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# NATIONAL ESTIMATION OF SOCIETAL RISK OF FLOODING IN CHINA

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## ABSTRACT

Floods hits China every year with large damage in terms of loss of life and economic damage. The direct economic loss caused by floods accounts for roughly 1.6% of GDP per year in China (1990-2009) and the fatality is estimated at approximately 4510 per year during the past 60 years. This paper is going to address a question of what the nationally acceptable risk of flooding in terms of loss of life in China is. The objective is to estimate societal risk of flooding in term of loss of life in China, which provides a scientific basis for policy makers to make efficient and innovative mitigation measures on flood management. The main approach of estimation is based on the proposed risk averse measure of societal risk by Prof. Han Vrijling, which is used to test the situation on the loss of life of flood disaster on the national level and also proved by many applications in the Netherlands. The results indicate that it requires more efficient mitigation measures (engineering and non-engineering) on flood risk management.

## 1 INTRODUCTION

Flood is one of the top natural disasters in the world in terms of loss of life and economic damage. China has been frequently hit by large floods and suffered from flood disasters within a long history. In China, 8% of the land area located in the mid- and down stream parts of the seven major rivers are prone to floods. 50% of the total population of the country is living in the flood-prone areas and they contribute over 2/3 of total agricultural and industrial product value. According to the public report of Chinese flood and drought disaster (Chen 2009), the direct economic damage caused by flood disaster accounts for roughly 1.6% of GDP in China (1990-2009) and the average life loss due to flood during the past 60 years is estimated at approximately 4510 per year, although the loss of life due to flood in China has been reduced a lot in recent years resulting from improved flood defence system and good management with government's great attention.

## 2 PROBLEM DEFINITION AND OBJECTIVE

This paper is going to address a question of what acceptable risk of flooding in terms of loss of life in China is. From flood risk management point of view, taking moderate and acceptable flood risk is one of Chinese management's focuses in the near future (Kungang Li 2008), while there is limited research work on how to do the risk quantification and evaluate the risk level in China; so the objective of this paper is to estimate the societal risk of flooding in term of loss of life in China which can show the current status of risk level of flooding in order to provide a scientific basis for policy makers to make efficient and innovative mitigation measures on flood management.

## 3 INTRODUCTION OF SOCIETAL RISK OF LOSS OF LIFE

Risk to people can be considered as two forms: individual risk, which is the risk experienced by the individual person; the other one is social risk which is the risk experienced by a group of people. The individual risk is dependent on the geographic position, no matter whether people are at present or not in the position, while societal risk is characteristic by the position factor; thus, if no people are present around the hazardous activity, the societal risk is zero, whereas the individual risk may well be quite high. For the scope of this paper, the following section will focus on introduction of societal risk which is mainly based on the previous study of risk measures and acceptable risk by Prof. Han Vrijling (1995).

The societal risk for a hazardous activity is defined as the probability that a group of more than N person get killed due to an accident at the hazardous activity (Bottelberghs 2000). Normally, societal risk is displayed in the form of FN curve, which reflects a relationship of the exceedance of frequency as a function of N fatalities (a group of people) under an accident, on a double logarithmic scale. From the above definition and description, societal risk can be denoted as:

$$P(N \geq n) = 1 - F_N(x) = \int_x^{\infty} f_N(x) \cdot dx \tag{1}$$

Where: $f_N(x)$ is the p.d.f of the number of fatalities per year;

$F_N(x)$ is the probability distribution function of the number of fatalities per year, signifying the probability of fatalities less than x per year ( $F_N(x)$ = P(N< n) ).

The determination of the societal acceptable risk starts from the assumption that the accidents statistics reflect the result of a social process of cost-benefit appraisal (J.K.Vrijling, et al. 1998). That is to say, if the statistics reflects the preference, a standard can be derived from them. The situation is tested against the norm of $\beta_i$ *MF casualties by the following form which takes the risk aversion into account:

$$E(N_{di}) + k\sigma(N_{di}) < \beta_i MF \tag{2}$$

From this norm, risk aversion is represented mathematically by increasing the expectation of the total number of deaths per year $E(N_{di})$, by the desired multiple $k$ (risk aversion index) of the standard deviation $\sigma(N_{di})$.

Norm (2) can be transformed into the VROM- type (VROM 1998) of safety criterion which is applied to the plant level in the Netherlands (see formula (3) (4)). The national risk level relate to the common shape of a FN-curve is set under a criterion in the form as underlying, which is inversely proportional to the number of independent locations $N_{Ai}$ and the square of the policy factor $\beta_i$ ..

$$1 - F_{N_{dij}}(x) \le \frac{C_i}{x^n} \quad \text{for all } x \ge 10 \tag{3}$$

Where:

$$C_i = \left[ \frac{\beta_i \cdot MF}{k\sqrt{N_{Ai}}} \right]^2 \tag{4}$$

$x$ - **number** of fatalities;

$F_{N_{dij}}$ - **Probability distribution function** of the number of death people (casualties) of the accidents of activities $i$ on one location $j$ ;

$\beta_i$ - **Policy factor**, in many practical cases is specifically chosen from the range 100> $\beta_i$ >0.01 (see figure 1). (more explanation in reference (J.K.Vrijling, et al. 1995) ;

$MF$ - **country-specific factor** represents the failure of non-voluntary activities in term of death. (Explanation in section 4)

$k$ - **risk aversion index,** which has been tested based on 3 in different activities in the Netherlands by J.K.Vrijling, et al. (1998);

$N_{Ai}$ - **Number** of the independent locations with the activity $i$ ;

$n$ - **Steepness of the criterion line**, a standard with steepness of n=1 is called risk neutral. If the steepness n=2 is called risk averse (S.N.Jonkman et al. 2003)

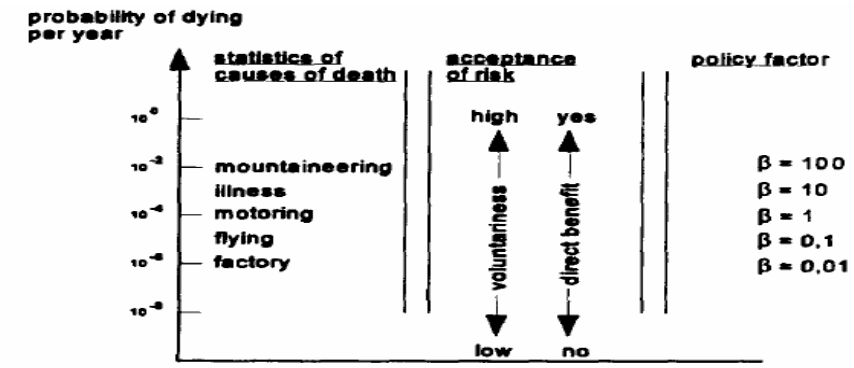


**Figure 1.** Personal risk in Western countries, policy factor $\beta$ represents the acceptance of risk as function of voluntariness and direct benefit (J. K. Vrijling et al. 1995)

A typical FN-curve is shown in figure 2, which shows that $C_i$ determines the vertical position of the criterion line. The criteria line on the F-N curve can help to determine what societal risks are tolerable or unacceptable. If a system's F-N- curve lies wholly below the criterion (limited) line, the system should be regarded as acceptable, but if any part of the F-N curve crosses the criterion line, the system should be regarded as unacceptable.

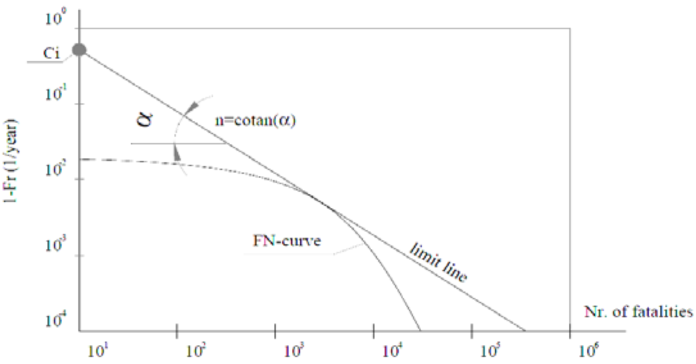


**Figure 2.** FN curve with the criteria (limited) line at the steepness of n and vertical position of $C_i$ (Cong 2010)

## 4 ESTIMATION OF SOCIETAL RISK OF FLOODING IN TERMS OF LOSS OF LIFE IN CHINA

### 4.1 Present safety standards in China

The average death rate in China is determined by the average number on 1978-2008 data set (NBS 2009) which is r=6.6*$10^{-3}$ per year. This number takes all the possible causes of death into account and no distinction is made between activities.

Applying the risk norm (2), the country-specific factor need to be determined, which is 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 (in average 20 sectors) and the size of the population of the country (Cong 2010) .

$$MF = (p_{all\_cause} N_p)\frac{\left(\frac{p_{non\_vol}}{p_{all-cause}}\right)}{N_A} = \frac{N_p \cdot p_{non\_vol}}{N_A} \qquad (5)$$

Where:

$N_p$ : total population of the country;

$N_A$ : number of the hazardous activity categories in a country

$p_{all\_cause}$ : probability of decease due to all possible causes of death, independent from activity;

$p_{non\_vol}$ : probability of death due to non- voluntary activity.

The norm (2) states that an activity is acceptable if the expected number of deaths fewer than $\beta_i MF$ per year. MF in the Netherlands is used by 100 widely (J.K.Vrijling, et al. 1995); in South Africa MF is 750 (Pieter van Gelder and Ouwerkerk 2004); In Vietnam, MF is found with the number of 550 (Cong 2010);

In China, the probability of death due to non-voluntary activity is 1.55*$10^{-5}$, the ratio of probability of death due to non-voluntary activity and the average death rate is nearly 1/426 ( In Netherlands, this number is roughly calculated into 1/600).

So $$MF_{CN} \cong 6242$$

Compares to the MF 100 in other countries, the country-specific multiplication factor 6242 in China seems reasonable as a big population base in this country. Therefore, this value can be used as tentative parameter for the following risk evaluation in the Chinese situation.

### 4.2 Historical loss of life due to floods and storms in China

In this section, the safety norm is compared to the historical loss of life in Chinese situation. From the report published by Ministry of Water Resource of People's Republic of China, the data set related to the loss of life due to flooding from 1950-21st, July, 2010 in mainland of China is collected. The average life loss due to flood during the past 60 years is estimated at approximately 4510 per year and a standard deviation of 6320 fat./year, as the death number due to flood in 1954 and in 1975 reached above 40,000 and almost 30,000 respectively. But the loss of life due to flood in China has been improved a lot in recent years (after the year of 2000) resulted from improved flood defense system and good management with government's great attentions, which is obviously shown in the fig.2.

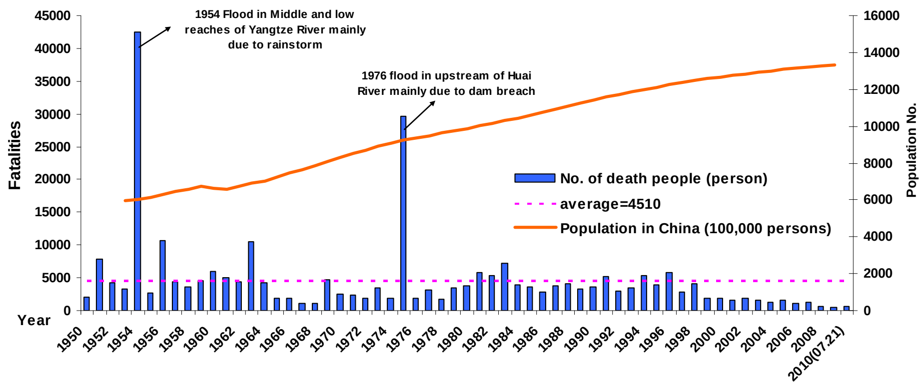


**Figure 3.** Chinese population and historical data of loss of life due to flooding during the past 60 years (the flooding includes all the causes of flooding by river, typhoon at coastal regions and storms at sea)

Referring to the established national standard TR= $4510 + k\,6320 < \beta_i\,6242$, in Chinese situation the policy factor $\beta_i$ is from 1.8 to 3.9 when the risk aversion index $k$ takes from 1 to 3. According to the ranges of policy factor in fig.1, this implies that the flooding in China is viewed as a neutral activity more than a voluntary activity without much benefit.

### 4.3 Societal risk due to flood in China

A FN-curve for flooding in China based on the historical data during the past 60 years is presented in figure 4. The historical data is well described by an exponential curve with an equation of $y = 1.05e^{(-2.36 \cdot 10^{-3} x)}$.

The societal risk limit by (3) and (4) can be generalized to a national scale by replacing the position constant $C_i$ by $C_N$ (national level), in which

$N_A$ replacing $N_{Ai}$ stands for number of independent places where hazards of flooding may happen.

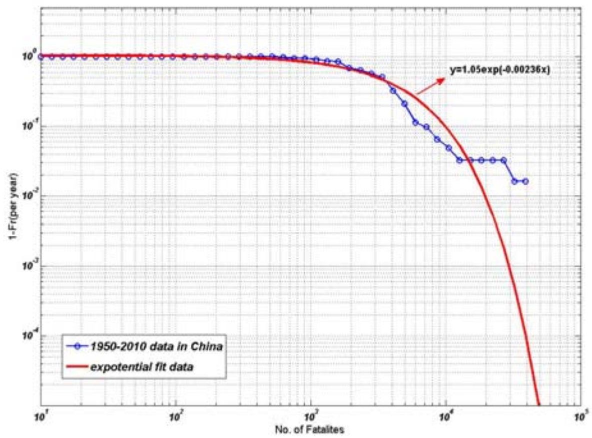


**Figure 4.** FN-Curve due to flood based on historical data in China

As to define the independent flood prone areas in China is a time-consuming task and till now there is just some results about the regionalization of flood prone zones in China (Shi 2003;Tian 2006): $N_A$ =4 and $N_A$ =10, respectively, the limitation for those results is these zones are not fully mutually independent then need refinement and improvement more.

Some researchers take the independent climate zones standing for $N_A$ (Cong 2010), where each zone is characterized on the basis of similarity of natural conditions (e.g weather characteristics and topographical features). The newest regionalization of climate zone in China was done with a result of 56 by classification on temperature characteristics and rainfall & evaporation characteristics, and if excluding plateau zones (highest part) of China the result becomes 44 (fig. 5) which is an improvement to the result of 36 and 49 by National Meteorological Administration (1979) and Chinese Academy of Science (1985). Therefore, here we take $N_A$ =44 as independent climate zones in China to represent independent flood prone areas.

The value of $C_i$ determines the vertical position of criteria line, and the steepness of criteria line is assumed as n=2 (also see in figure 2). The criteria line under the value of $\beta_i$ from 0.1, 1 to 10 is shown for Chinese situation. (See in fig. 6)

The figure 6 indicates that the societal risk curve of loss of life due to flood in China is only under criteria line with $\beta_i$ =10. The main parts of the FN-curve have been cross the criteria line with $\beta_i$ =1 and $\beta_i$ =0.1, respectively, which is consistent with the results from the norm (2) where the policy factor ranges from 1.8 to 3.9. As $\beta_i$ =0.1 may represent better on the risk of loss of life where it is truly taking flood as a non-voluntary with less benefit activity, current risk of flooding in China is considered as a not really acceptable activity, which needs more mitigation measures on social safety and security.

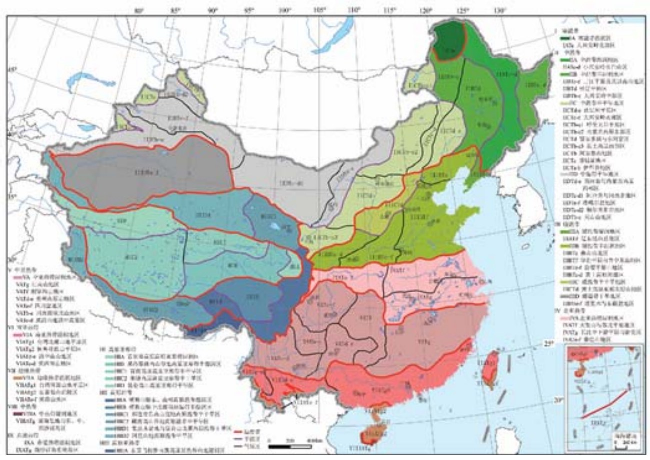

**Figure 5.** Climatic Regionalization of China (Zheng 2010)

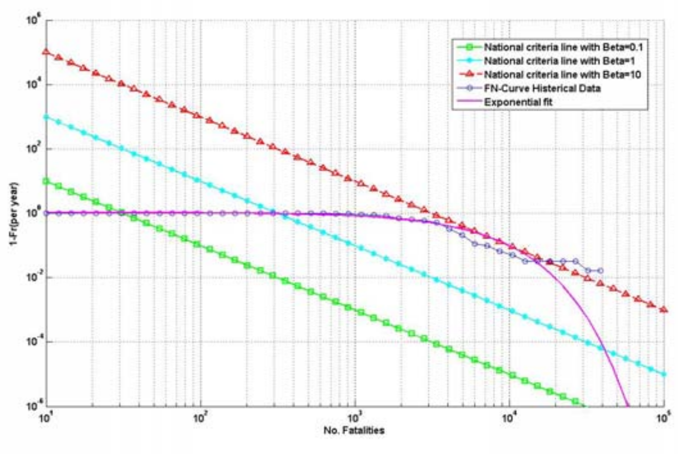


**Figure 6.** Societal risk of flooding in China when $N_A = 44$

Another result comes out in fig.7. As there are 53 (dike-ring) independent flood prone areas in the Netherlands, roughly taken $N_A$ =500 may represent the actual independent flood prone areas in China more accurately.

From fig.7, it is shown that the current situation of societal risk in China is higher than the criteria line with $\beta$ =0.1, 1, and 10, which indicates that unacceptable level of flood risk in China, much more mitigation measures should be taken to improve current situation.

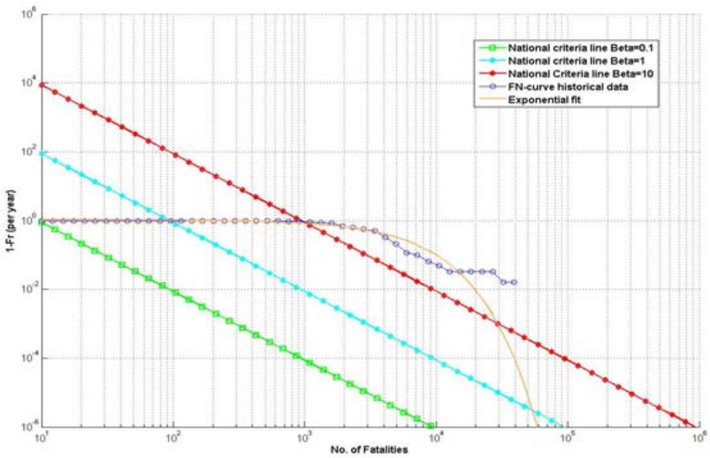


**Figure 7.** Societal risk of flooding in China when $N_A$ =500

## 5 DISCUSSION AND CONCLUSION

Table 1 represents some figures on the average loss of life per year, country-specific factor and policy factor in three countries: China, Vietnam and the Netherlands.

**TABLE 1** Comparison of actual risk of flooding in China, Vietnam and the Netherlands

| Country | No. death (person/year) | MF | Beta |
|---|---|---|---|
| **China** | 4510 | 6242 | 1.8-3.9 |
| **Vietnam** | 589 | 550 | 1-10 |
| **Netherlands** | 1.6 | 100 | 0.01-0.1 |

As for the risk averse measure of societal risk, it is involved in country-specific criteria, different country has different evaluation criteria. Because people in the different countries have different experiences to flood, the risk perception may vary among different countries. This safety norm $\beta_i$ *6242 applied here can be used to test acceptance of risk on the national level in China for this moment. The result of policy factor $\beta_i$ from 1.8 to 3.9 implies much more mitigation measures should be taken in order to reach tolerable level of flood risk from two points of view: hazards-alleviation and vulnerability-reduction (see fig. 8). Besides the engineering measures like strengthen and heighten the flood defense system, non-engineering measures such as flood insurance and early-warning system could contributes a lot on flood risk management.


**Figure 8.** Example of risk reduction measures (Jonkman 2007)

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