FLOOD RISK ANALYSIS OF VIETNAM COASTAL REGIONS

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Abstract: *In Vietnam, there has been a growing demand for the application of risk analysis, risk based decision making and risk management in various industries and sectors of government. Although the concepts i.e risk analysis and management, have been explored in various industries, there has not been yet any framework/guidance on how risk should be quantified and what would be the acceptable risk/risk criteria. In this paper an overview of concepts for risk management and risk evaluation is given. Risk concepts and methods and applications to establish an acceptable risk level and safety criteria are reviewed. Possible applications to Vietnam of a presented framework for evaluating risk are discussed. It is shown how the framework can be applied to propose an acceptable risk level of flooding at the national scale of Vietnam. The proposed criteria will be tested and applied in the assessment of flood risks in the low-lying coastal regions in Nam Dinh. Safety standards are explored by considering individual and societal acceptable levels of risk, and taking into account the current protected value and socio- economic developments.*

Keywords: ***risk evaluation, coastal risk, sea dikes, safety assessment, probabilistic design.***

1. Introduction

The concepts of risk and risk assessment have existed since our early history since prehistoric ancestors were threatened by natural hazards originating from wild fires, floods, earthquakes and wild animals. Some thousand years ago there had been various forms of belief and religion which played an important role in the attempts to narrow harm and in the ideas of assessing risk before making decisions.

The development of risk management has been described by Bernstein (1996), in the book "Against the Gods". It is a fascinating account of how human beings have lived with uncertainty from ancient times until now – from ascribing everything to the gods to the use of supercomputers for manipulating the vast quantity of data that we now have. The work which separates the past from modern times is the mastery of risk: “the notion that the future is more than a whim of the gods and those men and women are not passive before nature”.

Historically, the occurrence of disasters also triggered the improvement of protection systems. For example, the flood defence ystems in the Netherlands have mainly been shaped by flood disasters. The 30km long closure dam in the Zuiderzee (currently IJsselmeer) was constructed after the floods in that area in 1916. The storm surge disaster of 1953 flooded large parts of the southwest of the country and claimed more than 1800 fatalities. As a reaction to this disaster, the world famous Delta works were constructed to protect this region against sea flooding and the new safety policy against sea flood was established.

The hurricane Katrina hit New Orleans in 2005 and caused more than thousand deaths, serious economic and environmental damages. The event has not only induced a US $ 15 billion investment in better flood protection and a new flood safety policy in US . It also functioned as a wake-up call to some necessary improvements/ regulations of the safety policies against floods for many other countries, especially in Europe.

Traditionally, hazardous activities were designed and operated by references to codes, standards and hardware requirements. The present trend is a more functional orientation, in which the focus is on what to achieve, rather than the solution required. The ability to address risk is a key element in such a functional system. We need to identify and categorize risk to provide decision-making support concerning the choice of alternative arrangements and measures.

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The ability to define what may happen in the future, assess associated risks and uncertainties and to choose among alternatives lies at the heart of the risk management system, which guides us over a wide range of decision-making in various fields.

Corotis (2003) stated that the first introduction of safety through probability was made in a publication by the American National Bureau of Standards in 1945. Important theoretical developments were made in the field of structural safety in the 1940's and 1950's, for example in the papers by Freudenthal. In this field probabilistic methods have been used in design codes since the 1970's.

Bedford and Cooke (2002) describe the first applications of probabilistic risk analysis in other sectors. Basic probabilistic methods were developed in aerospace sector in the 1960's. Risk analysis was fully applied in the first time by the United States Nuclear Regulatory Commission (NRC, 1975). In this well-known Reactor Safety Study nuclear accident probabilities and consequences were assessed. In both fields of application, aerospace and nuclear engineering, the outcomes of quantitative risk analyses were heavily criticized and often rejected by decision makers. However, accidents, such as the incident with the Three Mile Island nuclear reactor in 1979 and the accident with the Challenger space shuttle in 1986, stimulated further development and application of risk analysis.

The chemical sector also has a similar history. Several accidents in 1970's, such as the Seveso accident in 1976 and the accident in Bhopal in India in 1984 triggered further development of quantitative risk assessment and risk regulation in the chemical industry (Fuller 1979 and Broughton 2005). Quantitative criteria for judging the tolerability of risks were proposed in the 1970' s and they were implemented in regulation in the Netherlands and the United Kingdom. A first full-scale risk analysis was undertaken in the United Kingdom in the Canvey Island study (HSE, 1978).

The principles of risk management were also applied to other areas. After the storm surge in the Netherlands in 1953 (see above), the optimal protection level that the new Delta Works should provide was determined in an econometric analysis. The costs of investments in dike safety were weighed against the benefits associated with risk reduction (van Dantzig, 1956). This approach resulted in an optimal level of safety with a corresponding failure probability of the dikes. Probabilistic techniques were used to design the Eastern Scheldt storm surge barrier, which is a part of the Delta Works. Furthermore, the risk based design concept for civil engineering systems was introduced in Vrijling et al. (1995) and further developed and applied widely in the field of flood defences in the Netherlands. The risk is assessed from different points of view resulting in different risk measures, i.e. individual, societal and economic considerations from a local level to national extent. The risk has been proposed as the basis for the design (Vrijling et al., 1998).

In this paper, a framework for deriving an acceptable of risk is summarized. Possible applications of the methods to Vietnamese situation are discussed. Special attention is paid to how the risk based framework could be applied to Vietnam conditions in determining the acceptable risk level of flooding at the national scale of Vietnam. The proposed criteria will be tested and applied in the assessment of flood risks in the low-lying coastal regions in Nam Dinh. Various options for safety standards are explored by considering individual and societal acceptable levels of risk and by taking into account the protected value and socio-economic developments.

2. Risk concepts

2.1 Risk definition

Several definitions of risk exist, but a useful general definition is the following:

"Risk is a function of the probabilities and consequences of a set of undesired events."

In many applications risk is expressed in terms of the product of an independent probability and a consequence magnitude (i.e. expected loss):

Risk = (Probability) x (Consequence)(3)

The above definitions allow the inclusion of several existing risk concepts.

A comprehensive overview of risk concepts and measures is presented in Jonkman et al. (2003). A summary of some main concepts is given here. Risk is often displayed using the so-called risk curve, which graphically shows the probability of exceedance of a certain level of consequences.A well-known example of such a risk curve is the FN curve (see Figure 2) for an example of the curve). It displays the probability of exceedance of N fatalities and is mostly shown on a double logarithmic scale. The FN curve was originally introduced for the assessment of the risks in the nuclear industry and is now used to display and limit risks in various countries and sectors (see also Jonkman (2007) for more detail on inferences of the FN curve regarding risk criteria).

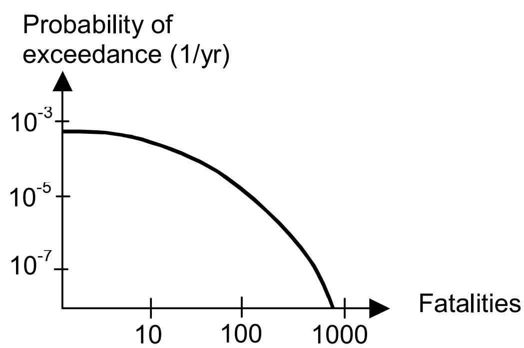

Figure 1: Example of an FN curve

In general, risk has units when quantified. However, the units of risk depend on how the likelihood and consequence are defined. Likelihood can be considered as a general concept that describes how likely a particular event is to occur. Frequency and probability can be used to express likelihood. However, these terms have different meanings and are often confusing. It is important to understand the difference between them.

Probability of an event can be defined as the chance of occurrence of the event compared to the population of all events. In other word, the probability can be viewed as the likelihood of that event occurring. Therefore, probability is dimensionless. It, however, often refers to a specific time frame or time unit, for example, as an annual exceedance probability or lifetime exceedance probability, generally per year.

Frequency defines the expected number of occurrences of an (particular extreme) event within a specific timeframe (in the case of return period this is usually expressed in years).

The consequence of undesirable event represents an impact such as human life, economic, social or environmental damage. These consequences can be considered as different dimensions of risk. Consequence may be expressed quantitatively by e.g. number of fatalities, monetary value, by ranking e.g. high, medium, low or descriptively.

Risk to people can be expressed in two complementary forms: Individual risk - the risk of death experienced by an individual person, and societal risk - the risk experienced by the whole group of people exposed to the hazard.

Risks of damage to an installation or property loss due to an accident of an activity are normally expressed in terms of costs of repair and damage. The risks in this case can be identified as economic risk. In a broader assessment, also other types of impacts, such as environmental, cultural and societal losses can be considered.

Individual risk

Individual risk is often defined as the probability that an average unprotected person, permanently present at a certain location, is killed due to an accident resulting from a hazardous activity. However, for various applications, such as flood hazards, the possibility to evacuate and the related reduction of individual risk is often included in the definition.

Vrijling *et al.* (1998) proposed to look at the pattern of preferences revealed in the accident statistics in order to derive an acceptable level of individual risk.

In the Netherlands the measure of individual risk is used to limit the risks nearby hazardous installations and transport routes. The Dutch Ministry of Housing, Spatial planning and Environment (VROM) has set $IR < 10^{-6}[year^{-1}]$. This standard is set for more or less involuntary imposed risks related to the sitting of hazardous activities. A broader set of risk standards ranging from voluntary activities to more involuntary risks is proposed by the Dutch Technical Advisory Committee on Water Defences (TAW, 1985):

$$IR = P_{fi} P_{d/Fi} < \beta_i \cdot 10^{-4} [year^{-1}] \quad (4)$$

In this expression the value of the policy factor β_i varies with the degree of voluntariness in which an activity i is undertaken and with the benefit perceived. It ranges from 100, in the case of complete freedom of choice like mountaineering (P_{fi},= 0.1 = $100*10^{-4}/10^{-1}$) to 0.01 in the case of an imposed risk without any perceived direct benefit. Vrijling (1998) proposed a β_i-value of 1.0 to 0.1 for flood risk. Recently, the Dutch government proposed an acceptable level of 1/100,000 (or 10^{-5}) per year as an acceptable level of risk for flooding.

Societal risk

The basis for calculation of societal risk is formed by the probability density function (pdf) of the number of fatalities. From the pdf an FN curve can be derived, which shows the probability of exceedance as a function of the number of fatalities, on a double logarithmic scale.

$$1 - F_N(x) = P(N > x) = \int_x^{\infty} f_N(x) \cdot dx \quad (5)$$

Where: $f_n(x)$the probability density function (pdf) of the number of fatalities per year; $F_N(x)$ probability distribution function of the number of fatalities per year, signifying the probability of less than x fatalities per year.

VROM from the Netherlands limits the societal risk for a chemical plant level by:

$$1 - F_{N_d}(x) < \frac{10^{-3}}{x^2} \quad for\ all\ x \geq 10 \quad (6)$$

In Vrijling *et al.* (1995) assumed that the accident statistics reflect the result of a social process of risk appraisal and that a standard can also be derived from them. In addition to that the total risk is considered also risk aversion in a society by adding the desired multiple k of the standard deviation to the mathematical expectation of the total number of deaths. Determination of the total risk was proposed by:

$$TR = E(N) + k \cdot \sigma(N) \quad (7)$$

Vrijling *et al.* (1998) notes that the societal risk should be judged on a national level by limiting the total number of casualties in a given year and tested against the norm of β_i*MF casualties by:

$$E(N_{di}) + k * \sigma(N_{di}) < \beta_i * MF \quad (8)$$

The multiplication factor *MF* is country-specific and based on: the value of the minimum death rate of the population, the ratio of the involuntary accident death rate (exclusive diseases) with the minimum death rate, the number of hazardous activities in a country (on average about 20 sectors) and the size of the population.

The translation of the nationally acceptable level of risk to a risk criterion for one single installation or plant is proposed by Vrijling *et al.* (1998) as:

$$1 - F_{N_{dij}}(x) < \frac{C_i}{x^n} \quad for\ all\ x \geq 10 \text{ with}$$

$$C_i = \left[\frac{\beta_i \bullet MF}{k \bullet \sqrt{N_{A_i}}} \right]^2 \quad (9)$$

where: N_A is number of independent installations; x is the number of casualties in a year, $F_N(x)$ is the distribution function of the number of casualties (probability of less than x casualties in a year); C_i is a constant that determines the position of the limit line; n is steepness of the limit line, a standard with a steepness of n=1 is called risk neutral. If the steepness n=2, the standard is called risk averse (Jonkman, 2007). It can also be transformed mathematically into a VROM-type of rule applicable at plant level for a single installation. For values of β_i = 0.03, k = 3 and N_A = 1000 the rule equates exactly to the VROM-rule.

Damage (economic) risk

Risks of damage to an installation are normally expressed in terms of costs of repair. These can be expressed in forms equivalent to group risks of death, as follows:

Expected annual damage cost: this is the long -term average cost of accidents per year.

Frequency-damage cost (FD) curves: these show the relationship between frequency and damage cost in the form of a plot of cumulative frequency (F) of accidents involving a given cost (D) or more.

The damage costs may be non-dimensionalized as fractions of the total replacement cost for the installation. Other forms in which damage risks may be expressed include:

- Frequencies of events of different severity, e.g. total loss frequency (FD curve)

- Contours of frequency of damage effect.

The FD curve displays the probability of exceedance as a function of the economic damage. The FD curve and the expected value of the economic damage can be derived from the pdf of the economic damage $f_D(x)$:

$$1 - F_D(x) = P(D > x) = \int_x^{\infty} f_D(x) \cdot dx \text{ and [13]}$$

$$E(D) = \int_0^{\infty} x \cdot f_D(x) \cdot dx \qquad (10)$$

where: $F_D(x)$: the cumulative distribution function of the economic damage; *E(D)*: expected value of the economic damage;

3. Risk evaluation for flooding situation in Vietnam

In this section some of the concepts for risk evaluation presented in the previous section are applied to Vietnam.

3.1 National acceptable risk levels: Safety standard for Vietnam

To establish a standard for the acceptable level of risk for engineering structures it is more realistic to base on the probability of a death due to a non-voluntary activity than on the number of casualties in the car traffic, which seems on the verge of acceptance. The probability of a death due to a non-voluntary activity is 1.3×10^{-4} per year for Vietnam (Mai Van, 2010). If this observation-based frequency is adopted as the norm for assessing the safety of activity *i*, then after rearranging the expression, and adopting a rather arbitrary distribution over N_A categories of activities in a country, each claiming an equal number of lives per year, the following norm is obtained for an activity *i* with N_{pi} participants in a country:

$$P_{fi} N_{pi} P_{d|fi} < \beta_i MF \qquad (13)$$

MF coefficient is followed by:

$$MF = averaged\ nr.of\ deaths * \frac{proportion\ of\ non-voluntary}{nr.of\ harzardous\ activities} =$$

$$= \left(p_{all\_cause} N_p\right) \frac{\left(\dfrac{p_{non\_vol}}{p_{all\_cause}}\right)}{N_A}$$

The ratio of the non voluntary accident death rate and the average death rate is ($1.3 \times 10^{-4} / 6.19 \times 10^{-3}$), approximately 1/4.76 for Vietnam. The MF factor is determined in accordance to Vietnam situation is:

$$MF_{VN} = 526{,}150 \times \frac{\left(\dfrac{1.3 \times 10^{-4}}{6.19 \times 10^{-3}}\right)}{20} \cong 550 \qquad (14)$$

3.2 Historical loss of life due to storms and floods in Vietnam

In this section, the safety norm is compared to historical loss of life due to flooding in Vietnam.

From the Department of Dike Management and Flood Control[1] (DDMFC, 2007) of Vietnam yearly fatalities and economic loss data due to floods and storms is collected. The data set is available from 1970 to 2007.

From the online reports of the Asian Disaster Reduction Centre[2] (ADRC, 2006) the top 25 flood disasters of Vietnam in the 20th century are available. These events are considered as historical events and included in analysis.

Combining these data sources gives summary of the losses due to floods and storms since 1953, see Figure 2.

[1] A department under Ministry of Agriculture and Rural Developments of Vietnam

[2] Asian Disaster Reduction Centre, bases in Japan

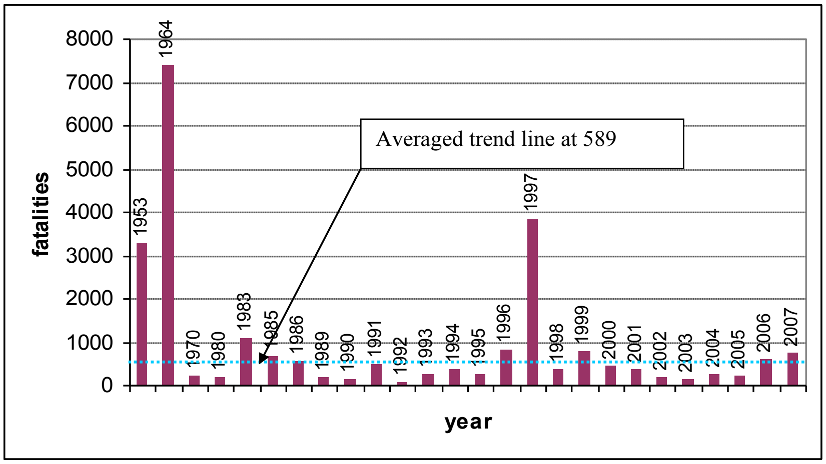

Figure 2: Historical data on loss of life due to floods and storms in Vietnam. Note that this is yearly total loss of life which is causes by inland floods, typhoon at coastal regions and storms at sea.

Based on the historical data of loss of life in Figure 2, an average life loss due to flood is estimated at approximately 589 fat. per year and a standard deviation of 1100 fat. per year. Practical experience in the last ten years also proves that flooding in Vietnam caused 500 deaths or more annually.

Referring to the established national standard, $TR=E(n)+k\sigma(n)<\beta$ 550, flooding risk in Vietnam over the whole country is relevant with the policy factor β from 1 to 10 (when k takes values of from 0 to 3). This implies that flooding is viewed and currently accepted by the Vietnamese as neutral.

Information on total number of affected people is available in 19 storm and flood events (see Figure 3). On that basis one can determine the average mortality rate for an event from the ratio of number of death and total number of affected people. The overall mortality rate for those directly exposed to floods in Vietnam in the last century is approximately $3x10^{-3}$ per event.

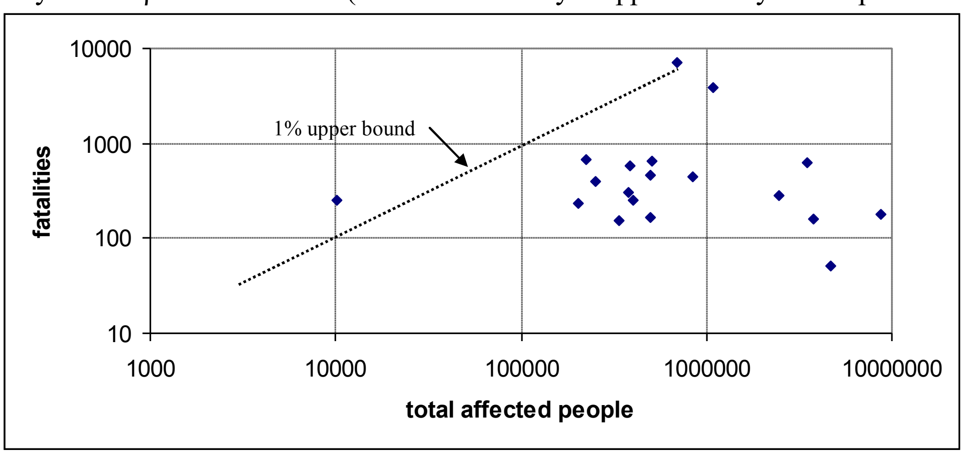

Figure 3: Observed fatalities due to floods vs. total number of affected people in Vietnam. The 1% upper bound line for mortality rate follows from an analysis of global data on coastal floods in Jonkman (2007).

The national safety norm of β*100 has been established and tested for various hazardous activities in the Netherlands (Vrijling, 1998). The interesting meaning of the norm is that for any activity under consideration, the norm means the total expected number of yearly deaths caused by the activity over the country. Comparing this with the situation in Vietnam for traffic and flooding (see Table 1), the norm of βx550 seems reasonable and has been applied to the analyses in the remainder of this chapter.

Table 1: Comparison of actual risk in the Netherlands and Vietnam

Activities	Netherlands			Vietnam		
	Mean (death/year)	MF	Beta	Mean (death/year)	MF	Beta
Traffic	1000	100	1 - 10	12300	550	15 - 25
flooding	1.6	100	0.01 - 0.1	589	550	1 - 10

3.3 Individual risk due to coastal flooding in Vietnam

The individual risk for coastal flooding, IR flood, in Vietnam can be estimated by:

$$IR_{flood} = p_{f-flood} \times p_{d/F-flood}$$

Where:

$p_{f\text{-}flood}$ is actual probability of inundation (per year).

$p_{d/F\text{-}flood}$ is conditional probability, which means a probability that an individual who lives in the protected coastal region would be killed given occurrence of the sea flood.

In Vietnam the existing coastal flood defences are required to meet 1/20 year design safety standard. If the flood defence system fulfils the standard, the inundation probability is of 0.05 per year. This is considered in estimating the individual risk due to flooding for the required situation. The failure probability of the actual existing dike system is estimated at 0.15 in the preceding reliability analysis. Therefore, estimation of actual individual risk due to flooding is based on this value.

In general the conditional probability of getting killed depends on various factors, namely e.g:

- Warning time before flood occurring
- Type of floods: predictable or unpredictable
- Possible shelters/ degree of exposure to flood, etc.
- Effectiveness of evacuation

Regarding these above aspects in estimating the conditional probability, since there is hardly any information available in Vietnam, it is suggested to base the estimation on expert opinions and past experiences of coastal flooding in Vietnam. The following information has been collected by means of meetings and/or communication with Vietnamese experts who have most knowledge on coastal flooding in Vietnam (representatives of the Dike Department, MARD and WRU) and other experts in the Netherlands. (21)

The Vietnamese coast is hit (almost) every year by typhoons. Therefore the populations in coastal areas are relatively well aware of and prepared for the risk flooding. It is expected that this awareness will lead to high evacuation percentages (90 – 98%). Given the relatively limited size of the flooded areas there are good opportunities to evacuate or find shelter within the area.

Additionally, in many coastal areas severe and deep flooding is limited to the area near to the coast (between 1 to 3 km from the coastline, depths can reach 1 to 3m, see also figure 4). Areas further away may affected by flooding but, generally, with limited depth (<1m).

The experiences of the last coastal flooding events shows that the evacuation in general goes as follows. Firstly, vulnerable people such as young, elderly people are transported out of the affected area. This could be 30 to 40% of the total affected population. Secondly, the rest of the population, approximately 60% moves away from the coastal strip to a more inland location that is less affected by flooding and characterized by limited flood depth (0.5m). These evacuations are often coordinated by local authorities. A small part of the population (5%), consisting of especially young men, stay in the direct coastal area to take care of property and direct recovery. This would mean that only 5% young men are affected directly by severe coastal flooding. The exposed rate in this case can be taken as 5% of the total population in the affected area.

Jonkman (2007) has shown that the mortality due to these coastal flood events is generally around 1%. This research was based on historical information of coastal floods in the Netherlands, U.K, U.S and Bangladesh. This “1%-rule of thumb” was considered relatively high for flood events along the Vietnamese coast. A value of 0.2% is proposed in Mai Van (2010) for Vietnam based on discussions with Vietnamese experts. In the previous section, based on the historical data of loss of life and total number of effected people due to storm induced flood of the coastal regions in the last century (ADRC, 2006) the rate is estimated at approximately 0.3%. This means that 0.3% of the exposed population will not survive.

The conditional probability then can be determined by:

$p_{d/F\text{-}flood}$=p(exposure) x p(death given exposure)= 0.05 x $3.10^{-3}=1.5\text{x}10^{-4}$

Substitutes $p_{f\text{-}flood}$ and $p_{d/F\text{-}flood}$ to Eq.(21) lead to an actual individual risk of approximately $2.25\text{x}10^{-5}$ per year.A proposal for a required individual risk due to flooding in Vietnam would be $7.5\text{x}10^{-6}$ per year and thus current individual risk is higher than desired.

Referring the actual IR to the IR criteria, the policy factor for flooding in Vietnam becomes 0.1. Comparing IR_{flood} to individual risk due to traffic accident, the risk due to flood is lower and a factor of approximately 10 is found.

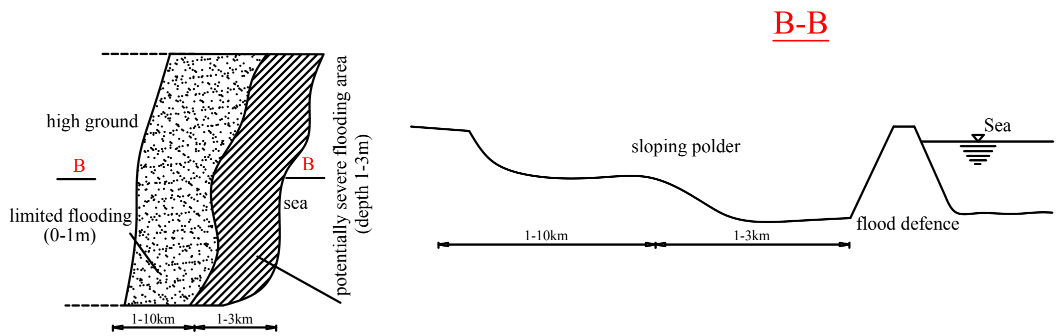

Figure 4: Schematic plan view of typical flood pattern for coastal flooding in Vietnam, e.g. in Nam Dinh

3.4 Societal risk due to flood on a country level

An FN-curve for flooding for the whole Vietnam including top 25 historical flood events is presented in Figure 5. The FN-curve has an expected value of 541 fat/year and standard deviation of 1169 fat/year when fitting to lognormal distribution.

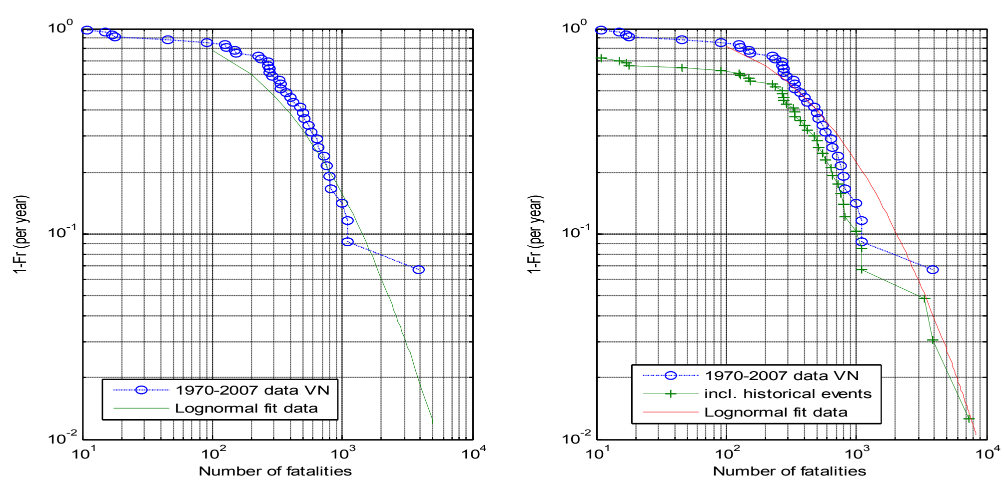

Figure 5: FN-curve due to flooding in Vietnam

The historical data is well described by an lognormal curve with a shape parameter α=728 fat/year. In Figure 6, the FN curve for the flooding in Vietnam is compared to some other risks in the Netherlands (data taken from Vrijling et al. 1998). The figure shows that the risks of sea flooding in Vietnam are much higher than other risk types in the Netherlands, including flood. This could be due to two reasons: (i) natural difference between Vietnam and the Netherlands. Vietnam has a relatively narrow low-lying coastal strip along the coast so coastal flood defences are not so crucial comparing to those in the Netherlands, a country which has more than half of the land areas below the mean sea and river level; and (ii) the fact that flood occurs quite frequently in Vietnam and therefore the Vietnamese population gets more used to floods than most Western population.

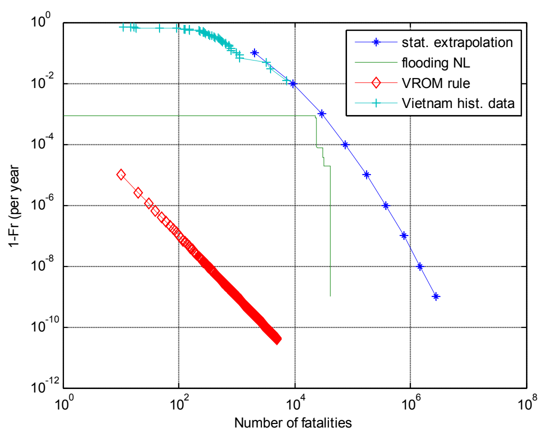

Figure 6: Flood risk in Vietnam compares to that of the Netherlands (FN-curve for flood risk in the Netherlands is based on scenario analysis and simulations, not on actual loss of life data).

In order to satisfy the criteria for the case of Vietnam, $TR=E+k\sigma < \beta x550$, different choices for k give different policy factors β approximately ranging from 3.7 to 8.6 and the norm coefficient (C_i) is found accordingly. This shows a significant difference with the situation in the Netherlands where β ranges from 0.1 to 1.0. This difference is found by factor 10 when comparing the flood policy factors of Vietnam and Netherlands.

Table 2: Actual policy factor tested for flooding in Vietnam

K	TR	β
1	2060.8	3.7
2	3382.8	6.2
3	4704.8	8.6

3.5 Evaluation of flood risk at a national scale

The societal risk limited by Eq. (9) can be generalized to a national scale by replacing the position constant C_i by C_N, in which N_A takes into account number of independent places where a considered hazardous may take place in a country, in the following form.

$$1 - F_{N_d}(x) < \frac{C_N}{x^n} \quad (22)$$

$$\text{with } C_N = \left[\frac{\beta \times MF}{k\sqrt{N_A}}\right]^n \quad (23)$$

where k- constant, with a proposed value of k=3 (see Vrijling *et al.* 1998 for further background) which counts for a large uncertainty in loss of life estimation;

The policy factor β expresses the characteristic of the activity under consideration. For establishing a limit line for flooding in Vietnam it was suggested to use β=0.1 as actual individual flood risk;

The exponent n reflects risk aversion toward large accidents. In further analysis, a value of n=2 is assumed for the limit line as it has been used and tested for various situations worldwide (Netherlands, U.S and Bangladesh).

The number of independent places N_A on a national scale is supposed to equal the number of independent climate zones, in which each zone is characterized on the basis of similarity of natural conditions (e.g weather characteristics, topographical features, frequency of storms and typhoons landing and flooding characteristics and frequency) and has a size approximately as large as the size of a typhoon affected area. Vietnam has been divided into 6 zones that are also widely used for weather forecast system.

The value of the constant C_N that determines the vertical position of the limit line at a national scale can be calculated by Eq.(9). The limit line for flooding in Vietnam is plotted in with different values of the policy factor in range of 0.1 to 10 (see Figure 9).

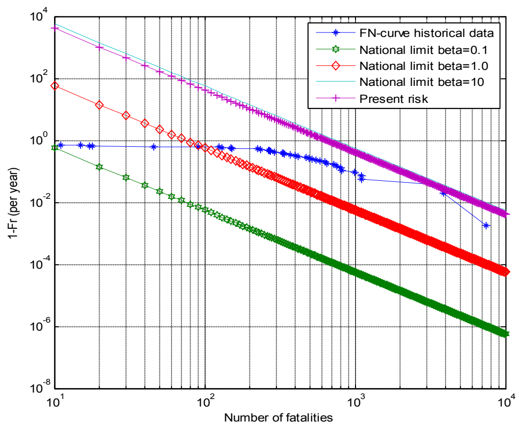

Figure 9: Societal risk and limit line at national scale for flooding in Vietnam (N_A=6, beta=0.1, 1.0 and 10)

3.5. Discussion

Inspection of the FN-curve and limit lines in Figure 9 yields the following insights:

The estimated level of flood risk shows that living in a flood prone area in Vietnam has higher risk than participating an involuntary activity, which is characterized by IR=10^{-5} per year and policy factor β=0.1). The limit line for present situation of Vietnam corresponds to a constant value of C_N=56.

Flood events that claim less than 100 fatalities are accepted with the limit when the policy factor is 1.0, which is similar to acceptable risk limit for present traffic accident risks.

With the policy factor β=10 the limit line lies above the FN-curve. This means that flooding in Vietnam would be acceptable if flood accident is viewed as a voluntary activity with direct benefit. This might be true only for some specific rural areas in the low-lying Mekong river delta where floating house is popular and annual flood brings fertile sediment to the rice fields, but less true for other coastal parts of Vietnam. Based on the presented framework a policy factor of β=1 (or lower) seems more appropriate and risk reduction is thus recommended from this point of view. If flooding probabilities are reduced to 1/100 to 1/1000 per year, societal risk would be more acceptable.

Actual societal risk at national scale for Vietnam is expressed by β=8.6. This is only acceptable with for a situation with a limit line that that has $C_N \cong 5.10^5$.

4. Conclusions

Risk due to flooding is significantly differences between Vietnam and the Netherlands. The policy factor β which reflects the actual flood risk of Vietnam was found in the range of 3 to 7.5 while in the Netherlands it is from 0.01 to 1.0.

Current average individual risk in Vietnam for flooding seems almost acceptable according to the standards that follow from the risk framework. However, it is recommended to investigate the local values of individual risk for the more high hazard flood prone areas.

Current societal risks seem rather high when compared to the accepted values according to the risk framework. As a result safety standards in Vietnam towards flood risk should be based on a higher safety standard of of 1/1000-1/100 per year.

Taking into account accident statistics and characteristics of flooding in Vietnam a proposal has been developed for a national criterion for acceptable risk for Vietnam. It should be noted that the safety norms are country specific and the acceptable risk levels are not the same for different nations because attitudes of people and society towards risks are also country specific. Behavior and perception of people towards flood risks in Vietnam should be studied separately to get more insight in further establishment of the safety norms.

This paper has focused on individual and societal risk. Additional studies on economic risk analysis (Mai Van, 2010) showed that the actual safety standard of coastal flood defences of the Vietnamese case study (1/20 years) is not safe enough in views of the current Vietnamese development with fast economic growth. An optimal choice of the acceptable risk level is recommended at 1/100 years. This is in good agreement with the upper bound of the result of societal acceptable risk of Vietnam.

The presented risk based models are thought to be powerful tools to support the decision making process to set (or re-set) the safety levels of protection in relation to investments and acceptable consequences for various scales of flood protection in Vietnam. It is recommended to perform a full scale risk analysis for flood defence systems in Vietnam and use the outcomes as a basis for societal and political discussion on appropriate safety standards.

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