DEVELOPING TROPICAL CYCLONE RISK WARNING SYSTEM FOR NORTH CENTRAL VIET NAM

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Abstract: *Viet Nam is one of the most impacted countries by climate natural disasters especially tropical cyclone and tropical depression. Under climate change context, the natural disasters in prone areas have becoming more extreme. With the supporting of advance technology, warning systems are considered as effective measures to prevent and mitigate damages of natural disasters, in particular, tropical cyclone and tropical depression. Locating in the middle of Viet Nam and Gulf of Tonkin, the North Central region is directly affected by one to two tropical cyclones every year, one of the most tropical cyclone - impacted regions in Viet Nam. Developing an effective tropical cyclone risk warning system would be helpful to protect local people in tropical cyclone seasons. This paper proposes a methodology to assess tropical cyclone risk and introduce a practical risk warning system to apply to local hydrometeorological stations.*

Keywords: *tropical cyclone, risk assessment, warning system, North Central region.*

1. Introduction

Viet Nam is located in the Western Pacific region, the area with the most active tropical cyclones (TCs) in the world. Every year, on average about 5 - 7 TCs and tropical depressions make landfall or directly impact on Viet Nam, causing heavy damage to people, economic, social and environmental. For example, Typhoon Doksuri in 2017 killed 6 people, injured 37 people, collapsed more than 800 houses, damaged 190,000 houses and damaged 2,855 power poles. Total damage was estimated at over VND 11,000 billion [12]. In recent years, due to the effects of climate change, TC and tropical depression activity in the East Sea have been abnormal, causing more serious consequences [11]. Therefore, assessing the risks caused by TC is one of the necessary tasks for disaster prevention, control and response [1, 9].

The assessment of disaster risk in general and risk due to TC in particular is carried out in two approaches: Risk assessment based on consequences of natural disasters and risk assessment based on constituent elements. The approach to risk assessment based on the consequences of natural disasters is expressed through the assessment of the probability of occurrence of a disaster and its consequences [6]. Applying this approach, a TC risk assessment was carried out in Queensland (Australia), in which the consequences of the TC were determined to include damage to power lines, communications, houses, infrastructure and transport infrastructure [10]. This approach does not require complicated calculations and can be used to assess risk for disaster impact zoning. However, the assessment of consequences requires observations and historical records, so this approach can hardly be applied in disaster risk forecasting and warning.

Many studies in the direction of risk assessment approach based on constituent factors have been carried out to assess TC risk. Hurricane risk for coastal areas in the United States is assessed through the Hurricane Risk Index (HDRI) [2]. The

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HDRI index is built as the criteria of factors H, E, V, in which V includes two components: sensitivity level (S) and adaptive capacity (AC). The criteria for expressing H include wind, storm surge and rain. Expression criteria E includes population, buildings and power lines. For S, research focuses on population, housing and economic criteria. The area's AC is mainly the criteria of connectivity, shelter, communication and other resources. Similar approaches have also been taken in the coastal areas of China [25, 26] and in Bangladesh [17].

In order to build a real-time TC risk warning system for the North Central region to serve natural disaster prevention and control, the article conducts a pilot study on risk warning for tropical storm Sinlaku occurring in 2020. For the calculation of factor H for real-time risk warning, wind and rain forecast data will be established from the TC forecast bulletins of the National Center for Hydro - Meteorological Forecasting (NCHMF) combined with results of the numerical weather prediction (NWP) models. The study is limited to the scope of the Hydro - Meteorological Station in the North Central region [16], including three provinces: Thanh Hoa, Nghe An, and Ha Tinh.

2. Study area and Methodology

2.1. Study area

The study is pilot conducted in the North Central region of Viet Nam including Thanh Hoa, Nghe An and Ha Tinh. These coastal provinces were formed by Ma and Ca rivers that flowing from scattered rocky mountains to Tonkin Gulf. The North Central region is a populated and large region that occupies 7.8% of total population and 10.1% of area. The North Central region has an important location of Viet Nam with the Tonkin Gulf in the east, Lao PDR in the west, Red River Delta in the North and Mid Central region in the south. Locating at an inner corner of the S-shape of Viet Nam map, North Central is one of the most TC - impacted regions. Every year, the region is directly affected by one to two tropical cyclones with the maximum sustainable wind reaching upto Category 14.

In 2020, tropical storm Sinlaku began as a tropical depression on July 31 in the East Sea. The Sinlaku strengthened into a tropical storm the following day. On August 2nd, the center of the Sinlaku was at 19.4°N and 106.4°E, on the coastal areas of Ninh Binh - Nghe An province. The maximum sustainable wind reached Category 8 (60 - 75 km/h) with gust wind reaching Category 10. The Sinlaku made landfall on Ninh Binh - Thanh Hoa province at 13:00 on August 2nd, then rapidly weakened and dissipated on August 3rd, 2020 [4].

2.2. Data

Data sources (primary and secondary) used in disaster risk warning due to TC for the North Central region include:

- Data on economy and society of 3 provinces Thanh Hoa, Nghe An, Ha Tinh detailed to district level are collected from statistical yearbooks at provincial and district level [18, 19, 20].

- Data on communication, disaster prevention works, number of coastal resorts are collected through field surveys in localities.

- Data of the 10 m wind speed, 24-hour accumulative rainfall and the forecast confident interval are taken from existing NWP products at NCHMF combined with the NCHMF's TC forecast bulletin.

2.3. Method

The TC risk warning system is conducted using indicator-based risk assessment. In which, risk is assessed from three components hazard, exposure and vulnerability [8]. Hazard is defined as a danger potentially causing damages in human, property, society, economy, and environment [23]. The hazard refers to the magnitude, frequency, and extent of disasters. Exposure indicates the presence of properties in the adversely affected area of hazards. Vulnerability (V) refers to the tendency of hazards, such as people, their lives, and their assets, to be adversely affected by hazards [23]. The following will introduce the detailed estimation of each component of risk.

2.3.1. Determination of TC hazard from meteorological forecasting reports

According to [14] the TC hazard is composed by criteria of intensity and probability of occurrence. In which, the hazard intensity is characterized by the TC maximum 10 m sustainable wind and the amount of rainfall due to TC. In this paper, the 10 m wind speed (Vmax) and 24-hour accumulative rainfall (R24) corresponding to forecast lead times are calculated of each district for determination of the hazard intensity. For the forecast lead time less than 24 hours, R24 is considered the accumulative rainfall in the first 24 hours of the forecast. The probability of TC occurrence is assumed to be equivalent to the confident interval (CI) of TC forecast. In order to calculate and warning the TC hazard nearly real time, it is necessary to forecast CI corresponding to forecast lead times for each district.

a. Determination of the 10 m wind speed

At each forecast lead time, Vmax for each district is calculated based on two information sources with including the NCHMF's TC forecast bulletin and results of the NWP model. For districts located inside the forecasted strong wind radius affected by TC, Vmax is assigned by the wind speed corresponding to the determined TC wind category. It is worth noting that the NCHMF's TC forecast bulletin only has information about the forecasted TC location and strong wind radius corresponding to the basic TC wind categories (Beaufort category of 6 and 10). Using the TC wind distribution profiles depending on the intensity and the strong wind radius corresponding to the basic TC wind categories, it is able to interpolate strong wind radius corresponding to the other TC wind categories.

b. Determination of the 24-hour accumulative rainfall

The 24-hour accumulative rainfall at each forecast lead time is taken from the NWP model similar to determining Vmax (in case the district location is outside the forecasted strong wind radius affected by TC).

c. Determination of the confident interval of TC forecast

In order to determine the confident interval of TC forecast, it is necessary to carefully analyze the method of determining this indicator. For a set of operational TC forecast data long enough, it is able to determine forecast error and CI. The CI could be determined by the high percentile (90%, 95%) or error intervals of approximately 1 - 3 times the standard deviation [24] or statistical empirical formulas [15] or using the method of random sampling with a large number of tests to ensure the level of statistical limitation for each specific sample set [5]. On the other hand, according to Tien et al [21], increasing the forecast quality of the TC track is also increase the forecast quality of the TC intensity, although this increase rate not really linear. Therefore, this paper approaches in a different way to determine CI assumed that the TC intensity forecast is considered as a conditional forecast for the TC track forecast.

This study uses the NCHMF's TC forecast data from April 2008 to September 2020 to calculate the Direct Position Error (DPE). The DPE of the models running in the NCHMF's is also evaluated to provide a basis for data addition with locations where the NCHMF's TC forecast bulletin is missing. Details of the DPE calculation are given in [22] and [13].

2.3.2. Assessing exposure and vulnerability

In this study the TC exposure is estimated based on indicators of people (E1), agriculture (E2), economy (E3) and infrastructure (E4). The sub-indicators of them are collected from statistic books or field survey. The estimation method is extracted from [7].

The V factor is made up of two components of sensitivity (S) representing characteristics of the exposure elements that increase the risk of natural disasters and adaptive capacity (AC) denoting the region's capacity in terms of technical, information, economic and educational capacities to enhance disaster resilience [23]. The list of indicators of exposure and vulnerability is summarized in Table 1.

Table 1. List of exposure and vulnerability indicators

Factor	Indicator	Sub-indicator
Exposure	People (E1)	Population
	Agriculture (E2)	Agricultural area
		Number of livestock and poultry
		Number of ships and boats with marine fishing engines
		Aquacultural area
	Trade and services (E3)	Number of businesses and economic establishments operating in the area
		Number of coastal tourist areas
	Infrastructure (E4)	Number of kilometers of roads, including national highways, provincial roads, and district roads
		Number of key projects (headquarters, schools, medical stations)
		Residential land area
Sensitivity	Socio-economy (S1)	Value of products obtained per hectare of cultivated land
		Value of products obtained per hectare of aquaculture water surface
		Percentage of poor and near-poor households
	Environment (S2)	Percentage of households that do not use hygienic latrines
		Percentage of households that do not use clean water
Adaptive capacity	Education (AC1)	Percentage of people graduating from high school and above/ Total population
	Economy (AC2)	Per capita income
	Social groups (AC3)	Percentage of people participating in health insurance
		Percentage of people participating in social insurance
	Health (AC4)	Number of health facilities/commune number
		Number of hospital beds/1000 people
		Number of medical staff/1000 people
	Information Communication (AC5)	Percentage of households using the internet
		Percentage of phone users
	Disaster prevention (AC6)	Traffic density
		Total capacity of mooring area

2.3.3. Classification of TC risk level

The factors H, E, V of TC are classified into five levels (very low, low, moderate, high, very high) and formed into 3 matrices of size 5 x 1 correspondingly. The risk level of TC is identified by a combination of these matrices. In this study, risk value is a product of hazard, exposure and vulnerability levels. More specifically, a value in grids of Figure 1 is equal to hazard level (vertical axis) multiply with exposure and vulnerability level (up and down horizontal axes). The maximum value is 5 × 5 × 5 = 125 and the minimum value is 1. These risk values are then classified into five levels corresponding to magnitude of storm risk in the study area (1 = very low, 5 = very high). Figure 1 is conducted to visualize the three-dimensional matrix of risk.

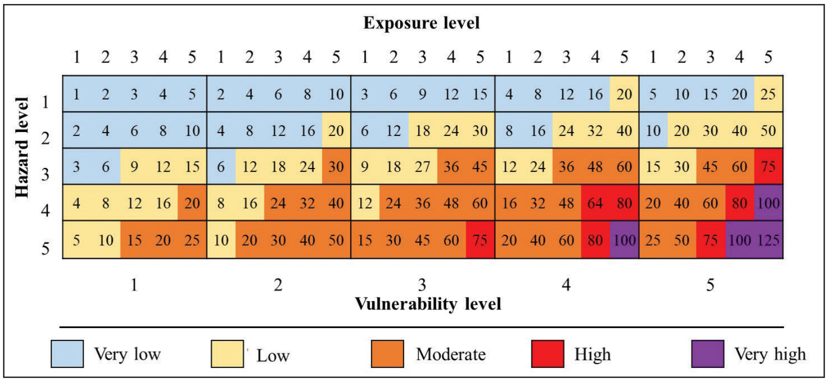

Figure 1. The combination of hazard, exposure and vulnerability

In which, risk value of 60 is product of hazard level 4 with exposure level 5 and vulnerability level 3 (4 × 5 × 3 = 60). TC risk levels are determined using professional knowledge of experts based on practical analysis. In this approach, the experts stated that the E and V are relatively static factors while H is considered as a dynamic factor (changes according to the TC forecast reports) in the risk warning system. The H factor dominates the exposure and vulnerability and the risk level increases as the level of E × V increases. Risk level of 5 is product of hazard level at least 4 and hazard level of 1 and 2 only product to risk level of 1 and 2 correspondingly. If hazard is at level 5, the consequently risk is at least level 3.

2.3.4. Developing TC risk warning system

The proposed warning system of TC risk consists of four elements: (1) Input data, (2) Risk knowledge; (3) Risk warning and (4) Risk information. The diagram of proposed warning system is presented in Figure 2.

The input data includes static data that is periodically updated such as socio-economic and meteorological data and dynamic inputs that is real-time updated during the TC event. The risk knowledge component refers to risk assessment and mapping. The third element is warning in terms of hazard and risk of the TC. The fourth element is to translate the risk warning into levels indicated in Decision No. 18/2021/QD-TTg [3].

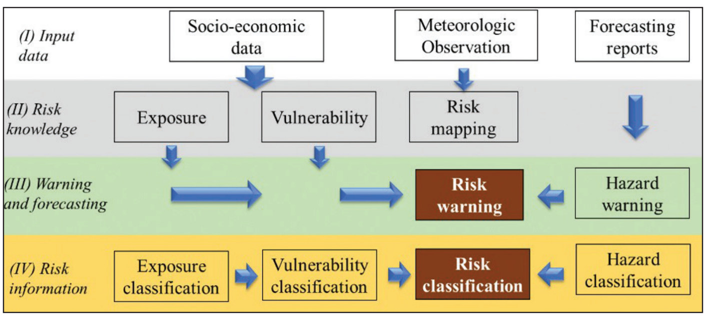

Figure 2. Diagram of TC risk warning system

The steps to develop the TC risk warning report in a TC is summarized following:

Step 1: Prepare risk knowledge before TC events.

This step can be conducted before TC events using historical observation and survey. The information of exposure, vulnerability and risk maps is provided.

Step 2: Calculate hazard indicators of TC from the NCHMF's TC forecast bulletin and the NWP model.

The third component is implemented once TC forecast bulletins are provided by NCHMF. The assessment is automatically updated following the real-time TC forecast (Figure 3).

Step 3: Transfer the risk assessment to risk level by a combination of matrix as Figure 1.

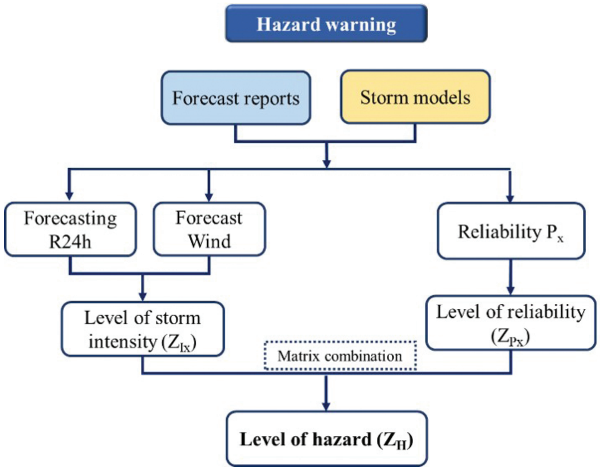

Figure 3. Method of hazard level estimation

3. Results and Discussion

3.1. Assessing exposure and vulnerability in North Central region

The map of TC exposure and vulnerability of the North Central region is shown in Figure 4. Accordingly, the exposure to TCs in coastal districts, towns and cities is usually at very high and high levels while in mountainous districts it is at low and very low levels. This is quite consistent with the actual nature of socio-economic and human characteristics. The TC vulnerability of the North Central region shows the highest vulnerability in mountainous and midland areas with underdeveloped economic conditions, high rates of poor and near-poor households such as Tuong Duong, Quy Chau districts (Nghe An province) or lowland areas where income is mainly based on farming and aquatic products such as Vinh Loc, Quang Xuong (Thanh Hoa province), Dien Chau (Nghe An province), Nghi Loc (Ha Tinh province) districts.

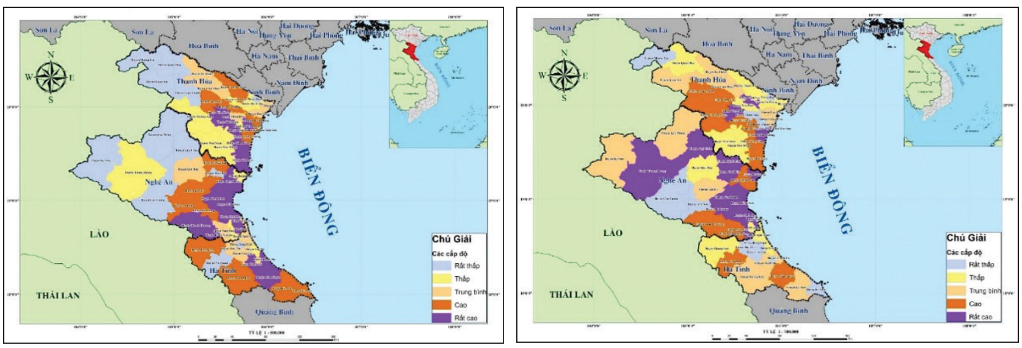

Figure 4. Maps of exposure (left) and vulnerability (right) in the North Central region

3.2. Pilot application of TC risk warning system in North Central region

The results of risk warning in tropical storm Sinlaku at the forecast lead time of 6, 12, 18 and 24 hour from 12 UTC on August 1, 2020 are shown in Figure 5. In general, risk caused by tropical storm Sinlaku is very low and low at the 6, 18, and 24 hour forecast lead times. The Sinlaku risk in North Central region reaches moderate (Level 3 categorized in Decision No. 18/2021/QD-TTg) at 12 hour forecast. The evaluation of risk warning shows an acceptable consistency with the actual impacts of Sinlaku on the North Central region. More specifically, at 7 am August 2, 2020 (Viet Nam time zone) the tropical storm approached the coast of Nghe An and Thanh Hoa provinces before landing in the coastal areas of Thanh Hoa - Ninh Binh provinces, then rapidly weakening on August 2, 2020.

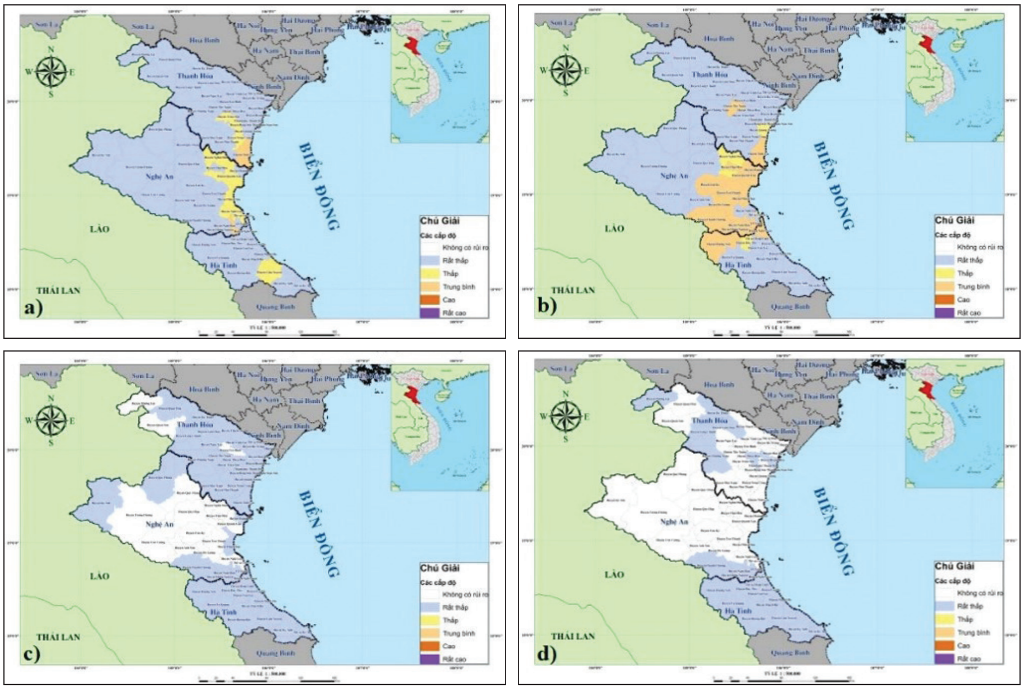

Figure 5. Warning maps of tropical storm Sinlaku at the forecast lead time of 6, 12, 18 and 24 hours from 12 UTC on August 1, 2020

4. Conclusion

The paper introduced a method to estimate TC risk using indicator-based approach. The proposed method is then adopted to develop the TC risk early warning system for North Central region. The estimation of TC risk demonstrates that risk level is different at provincial and district scales depending on local hazard, exposure and vulnerability. Even the Decision No. 18/2021/QD-TTg provide a classification of TC risk from the Beaufort based TC wind category and for provincial resolution, it is valuable to identify TC risk at district level in a combination of hazardous factor, natural and social characteristics and resilience of the local areas. The evaluation in the pilot case study shows promising applicability of the proposed warning system in other areas.

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References

1. Ahmed, B.; Kelman, I.; Fehr, H.; Saha, M. (2016). *Community resilience to cyclone disasters in coastal Bangladesh*. Sustainability, 8, 805.
2. Davidson, R.A.; Lambert, K.B. (2001). *Comparing the hurricane disaster risk of U.S. coastal counties*. Nat. Hazard. Rev., 2, pp-pp.
3. *Decision No. 18/2021/QD-TTg on detailed regulations on natural disaster risk levels.*
4. *Digital Typhoon: Typhoon Images and Information*. Available online: http://agora.ex. nii.ac.jp/ digital-typhoon/.
5. Efron, B. (1987). *"Better Bootstrap Confidence Intervals", J. Am. Stat*. Assoc., 82, 171–185.
6. Einstein, H. (1988). *"Landslide risk assessment procedure", Proceedings Fifth International Symposium on Landslides, Lausanne (Balkema)*, 2, 1075-1090.

7. Huong, H.T.L.; Hien, N.X.; Thuy, N.T.; Hang, V.T. (2020). *"Pre-disaster assessment of flood risk for mid Central Viet Nam", International Journal of Disaster Resilience in the Built Environment*. 1759-5908 DOI 10.1108/IJDRBE-06-2020-0065.
8. IPCC (2012). *"Managing the risks of extreme events and disasters to Advance clime change adaptation". A special report of working groups I and II of the Int' governmental Panel on climate change.* In: Field, C.B., Barros, et al, Cambridge University Press, Cambridge, UK, and New York, NY, USA, p. 582.
9. Joyce, K.E.; Belliss, S.E.; Samsonov, S.V.; McNeill, S.J.; Glassey, P.J. (2009). *"A review of the status of satellite remote sensing and image processing techniques for mapping natural hazards and disasters"*. *Prog. Phys. Geogr.,* 33, 1-25.
10. Middelmann, M.H. (Eds) (2007). *Natural Hazards in Australia. Identifying Risk Analysis Requirements*, Geoscience Australia, Canberra.
11. MONRE (2016). *Scenarios of Climate change and sea level rise*. Viet Nam Publishing house of Natural Resources, Environment and Cartograph.
12. NCHMF National Centre for Hydro-Meteorological Forecasting (2018). *Characteristics of Viet Nam hydro-meteorology (in Viet Namese)*.
13. Nang, T.Q.; Tien, T.T. (2020). *"Evaluation of the tropical cyclone track forecasting skills of the combinatorial model system", Viet Nam Journal of Hydro - Meteorology*, 717, 11-19 (Viet Namese).
14. Hien, N.X. (2020). *Research the scientific basis for classifying risk levels for natural disasters in Viet Nam*, Final report of the scientific and technological research project at ministerial level, code number TNMT.2017.05.04, Viet Nam institute of Meteorology, Hydrology and Climate Change (Viet Namese).
15. North, G.R.; Bell, T.L.; Cahalan, R.F.; Moeng, F.J. (1982). *"Sampling errors in the estimation of empirical orthogonal functions", Mon. Weather Rev.*, 110, 699-706.
16. North Central Hydro-Meteorological Station, Viet Nam Hydro-Meteorological Administration. http://dkvbtb.gov.vn/.
17. Quader, M.A.; Khan, A.U.; Kervyn, M. (2017). *"Assessing Risks from Cyclones for Human Lives and Livelihoods in the Coastal Region of Bangladesh". Int. J. Environ. Res. Public Health*, 14, 831.
18. *Statistic book of Thanh Hoa province (2018)*. Thanh Hoa Statistics Office (Viet Namese).
19. *Statistic book of Nghe An province (2018)*. Nghe An Statistics Office (Viet Namese).
20. *Statistic book of Ha Tinh province (2018)*. Ha Tinh Statistics Office (Viet Namese).
21. Tien, D.D.; Thanh, N.D.; Mai H.T. (2013). *"A study of the connection between tropical cyclone track and intensity errors in the WRF model", Meteorol. Atmos. Phys.*, 122, 55-64.
22. Tien, D.D.; Thanh, N.D.; Chanh, K.Q.; Hang, N.T. (2016). *"Surveying forecasting error and skill of the tropical cyclone track and intensity of forecasting centers and NWP models in the East Sea", Viet Nam Journal of Hydro - Meteorology,* 661, 17-23 (Viet Namese).
23. UNISDR (2009). *Terminology on disaster risk reduction*. https://www.undrr.org/publication/2009-unisdr-terminology-disaster-risk-reduction.
24. Wilks, D.S. (2006). *Statistical Methods in the Atmospheric Sciences,* Academic Press, pp. 704.
25. Yin, J.; Yin, Z.; Xu, S. (2013). *"Composite risk assessment of typhoon-induced disaster for China's coastal area". Nat. Hazards,* 69, 1423-1434.
26. Zhang, J.; Chen, Y. (2017). *Risk assessment of flood disaster induced by typhoon rainstorms in Guangdong province, China*. Sustainability, 11, 2738.