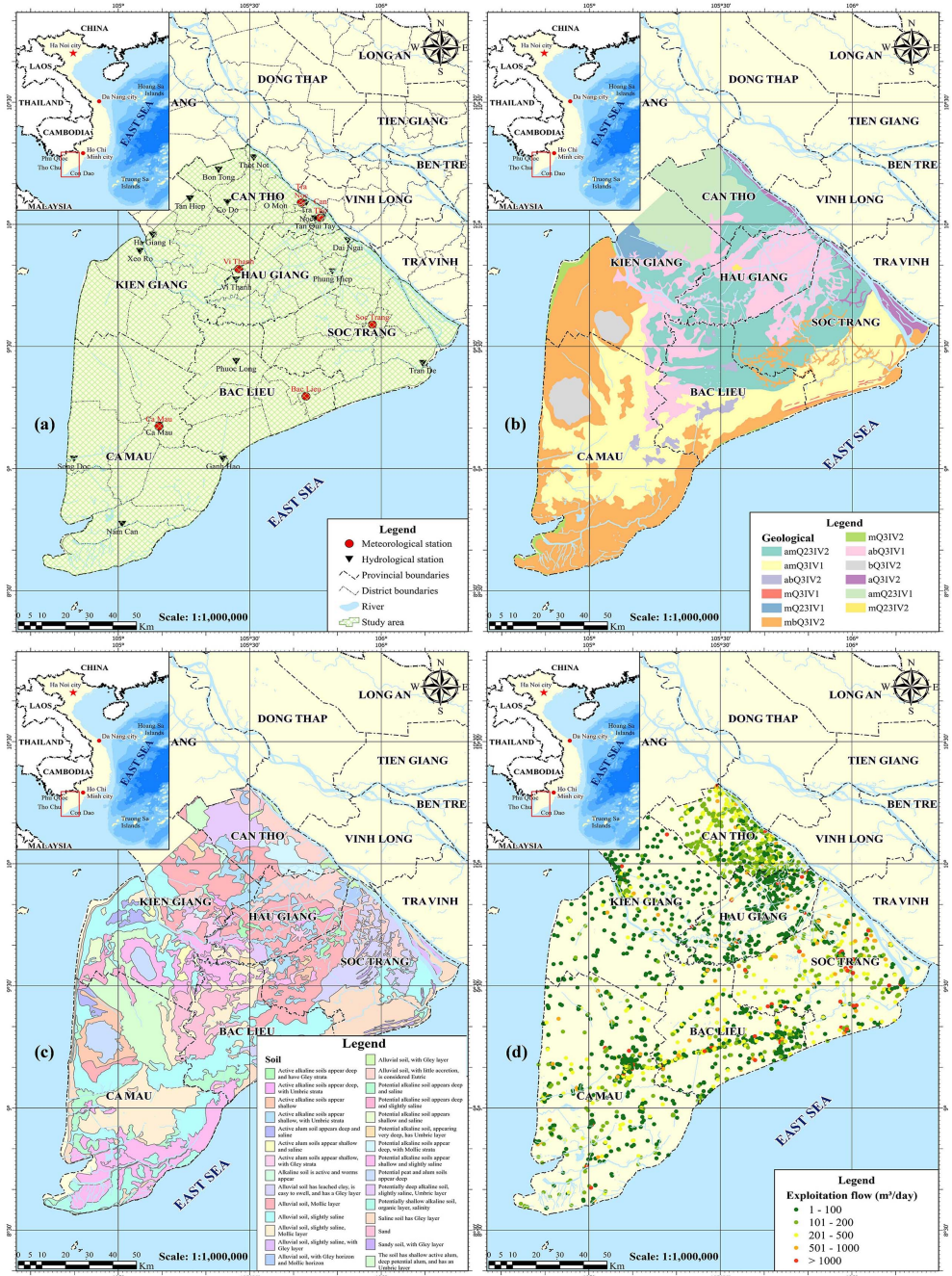
3.2. Results of Applying GIS technology to Determine Map Layers of Factors Affecting Subsidence

Hydro-meteorological data at stations in the study area were collected from six meteorological gauges (Ca Mau, Bac Lieu, Soc Trang, Vi Thanh, Tra Noc, and Can Tho) and sixteen hydrology gauges (Thot Not, Bon Tong, Tan Hiep, Co Do, Ha Giang 1, Xeo Ro, Vi Thanh, Tra Noc, Tan Quy Tay, Dai Ngai, Phung Hiep, Tran De, Phuoc Long, Ganh Hao, Nam Cam and Song Doc) (**Figure 3(a)**). These data

were collected to calculate the flow and the amount of evaporation in the dry season in the study area. The data were collected from the Information and Data Center, Vietnam Meteorological and Hydrological Administration, Ministry of Natural Resources and Environment (MoNRE).

Geological, soil, and land use maps are presented in **Figure 3(b)**, **Figure 3(c)**, **Figure 3(e)**.

Groundwater exploitation documents were collected from the National Center for Water Resources Planning and Investigation (NAWAPI) (**Figure 3(d)**).



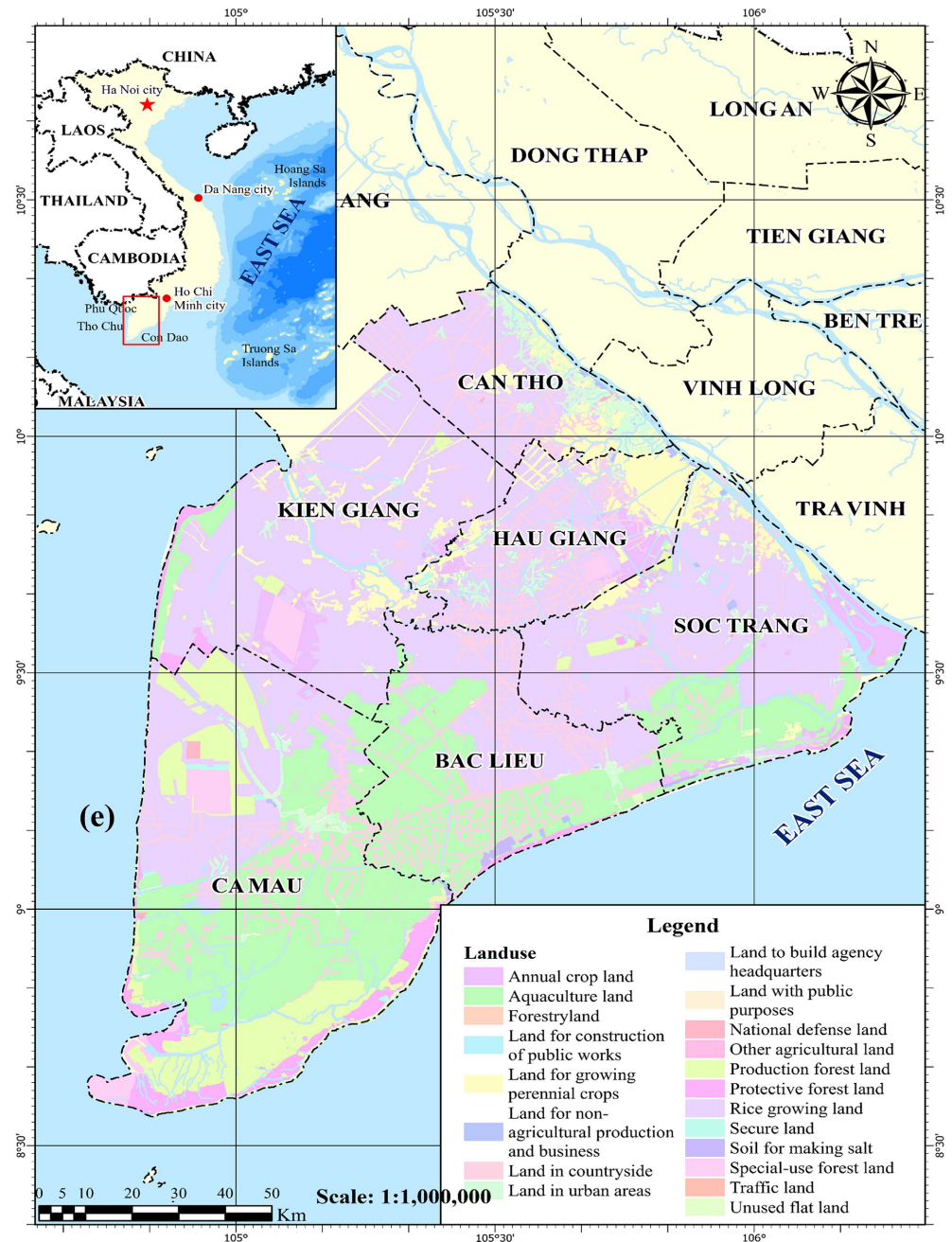


Figure 3. (a) Hydro-meteorological data at stations in the study area, (b) geological, (c) soil, (d) groundwater flow exploitation, (e) land use maps (Tri et al., 2024).

3.3. Early Warning System for Subsidence Risk Due to Drought and Groundwater Exploitation

The system after construction has the interface as shown in **Figure 4**.

The main modules of the system include:

- The module for updating total water volume data which allows users to update the total water volume that fluctuates over time or the total water volume forecast (calculated according to long-term hydrological forecasts—one month period).

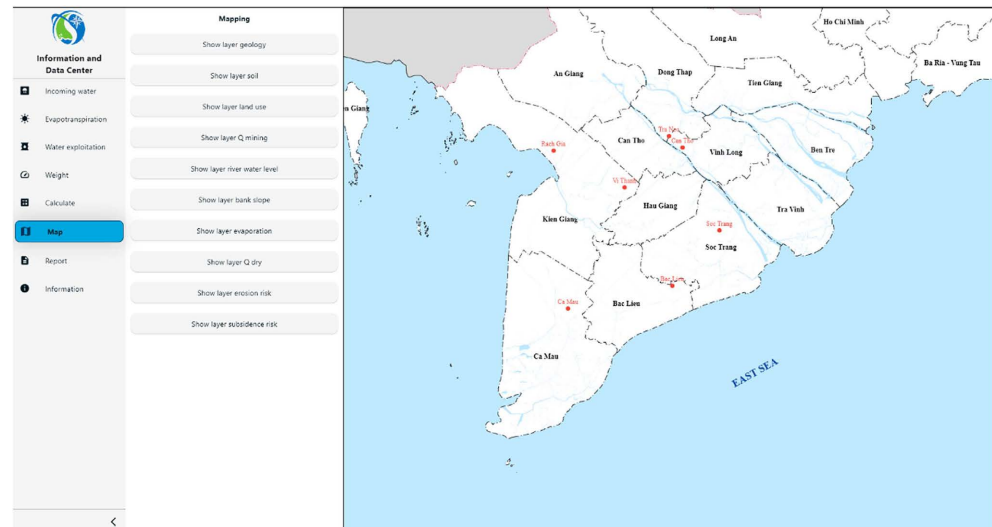


Figure 4. Interface of the warning system for the risk of subsidence due to drought and groundwater exploitation.

- The module for calculating evapotranspiration allows users to calculate the forecast evapotranspiration according to the selected formula.
- The module for allocating water volume for exploitation and use according to space and time allows updating values related to the amount of water replenished as well as the total amount of water exploited and used in the study area.
- The module for updating influencing factors layers allows users to update changes in factors affecting landslides and subsidence in the area.
- The module for updating the classification and grouping of data layers allows updating the classification of groups of influencing factors.
- The module for updating weights corresponding to data layers allows users to update and change the weights of influencing factors.
- The map overlay module allows users to edit maps that overlap maps of factors affecting components in the study area.
- The reading and displaying module will allow users to display maps of areas at risk of landslides and subsidence according to groundwater exploitation plans as well as drought conditions.
- The warning message publishing module will allow users to publish news in Word format according to a pre-determined format to send to relevant parties.

The warning system for the risk of subsidence due to drought and groundwater exploitation after construction has been tested with the drought period of 2024. Below are the results of the system testing.

3.4. System Test Results

The system has been tested for the dry season in 2024. The subsidence risk map results from the system were compared with the subsidence location of the research area that was surveyed. **Table 3** is the actual surveyed subsidence location in the dry season in 2024.

Table 3. Subsidence locations in the study area.

No	Subsidence locations	Characteristic
1	Rach Ruong Canal, Khanh Loc Commune, Tran Van Thoi District	- Subsidence of about 500 m (new canal and road built in 2023, about 1km long) - Subsidence just occurred in 2024, never occurred before
2	Canal No. 2, Khanh Loc Commune, Tran Van Thoi District	- A section of road subsided about 30 m - The subsidence just occurred in 2024, never happened before
3	Rach Ruong C, Khanh Loc Commune, Tran Van Thoi District	- Subsidence of about 50 m road - Subsidence occurred in 2024, never happened before
4	Hao Sai Canal, Khanh Loc Commune, Tran Van Thoi District	- A road section of about 200 m has subsided - The subsidence just occurred in 2024, never happened before
5	Nha May Canal, Khanh Hung Commune, Tran Van Thoi District	- Subsidence of about 70 m road - Subsidence just occurred in 2024, never happened before
6	Hang B Canal, Khanh Hung Commune, Tran Van Thoi District	- A section of road subsided about 2 5m - The subsidence just occurred in 2024, never happened before
7	Khanh Hung Commune, Tran Van Thoi District	- A road section of about 100 m subsided - The subsidence just occurred in 2024, never happened before
8	Cong Nghiep B Canal, Hung Commune, Tran Van Thoi District	- A road section subsided about 60 m - New subsidence occurred in 2024, never happened before
9	Ngang Canal, Trum Thuat B Hamlet, Khanh Hai Commune, Tran Van Thoi District	- A road section subsided about 50 m - New subsidence occurred in 2024, never happened before
10	Khanh Hung A Canal, Khanh Hung A Hamlet, Khanh Hai Commune, Tran Van Thoi District	- A road section subsided about 30 m - New subsidence occurred in 2024, never happened before

The comparison results are shown below in **Figure 5**. It is evident that the computation results when compared to real survey data collected in the research area, are reasonably accurate in terms of the sites of subsidence that happened during the dry season of 2024 at certain points. The map of subsidence risk, which is the outcome of a warning system for the risk of subsidence due to drought and groundwater exploitation that has been tested, shows that the 10 points in the study area where subsidence actually occurred during the dry season of 2024 all correspond with areas with high risk of subsidence (orange).

As a result, a warning system for the possibility of landslides and subsidence in the Ca Mau peninsula region has been constructed using calculating software.

4. Conclusion

In recent years, the impact of climate change has become increasingly severe in Vietnam in general and the Ca Mau peninsula in particular. Drought is increasingly severe, leading to a serious shortage of fresh water in the study area. As a result, groundwater is increasingly overexploited in the area, leading to increasing subsidence. This is one of the urgent issues not only for the study area but also for the whole society. A warning system for the risk of subsidence due to drought and groundwater exploitation has been built and validated for the dry season in 2024. The results of the system have provided a map showing the location of the

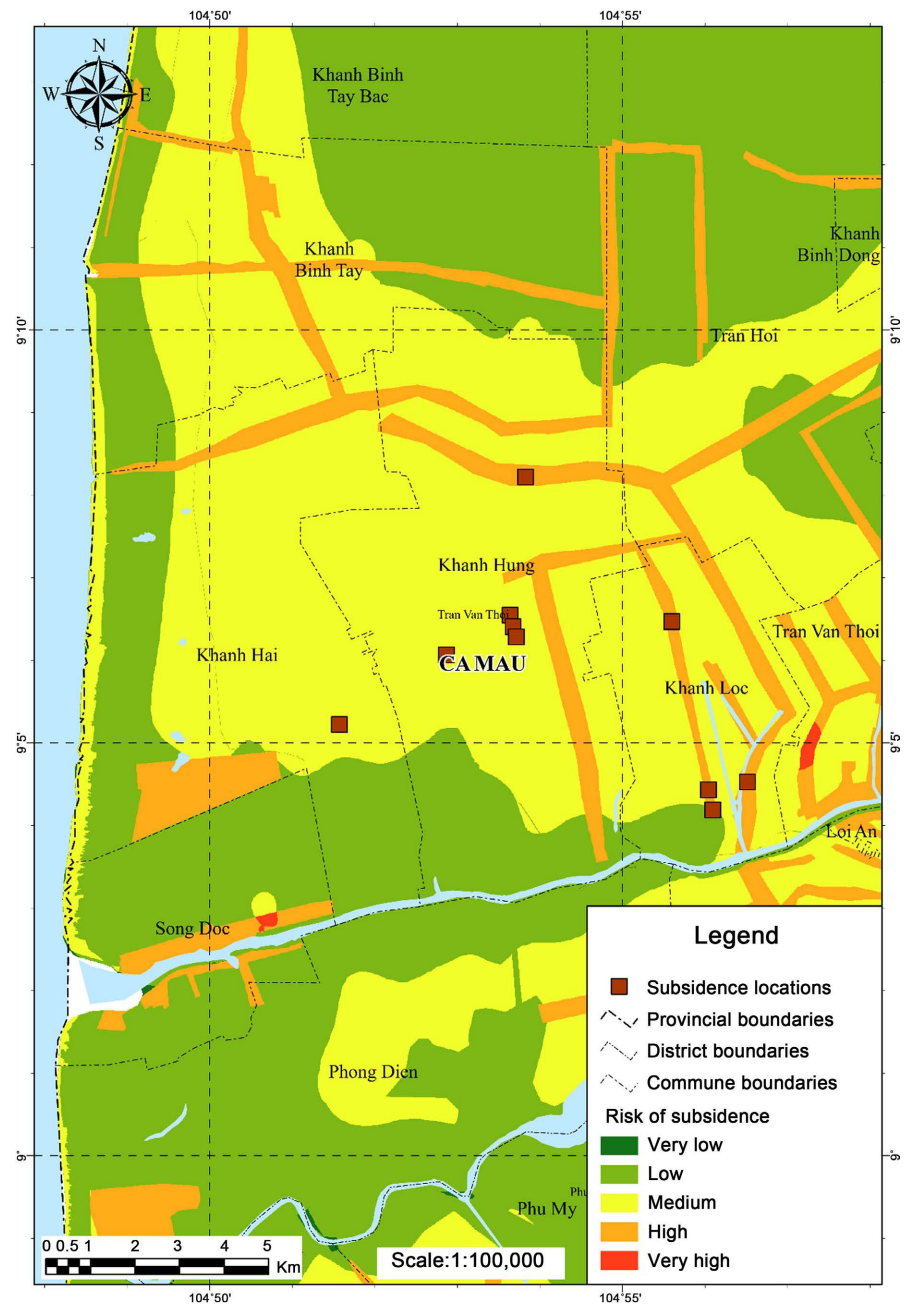


Figure 5. Comparison of actual subsidence locations and subsidence locations from warning system.

potential for subsidence in the dry season in 2024, which is relatively accurate when compared with the subsidence points that were investigated and surveyed later. The warning system is built based on the factor weighting method combined with GIS technology. This system can be replicated in areas facing increasing subsidence.

During the operation of the warning system for the risk of subsidence due to drought and groundwater exploitation, users can continue to improve the accuracy of the system results by changing the factor weights to suit the impacts of

climate change as well as socio-economic development activities. This is one of the main advantages of this system. The research results will be continuously adjusted to improve accuracy.

The main contribution of this study is to build a subsidence risk warning system for the Ca Mau Peninsula, where subsidence is increasingly serious and there is no early warning system for this phenomenon. The system contributes to supporting forecasters in warning of the risk of subsidence.

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Conflicts of Interest

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

References

- (n.d.). *WRI*.
<http://wri.monre.gov.vn/pages/nghien-cuu-xay-dung-cong-nghe-canh-bao-som-nguon-nuoc-mua-can-va-nguy-co-han-han-cho-dong-bang-song-cuu-long.aspx>
- Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop Evapotranspiration—Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper 56. Food and Agriculture Organization of the United Nations.
- Chen, Y., Guo, L., Xu, J., Yang, Q., Wang, H., & Zhu, C. (2024). Monitoring and Cause Analysis of Land Subsidence along the Yangtze River Utilizing Time-Series InSAR. *ISPRS International Journal of Geo-Information*, 13, Article 230.
<https://doi.org/10.3390/ijgi13070230>
- Cheng, E. W. L., Li, H., & Ho, D. C. K. (2002). Analytic Hierarchy Process (AHP): A Defective Tool When Used Improperly. *Measuring Business Excellence*, 6, 33-37.
<https://doi.org/10.1108/13683040210451697>
- Fadhillah, M. F., Achmad, A. R., & Lee, C. (2020). Integration of InSAR Time-Series Data and GIS to Assess Land Subsidence along Subway Lines in the Seoul Metropolitan Area, South Korea. *Remote Sensing*, 12, Article 3505. <https://doi.org/10.3390/rs12213505>
- Food and Agriculture Organization of the United Nations (FAO) (2020). *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements*.
- Franczyk, A., Bała, J., & Dwornik, M. (2022). Monitoring Subsidence Area with the Use of Satellite Radar Images and Deep Transfer Learning. *Sensors*, 22, Article 7931.
<https://doi.org/10.3390/s22207931>
- Gao, L., Song, Y., & Zhao, B. (2021). 3D Visualization Monitoring and Early Warning of Surface Deformation in Subsidence Area Based on GIS. *Complexity*, 2021, Article ID: 6675241. <https://doi.org/10.1155/2021/6675241>

- Ghosha, J. K., Bhattacharyab, D., Boccardoc, P., & Samadhiya, N. K. (2010). A Landslide Hazard Warning System. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science*, XXXVIII, 261-265.
- Hemmelder, S., Marra, W., Markies, H., & De Jong, S. M. (2018). Monitoring River Morphology & Bank Erosion Using UAV Imagery—A Case Study of the River Buëch, Hautes-Alpes, France. *International Journal of Applied Earth Observation and Geoinformation*, 73, 428-437. <https://doi.org/10.1016/j.jag.2018.07.016>
- Hu, B., Yang, B., Zhang, X., Chen, X., & Wu, Y. (2019). Time-Series Displacement of Land Subsidence in Fuzhou Downtown, Monitored by SBAS-INSAR Technique. *Journal of Sensors*, 2019, Article ID: 3162652. <https://doi.org/10.1155/2019/3162652>
- Jena, J., Mahed, G., Chabata, T., Doucoure, M., & Gibbon, T. (2024). Monitoring and Early Warning Detection of Collapse and Subsidence Sinkholes Using an Optical Fibre Seismic Sensor. *Cogent Engineering*, 11, Article ID: 2301152. <https://doi.org/10.1080/23311916.2023.2301152>
- Mallick, A., & Parvin, M. (2019). *Risk Informed Early Warning System and Non-Migration Pattern Riverbank Erosion Areas*. https://www.preventionweb.net/files/67631_67631rivererosionearlywarningreport.pdf
- Minh, N. D., Duong, H. H., & Tien, N. M. (2018). Building an Agricultural Drought Monitoring System Using Satellite Data, Piloted in Ninh Thuan Province, Vietnam. *Journal of Water Resources Science and Technology*, 50, 1-7. (In Vietnamese)
- Ning, D., Zhu, J., Guo, H., Zang, X., & Wang, H. (2023). Research on Monitoring, Early Warning and Prevention System of Land Subsidence in Beijing-Tianjin-Hebei Region. *Journal of Physics: Conference Series*, 2468, Article ID: 012149. <https://doi.org/10.1088/1742-6596/2468/1/012149>
- Ochungo, E. A., Ouma, G. O., Obiero, J. P. O., & Odero, N. A. (2019). An Assessment of Groundwater Grab Syndrome in Langata Sub County, Nairobi City-Kenya. *Journal of Water Resource and Protection*, 11, 651-673. <https://doi.org/10.4236/jwarp.2019.115038>
- Phuong, T. A., Tra, T. V., Duc, N. A., Son, D. H., Cuong, T. M., Anh, P. N., Linh, B. H., & Nhung, T. T. (2022). Development of a WebGIS-Based Integrated Flood and Drought Monitoring and Early Warning System in Real-Time: A Preliminary Study. *Vietnam Journal of Hydrometeorology*, 4, 314-324. [https://doi.org/10.36335/vnjhm.2022\(eme4\).314-324](https://doi.org/10.36335/vnjhm.2022(eme4).314-324)
- Pourmorad, S., Mohanty, A., Sushree Sangita Dash, S. S. (2021). *Prediction and Potential Detection of Land Subsidence by Integrating AHP and Programming Methods: Case Study of South Eastern Iran*. Research Square. <https://doi.org/10.21203/rs.3.rs-853378/v1>.
- Quang, P. H., Cong, P. H., & Chinh, P. Q. (2021). *Effective Solution for Early Warning of Landslides and Flash Floods Based on IoT and WSN Technology*. (In Vietnamese) https://cic.vast.vn/index.php?option=com_content&view=article&id=229:gi-i-phap-hi-u-qu-c-nh-bao-s-m-s-t-l-d-t-va-lu-quet-d-a-tren-cong-ngh-iot-va-wsn&catid=11&Itemid=104
- Saaty, T. L. (2008). Decision Making with the Analytic Hierarchy Process. *International Journal of Services Sciences*, 1, 83-98. <https://doi.org/10.1504/ijssci.2008.017590> <https://www.rafikulislam.com/uploads/resources/197245512559a37aadea6d.pdf>
- Salameh, E., Abdallat, G., & Odeh, T. (2024). The Damaging Effects of Abstracting the Deep Aquifers’ Groundwater in Jordan-Quality Constraints. *Journal of Geoscience and Environment Protection*, 12, 250-278. <https://doi.org/10.4236/gep.2024.123014>
- Soil Conservation Service, SCS (1964). *National Engineering Handbook, Section 4, Hydrology*

(p. 450). Department of Agriculture.

Soil Conservation Service, SCS (1972). *National Engineering handbook, Section 4, Hydrology* (p. 762). Department of Agriculture.

Song, Y., Chen, X., Zou, B., Mu, J., Hu, R., Cheng, S. et al. (2023). Monitoring Study of Long-Term Land Subsidence during Subway Operation in High-Density Urban Areas Based on DinSAR-GPS-GIS Technology and Numerical Simulation. *Computer Modeling in Engineering & Sciences*, *134*, 1021-1039.

<https://doi.org/10.32604/cmes.2022.021164>

Tri, D. Q., Nhat, N. V., Tuyet, Q. T. T., Pham, H. T. T., Duc, P. T., & Thanh Thuy, N. (2024). Applying an Analytic Hierarchy Process and a Geographic Information System for Assessment of Land Subsidence Risk Due to Drought: A Case Study in Ca Mau Peninsula, Vietnam. *Sustainability*, *16*, Article 2920. <https://doi.org/10.3390/su16072920>