Establishing the Vertical Movement Map of Cuu Long Delta River by GNSS Data

NGUYEN Gia Trong[1,5)]*, *NGUYEN Viet Nghia*[1)], *LY Lam Ha*[1,2)], *VU Trung Dung*[3)], *NGUYEN Quoc Long*[1)], *KIM Thi Thu Huong*[1,4)], *PHAM Ngoc Quang*[1)], *NGUYEN Viet Quan*[1)]

[1)] Hanoi University of Mining and Geology, 18 Vien street, Hanoi, Vietnam
[2)] Department of Economic Infrastructure, Cam Lam, Khanh Hoa Province, Vietnam
[3)] Delta technology development and Investment joint stock company, Bac Giang Province, Vietnam
[4)] AGH University of Science and Technology, Krakow, Poland
[5)] AGH University of Science and Technology, Krakow, Poland

http://doi.org/10.29227/IM-2023-02-26

Submission date: 19-08-2023 | Review date: 10-09-2023

Abstract

Mekong Delta is an area with an important position in the socio-economic development of Vietnam. However, due to the impact of climate change as well as of the construction of hydroelectric dams in the upstream of the Mekong River in recent years, saline intrusion and flooding have been occurred because of high tide. According to published researches, the Mekong Delta is being experienced surface subsidence with a rate of up to centimeters per year, that exacerbates the impact of saline intrusion and flooding. Thus, studying to establish the surface subsidence map is an urgent need in this site. There are many of technologies to create the vertical movement map such as: Levelling, INSAR, GNSS, etc. Up to now, there are no scientific reports on the application of GNSS to monitor the vertical movement in this area. In this paper, the authors have calculated the largest vertical displacement velocity up to 3cm/year based on processing GNSS observations of nearly 20 GNSS monitoring station in the area using Bernese software. From these results, the research team has made the vertical movement map of Mekong, Vietnam.

Keywords: *land subsidence, GNSS, vertical crustal deformation, Mekong del*

1. Introduction

Land subsidence is a global environmental hazard due to many natural and human activities. In many places on the world, it has been observed that there are about 150 countries recorded land subsidence. Land subsidence affects to infrastructures, building on the earth surface, then the living of human and animals living on the surface. Therefore, it is necessary to find the solutions, create subsidence maps to minimize negative effects of land subsidence on both humans and environment.

Currently, there are some methods to determine land subsidence. There are methods, which have been used for a long time, called conventional methods, such as geodetic leveling, total station, Global Navigation Satellite System (GNSS). There are non-contacts technology methods, such as Unmanned Aerial Vehicle (UAV) [1], Interferometric Synthetic Aperture Radar (InSAR) [2] and Laser Scanner [3]. The model non-contact technologies have shown big significant advantages, such as allowing monitor the large areas surface with a low spatial spacing. Meanwhile, the conventional methods have disadvantageous in limit and discrete measurement points on the Earth's surface, but it provides high result accuracy, approximate 1mm / 3years [10]. Such monitoring can be carried out in discrete cycles or continuous measurement depending on the used technology. Before the continuous satellite receiver station (CORS) was built, the application of GNSS technology to determine the displacement of the continental plates was measured, according to the traditional relative static method. When the predetermined measurement time is reach, the receiver will be placed at the points to receive the satellite signal. CORS technology, with the advantage of providing continuous data over time, allows to determine the land displacement better and with higher reliability [4].

On the world, using GNSS to monitor the land displacement is conducted widely. In 2009, Jing Xiang and partners published a article about using GNSS for monitoring land subsidence in mining areas and hazard early warning [5]. GW Michel and partners determined surface displacement in Eastern and South-Eastern of Asia by GPS measurements of Geodysea project in 2020, 2021 [6, 7]. Abou Aly and his partners in 2021 used GNSS to monitor land deformation in the Nile Delta. Basing on the results, they found the displacement areas, combine with geological characteristics, research group gave assessment and forecast for future subsidence [8].

In Vietnam, almost research projects have been focused on using GNSS technology to determine horizontal displacements.[4]. Nguyen Anh Duong and partners assessed the modern displacement of The Lai Chau - Dien Bien fault zone using the series of GPS measurements from 2002 to 2010. They showed that this fault zone moved to the East-Southeast direction 34.6 mm/year, and moved to the left 2.3 mm/year [9]. Nguyen Gia Trong and partners used Gamit/Globk to determine the displacement of CORS stations distributed over the territory of Vietnam [10]. In 2023, Vu Ngoc Quang and partners published an article about building a displacement monitoring and early warning system using GNSS-RTK techniques [11].

In this study, we use GNSS technology to monitor the land subsidence in the area of Mekong Delta, Southern of Vietnam. For this area, GNSS-derived vertical deformation has not been studied so far. The study is based on approxi-

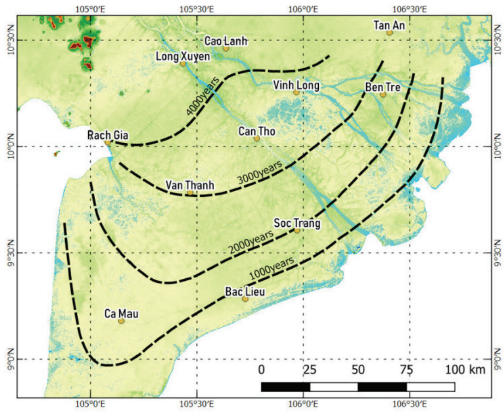

Fig. 1. Evolution of sedimentation and erosion in the Mekong Delta

Fig. 2. Flooding due to high tide in Can Tho, Vietnam

mately 1 years GNSS data, from 2020 to 2021. Vietnam has been seen one of the most threatened countries in the world by the climate change. Mekong Delta is one of the largest deltas on the world. The height of this area is almost the sea level, then it is always threatened by the sea level rise. Under the natural and human activities, the ground in this delta is continuously compacted, causing land surface subsidence. This subsidence process in some local is faster than the sea level rise. One day, low-lying areas of Mekong Delta will be flooded by the sea level rise if effective measures are not taken [12].

The remainder of the paper is structured as follows: Section 2 introduces the study area and data set. Section 3 shows the experimental results and discussion. Section 4 concludes the study.

2. Data and methodology

2.1 Area study

The Mekong Delta is one of the major deltas in the world and is also an important economic region of Vietnam. The topography of the Mekong Delta is very low, most of which are only a few meters above sea level and is regularly affected by saline intrusion and flooding caused by high tides. Is a relatively young delta in geological time, formed by sediments from the Himalayas flowing down the Mekong River about 6000 years ago. Over time, the sediment deposited on the seabed is raised to create land. The evolution of the deposition and erosion in the Mekong Delta is shown in Fig. 1 [12].

In the process of development, dyke systems were built to prevent flood water from entering agricultural lands, leading to the sediment of the Mekong River no longer distributed throughout the delta but deposited in rivers. or drift into the sea. During that process, the ground in this area continues to be compressed, causing surface subsidence. In addition, the construction of infrastructure works and the excessive exploitation of groundwater have contributed to the exacerbation of surface subsidence in the Mekong Delta.

Land subsidence has exacerbated the effects of tidal flooding (Fig. 2) [13] and saline intrusion [14] (Fig. 3) in the Mekong Delta.

2.2 Area study

The data used in this article is the data measured at 18 continuous GNSS data collection stations in Vietnam, provided by the Department of Survey, Mapping, and Geographic Information of Vietnam (DOSM) and Tuong Anh Science and Technology Equipment Joint Stock Company (TAST JSC) (as described in Tab. 1).

Among the stations described in Tab. 1, the stations managed by DOSM have benchmarks securely buried on the ground surface (Fig. 4a), while the stations managed by TAST JSC are civilian buildings (Fig. 4b).

All of the above data collection stations are continuous GNSS data collection stations, but due to data collection conditions, the research team only collected data in two days, January 1st, 2020, and January 2nd, 2021 respectively.

GNSS data is processed by Bernese software version 5.2, all baselines of network processed with data received by 18 CORS stations in Vietnam (as described in Tab. 1) and 6 stations in the IGS network including: DAEJ, DGAR, IISC, IRKJ, PIMO and POL2.

First, the data is processed on a daily basis (session) to get the coordinates of the stations in each data day. By combining the re-

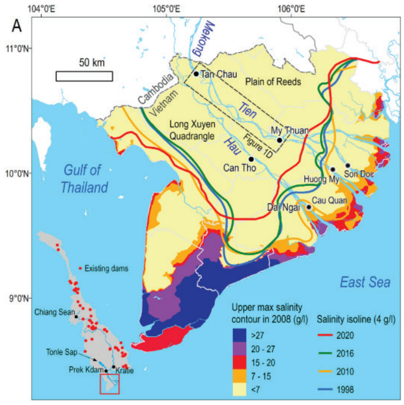

Fig. 3. Saltwater intrusion in the Mekong Delta, Vietnam

Tab. 1. Information about GNSS CORS stations

No.	Site's name	Receiver	Antenna	Interval (s)	Management
1	BLIE	LEICA GR50	LEIAR25.R4 LEIT	30	DOSM
2	BTRE	TRIMBLE NETR9	TRM55971.00 NONE	15	TAST JSC
3	BTRI	LEICA GR50	LEIAR25.R4 LEIT	30	DOSM
4	CAOL	LEICA GR50	LEIAR25.R4 LEIT	30	DOSM
5	CLAH	TRIMBLE NETR9	TRM55971.00 NONE	15	TAST JSC
6	CLON	LEICA GR50	LEIAR25.R4 LEIT	30	DOSM
7	CMAU	TRIMBLE NETR9	TRM55971.00 NONE	15	TAST JSC
8	CTH1	TRIMBLE NETR9	TRM55971.00 NONE	15	TAST JSC
9	CTHO	LEICA GR50	LEIAR25.R4 LEIT	30	DOSM
10	GOCO	TRIMBLE NETR9	TRM55971.00 NONE	15	TAST JSC
11	HCMC	TRIMBLE NETR9	TRM55971.00 NONE	15	TAST JSC
12	HGAN	TRIMBLE NETR9	TRM55971.00 NONE	15	TAST JSC
13	HOCM	LEICA GR50	LEIAR25.R4 LEIT	30	DOSM
14	HTIE	LEICA GR50	LEIAR25.R4 LEIT	30	DOSM
15	MHOA	LEICA GR50	LEIAR25.R4 LEIT	30	DOSM
16	MTHO	LEICA GR50	LEIAR25.R4 LEIT	30	DOSM
17	RGIA	TRIMBLE NETR9	TRM55971.00 NONE	15	TAST JSC
18	XMOC	TRIMBLE NETR9	TRM55971.00 NONE	15	TAST JSC

(a) (b)

Fig. 4. (a) CORS station managed by DOSM, (b) CORS station managed by TAST JSC

Tab. 2. Information about GNSS CORS stations

No.	Site'name	Displacement (m)	RMS (m)
1	BLIE	-0.0301	0.0048
2	BTRE	-0.0477	0.0111
3	BTRI	-0.0117	0.0046
4	CAOL	-0.0297	0.0046
5	CLAH	0.0286	0.0168
6	CLON	-0.0223	0.0048
7	CMAU	0.0021	0.0121
8	CTH1	-0.0638	0.0051
9	CTHO	-0.0211	0.0046
10	GOCO	-0.0129	0.0047
11	HCMC	-0.0563	0.0375
12	HGAN	-0.0399	0.0128
13	HOCM	-0.0027	0.0046
14	HTIE	-0.0076	0.0052
15	MHOA	-0.0063	0.0046
16	MTHO	-0.0121	0.0046
17	RGIA	0.0093	0.0149
18	XMOC	-0.0092	0.0047

sults of the normalization between the two periods, the amount of displacement of the points over time can be determined.

The results of determining vertical displacement at stations in this study are compared with published calculation results such as Nguyen Gia Trong et al. [4], GIZ Energy Support Program [12] and Nguyen Viet Quan et al. [15].

3. Results and discussions

The vertical displacement of the points determined by Bernese 5.2 software is as follows:

From the results given in Tab. 2, it can be seen that the displacement determination error of some receiver stations managed by TAST JSC has a large RMS error (more than 1

Tab. 3. The vertical displacement of this study is with the results published by Nguyen Gia Trong (PA1) et al. [4], Nguyen Viet Quan et al. (PA2) [15].

No.	Site's name	Displacement (m)	Comparative data (m) PA1 PA2	Differrence (m)
1	BLIE	-0.0301	- -	- -
2	BTRI	-0.0117	-0.0167 -0.0048	-0.0050 0.0069
3	CAOL	-0.0297	- -0.0266	- 0.0031
4	CLON	-0.0223	-0.0255 -0.0163	-0.0032 0.0060
5	CTHO	-0.0211	-0.0143 -0.0100	0.0068 0.0110
6	HOCM	-0.0027	- 0.0015	- 0.0012
7	HTIE	-0.0076	-0.0052 -0.0016	0.0024 0.0060
8	MHOA	-0.0063	- -0.0038	- 0.0029
9	MTHO	-0.0121	- -0.0010	- 0.0111

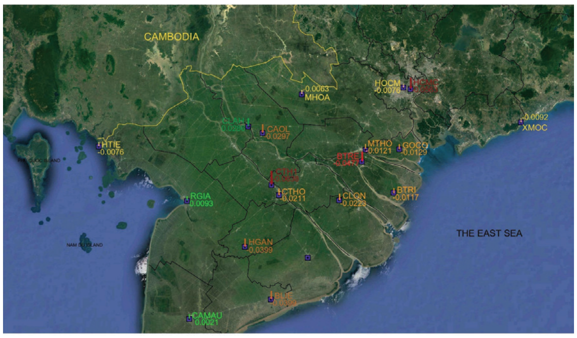

Fig. 5. Map of vertical displacement stations in the Mekong Delta, Vietnam

cm), it is necessary to study a plan to eliminate errors in the measurement data. The RMS error of displacement of all stations managed by DOSM is approximately 5 mm which can be partly influenced by the error of the remaining stations. Stations RGIA, HCMC, CTH1, CMAU, CLAH have an irregular amount of displacement possibly due to station structure.

The vertical displacement of this study is compared with the results published by Nguyen Gia Trong (PA1) et al. [4], Nguyen Viet Quan et al. (PA2) [15]. The results of the comparison are shown in Tab. 3.

From the results in Tab. 2, it is shown that the difference in the amount of displacement is determined at the mm level.

According to the published displacement determination results [12], the subsidence level of 100 m of sediment from the ground is at 2-3 cm/year in Ca Mau; In Can Tho, by using a shallow observation pile system, the settlement level is 17 mm/year, while the subsidence rate of residential buildings is 27 mm/year determined from InSAR data [12]. Combined with the comparative data in Tab. 3, it can be seen that the vertical displacement determination results of the stations managed by DOSM in this study are relatively consistent with the previously determined results.

Based on the results of determining the displacement of the points as presented above, build a map representing the displacement of the points as shown in Fig. 5.

4. Conclusion

Subsidence along with the effects of climate change such as inundation and saltwater intrusion has had a great impact on the Mekong Delta of Vietnam. Accurately determining the amount of displacement is a very necessarily need to be able to make decisions related to socio-economic development for this area.

This study provides initial results on vertical displacement mapping for the Mekong Delta of Vietnam. The results determined in this study are relatively consistent with the results previously determined both by GNSS technology and using shallow pile system to observe settlement.

The number of stations used to map vertical displacement in this study is relatively limited, so the results do not accurately reflect the vertical displacement for the whole region. Besides, it is necessary to analyze the GNSS data in time series to obtain more accurate vertical displacement results.

6. Acknowledgements

The authors would like to thank the Vietnam Department of Surveying, Mapping and Geographic Information (DOSM), Tuong Anh Science and Technology Equipment Joint Stock Company (TAST JSC) for providing experimental data in this article.

The paper was presented during the 7th POL – VIET International Conference on Scientific-Research Cooperation between Poland and Vietnam, 18-20.10.2023, AGH, Krakow, Poland.

Literatura – References

1. Dawei, Z., Lizhuang, Q., Demin, Z., Baohui, Z., & Lianglin, G. (2020). Unmanned aerial vehicle (UAV) photogrammetry technology for dynamic mining subsidence monitoring and parameter inversion: A case study in China. Ieee Access, 8, 16372-16386.
2. Kim, T.T.H., Tran, H.H., Phan, T.A., & Lipecki, T. (2022, October). Mining-Induced Land Subsidence Detected by Persistent Scatterer InSAR: Case Study in Pniówek Coal Mine, Silesian Voivodeship, Poland. In International Conference on Geo-Spatial Technologies and Earth Resources (pp. 23-42). Cham: Springer International Publishing. http://doi.org/10.1007/978-3-031-20463-0_2.
3. Matwij, W., Gruszczyński, W., Puniach, E., & Ćwiąkała, P. (2021). Determination of underground mining-induced displacement field using multi-temporal TLS point cloud registration. Measurement, 180, 109482.
4. Nguyen, G.T., Nguyen, V.N., Ly, L.H., Nguyen, H.T., Vu, T.D., Nguyen, V.Q., & Bui, H.T. (2022). Research proposal on the model for estimation vertical velocity by GNSS Technology. In Proceedings of The 5th National Conference on Sustainable Earth, Mine, Environment (EME 2022) for creative innovation and enhancement of the national competitiveness, Hanoi, 392-399. Doi: 10.15625/vap.2022.0192
5. Jing-Xiang, G., & Hong, H. (2009). Advanced GNSS technology of mining deformation monitoring. Procedia Earth and Planetary Science, 1(1), 1081-1088.
6. Michel, G. W., Becker, M., Angermann, D., Reigber, C., & Reinhart, E. (2000). Crustal motion in E-and SE-Asia from GPS measurements. Earth, planets and space, 52(10), 713-720.
7. Wilson, P., & Michel, G. W. (1998). The GEODYnamics of S and SE Asia (GEODYSSEA) Project.
8. AbouAly, N., Hussien, M., Rabah, M., Zidan, Z., & Saleh, M. (2021). Land deformation monitoring by GNSS in the Nile Delta and the measurements analysis. Arabian journal of geosciences, 14, 1-12.
9. Nguyen, A.D., FUMIAKI, K., Tran, D.T., Nguyen, D.X., Pham, D.N., Vy, Q.H., & Duong, C.C. (2011). Contemporary horizontal movement estimation for Lai Chau - Dien Bien fault inferred from repeated GPS measurements in 2002 – 2010. Vietnam Journal of Earth Sciences, 33(3), 690-694.
10. Nguyen, G.T., Nguyen, V.N., Pham, C.K., Nguyen, H.T., Ly, L.H., Vu, T.D., Nguyen, V.Q., Pham, N.Q. (2022). Determination of tectonic velocities in Vietnam territory based on data of CORS stations of VNGEONET network. Vietnam Journal of Hydrometeorology, 739, 59-66. doi:10.36335/VNJHM.2022(739).59-66
11. Vu, N.Q., Nguyen V.H., Vu, & D.C. (2023). Building a displacement monitoring system and early warning using GNSS-RTK technique. Journal of Science and Technology in Civil Engineering, 1V, 134-146. https://doi.org/10.31814/10.31814/stce.huce(nuce)2023-17(1V)-11
12. Ministry of Construction, (2019). Trouble underground - Land Subsidence in the Mekong Delta. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://www.eda.admin.ch/dam/countries/countries-content/vietnam/vn/sdc-publications/ground-subsidence_VN.pdf
13. http://daidoanket.vn/
14. Ho, H.L., Doan, V.B., Park, E., Shrestha, S., Tran, D.D., Vu, H.S., Nguyen, H.T.T., Nguyen, P.M., & Seijger, C. (2020). Intensifying saline water intrusion and drought in the Mekong Delta: From physical evidence to policy outlooks, Science of the Total Environment, 757,143919. https://doi.org/10.1016/j.scitotenv.2020.143919.
15. Nguyen, V.Q., Vu, D.T., Than, V.N. (2021). Application of VNGEONET system in surveying, mapping, earth sciences and other fields in digital transformation, In proceedings of National Conference on Geospatial Technology in the Earth Science and Environment, Hanoi, 25-32.