Original Article

Application of the Analytic Hierarchy Process to a Risk Assessment of Emerging Infectious Diseases in Shaoxing City in Southern China

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SUMMARY: This study aimed to assess the likelihood of an outbreak or epidemic of emerging infectious diseases (EIDs) in Shaoxing city, China, and its resulting impact to provide decision makers with quantitative, directive results. Factors related to the risk of EIDs were selected through meeting with experts and were arranged in a hierarchical structure. These evaluation factors were also weighted to allow the use of a point system for evaluation. As a result, 14 evaluation factors comprising a 3-layer hierarchy were generated. The riskiest top 10 EIDs were HIV/AIDS (consistency index [CI] = 3.206), cholera (CI = 3.103), SARS (CI = 2.804), acute schistosomiasis (CI = 2.784), malaria (CI = 2.777), legionellosis (CI = 2.743), avian influenza A/H5N1 (CI = 2.734), dengue fever (CI = 2.702), *Escherichia coli* O157:H7 enteritis (CI = 2.593), and plague (CI = 2.553). The risk assessment was specifically intended to support local and national government agencies in the management of high risk EIDs in their efforts to (i) make resource allocation decisions, (ii) make high-level planning decisions, and (iii) raise public awareness of the EID risk. The results showed that the EID risk in Shaoxing could be effectively assessed through an analytic hierarchy process.

INTRODUCTION

As China contains approximately a quarter of the world's population and a vast and diverse assortment of both wild and domestic animals living in close proximity to humans, it is likely to have the greatest potential for the emergence or reemergence of infectious diseases worldwide (1). Severe acute respiratory syndrome (SARS) is believed to have originated in southern China, as the first sporadic cases and small outbreaks were identified in Guangdong Province, China, between November 2002 and early January 2003 (2). As the world was preparing for an avian influenza A/H5N1 pandemic, we were blindsided by the 2009 influenza A (H1N1) outbreak (3). Four years after the global H1N1 influenza pandemic, a new type of avian influenza, H7N9, is emerging in mainland China. This was first reported in Shanghai on February 19, 2013 (4,5).

Emerging infectious diseases (EIDs) have exacted heavy public health and economic tolls. Infectious diseases are responsible for more than 25% of the annual global death rate and represent large disease and economic burdens (6). Given the large number of potentially introducible EIDs, the development of rapid detection methods and control strategies for every potential agent would be extremely difficult and costly. Therefore, a list of high-threat EIDs is needed to ensure the most effective allocation of resources.

A risk assessment is the overall process of risk identification, risk analysis, and risk evaluation. Here, we

assessed both the probability of an EID occurrence and the degree of potential consequent damage. This type of risk assessment process must consider a large number of characteristics (or criteria) associated with a pathogen or disease that would account for the features of the epidemiological triad, namely the agent, host, and environment. Objective and transparent methods are therefore required to address this multi-dimensional problem so that intelligence from a number of sources and the influence of stakeholders with differing agendas can be synthesized and future actions can thus be justified. Therefore, the aim of this study was to develop a risk assessment model based on the defined risk criteria and to determine the risk rankings of known EIDs in Shaoxing city, China. This model could be applied to establish a list of low, moderate, and high-risk EIDs that might be introduced accidentally or deliberately so that resources for developing countermeasures can be made available. The availability of this rating model will further allow the development of rapid detection assays and controls for highly rated EIDs.

MATERIALS AND METHODS

Study design: We developed a semi-quantitative EID risk assessment model. For this purpose, we initially decomposed the EID risk into a hierarchy of more easily comprehended subproblems (Fig. 1). We focused on the following 3 criteria related to the EID risk: (i) the infection reservoir, (ii) the transmission route and associated factors, and (iii) prevention and control measures. We invited experts to select suitable EIDs and optimal criteria and to subsequently to generate a hierarchical structure and collect data. The analytic hierarchy process (AHP) methods were then used to analyze the col-

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Fig. 1. Structure of the evaluation system for emerging infectious diseases proposed in this study, with appropriate factors and weights.

lected data. Finally, the optimal EID risk assessment model based on this study was developed for future reference.

AHP: AHP combines both quantitative and qualitative criteria to analyze decision problems. In this study, AHP application involved 5 basic steps: (i) constructing the decision hierarchy for the EID risk, (ii) collecting data via paired comparisons, (iii) verifying the consistency of the material judgments, (iv) applying the eigenvector method for weight computation, and (v) aggregating the weights to determine the EID risk ranking. The weight values represent the relative importance of the indicators to each factor and were determined using the AHP method. When assessing the relative impor-

tance of a set of many indicators, AHP requires only paired comparisons of indicators rather than a direct, simultaneous comparison of all indicators.

Composition of the expert panel for consultation: Suitably qualified individuals were sought to comprise a panel of expert judges that would construct the evaluation system. As a result, 41 experts from Zhejiang Province, China were invited to participate. These experts had various specialties, including epidemiology, clinical pharmacology, microbiological examination, health care administration, control measures, general food safety, and public health. Two 2-day workshops were conducted during which the key criteria and suitable EIDs that could be used for prioritization were

Table 1. Master list of groups of criteria developed for risk assessment

General objective layer	Sub-objective layer	Criteria layer
A. Estimated risk of emerging infectious diseases	B1. Reservoir of infection	C1. Domestic distribution
		C2. World distribution
		C3. Degree of attention from China
		C4. Degree of attention from international community
	B2. Route of transmission and associated factors	C5. The influence of natural factors
		C6. The influence of social factors
		C7. Mechanism of transmission available
		C8. Probability of detecting by quarantine authority
		C9. Pathogens external environment resistance
		C10. Common incubation period
	B3. Prevention and control measures	C11. Ability to detect the pathogens early
		C12. Emergency response ability of CDC
		C13. Effective vaccine and medicine to prevent disease
		C14. The public awareness

elicited and defined.

Determination of the objective and preliminary list of criteria: During the first day of workshop, 4 scientific papers concerning the specific issue of EIDs were provided to the 41 selected experts (7–10). Through a workshop discussion on the likelihood of an outbreak, consequences of these diseases, and the natural and social environment of Shaoxing city, the experts reached an agreement and selected 21 EIDs for the risk assessment. The 21 EIDs included already known/detected/existing EIDs and those usually used for biological terrorist attacks. The selected 21 EIDs included acute schistosomiasis, anthrax, avian influenza A/H5N1, cholera, Creutzfeldt-Jakob disease, dengue fever, Ebola hemorrhagic fever, *Escherichia coli* O157:H7 enteritis, HIV/AIDS, hantavirus pulmonary syndrome, human infection of swine *Streptococcus suis*, legionellosis, malaria, Marburg hemorrhagic fever, monkeypox virus, Nipah virus encephalitis, plague, Rift Valley fever, SARS, smallpox, and West Nile fever.

Criteria selection is the first step in the development of a general prioritization framework. This process involves brainstorming to identify a preliminary list of criteria for possible inclusion in the final evaluation model while always bearing in mind the specific details of the prioritization goal or objective. In our case, we listed 26 criteria associated with the following 3 aspects: infection source, transmission route and associated factors, and prevention and control measures. A description and consistent definition for each criterion must be provided to ensure that all participants understand its meaning and relevance to the evaluation. During this step, there is considerable dialogue between participants to clarify the terms.

The second step is an assessment of the preliminary list of criteria with the objective of reducing the number and retaining only those criteria believed by participants to provide some maximal amount of usefulness for evaluating alternatives. The 41 experts all ranked the preliminary list of criteria in terms of their importance to EID evaluation such that the first item on the list was most important and the last item was least important.

Each item on an individual's list was assigned numeric points based on its rank, with the most points assigned to the first item on the list and the least points

Table 2. Graded number for pairwise comparison

Comparative judgment	Graded number
Ti and Tj are equally important	1
Ti is moderately more important than Tj	3
Ti is strongly more important than Tj	5
Ti is very strongly more important than Tj	7
Ti is extremely more important than Tj	9
Both Ti and Tj represent the indicators. The scale 2, 4, 6, and 8 are used and represent compromises among the scale 1, 3, 5, 7, 9.	

assigned to the last item on the list. For each specific criterion, a rank sum of all assigned points on each individual list was then calculated, and the list was presented in a rank order that reflected the priorities of all participants. A discussion was held to determine whether all the criteria were useful, given their rank order, for evaluating the chosen EIDs. Finally, a total of 14 criteria were included in the assessment model, which are presented in Table 1.

Determination of the criteria weights: In each level, each criterion was compared with other criteria in the same level and under the same group according to its relative contribution to the general objective. A 1–9 point scale was used for the pair wise comparison (Table 2). According to that scale, score of 1 was given to criteria that had equal importance. Scores of 3, 5, 7, and 9 denoted weakly, strongly, very strongly, and absolutely more important, respectively. Even scores (2, 4, 6, and 8) were used when slight differences existed between criteria (Table 2) (11,12).

Each member of the expert panel made pairwise comparisons of all evaluation criteria pairs in each level of the hierarchical structure. Consistency index (CI), consistency ratio (CR), and average random consistency index (RI) were calculated to evaluate the consistency of the pairwise comparisons. The nearer the CI and CR values were to 0, the greater the consistency of the pairwise comparisons, whereas larger values indicated lower consistencies. The pairwise comparisons were generally considered as consistent if their CI and CR values were <0.10.

The final values derived for the criteria at the lowest level or bottom of the hierarchy represent the impor-

tance or usefulness of those criteria relative to the goal as a percentage of that goal. Where multiple criteria are organized into a hierarchy, AHP spreads the 100% assigned to the goal across all criteria in the hierarchy in proportion to the ratios expressed in the pairwise comparisons. This process of percentage spreading is called weighting the criteria.

Determining the final scores (general index): Each EID was assigned a 3-level rating according to the criteria. The score for an individual disease is the sum of the products of the disease's score for each criterion multiplied by the criterion's weight; the scores vary on a scale that ranges from 0% to 100%. For example, if 1 criterion in the exemplar model has a weight of 10%, a high score is worth 10% added to the final score, a medium score is worth 5.6% added to the final score, and a low score is worth 1.1% added to the final score. A disease with high scores for every criterion would receive a rating of 100%. The total scores can be averaged when several individuals perform the ratings. All candidates are then evaluated and scores are assigned to each in terms of the criteria at the lowest level of the decision tree. The scores are then aggregated across all criteria for each candidate, and a summary score is determined. The summary scores allow comparisons of the candidates with respect to the goal of the decision.

RESULTS

A total of 14 factors that potentially influenced the EID risk were identified (Table 1). The results of the weight calculations are presented in Fig. 1; the factor that received the largest weight was domestic distribution (combined weight [CW] = 0.2416), followed by the influences of natural factors and social factors (CW = 0.1365 each) and world distribution (CW = 0.1129). These results indicated that these evaluation factors were considered more important than the other factors. The CI, CR, and RI values were 0.0005, 0.008, and 0.58, respectively, indicating greater consistency of the pairwise comparisons.

The results of the risk evaluation are presented in Table 3. The 14 criteria listed in Table 1 were applied to the selected high-risk diseases; HIV/AIDS, cholera, and SARS were the highest-rated diseases, with scores of 3.206, 3.103, and 2.804, respectively. Acute schistosomiasis, malaria, legionellosis, avian influenza A/H5N1, and dengue fever had intermediate scores of 2.784, 2.777, 2.743, 2.734, and 2.702, respectively. Monkeypox, Rift Valley fever, and Nipah virus encephalitis had the lowest scores at 1.864, 1.933, and 1.870, respectively.

DISCUSSION

The top 10 highest-risk EIDs determined in this risk assessment were HIV/AIDS, cholera, SARS, acute schistosomiasis, malaria, legionellosis, avian influenza A/H5N1, dengue fever, *E. coli* O157:H7 enteritis, and plague. The results of this study may support local and national government agencies in the management of high-risk EIDs in their efforts to (i) make resource allocation decisions, (ii) make high-level planning decisions,

Table 3. Results of risk evaluation of emerging infectious diseases

Emerging infectious disease	Sum of score	Sum of score multiplied with weight
HIV/AIDS	2.981	3.206
Cholera	2.643	3.103
Severe acute respiratory syndrome	2.596	2.804
Acute schistosomiasis	2.599	2.784
Malaria	2.515	2.777
Legionnaires' disease	2.669	2.743
Avian influenza A/H5N1	2.552	2.734
Dengue	2.568	2.702
<i>E. coli</i> O157:H7 enteritis	2.504	2.593
Plague	2.542	2.553
Creutzfeldt-Jakob disease	2.699	2.512
Anthrax	2.523	2.476
Human <i>Streptococcus suis</i> infection	2.308	2.314
Smallpox	2.209	2.102
Ebola hemorrhagic fever	2.418	1.965
Marburg hemorrhagic fever	2.397	1.940
Rift Valley fever	2.312	1.933
Nipah virus encephalitis	2.298	1.870
Monkeypox	2.324	1.864

and (iii) raise public awareness of the EID risk. Although many factors required evaluation, AHP helped reduce the complexity of the assessment process.

As reported, during the second half of the twentieth century, the impacts of social and environmental factors on infectious disease outbreaks have been greatly amplified by the doubling of the world's population, which has accelerated most rapidly in developing tropical and subtropical countries (13). Therefore, it is reasonable that the influences of natural and social factors would have the highest CWs in the risk assessment model. The finding that HIV/AIDS, cholera, and SARS received the highest EID risk scores is interesting and could help health administrative departments (HADs) to make public health decisions. For example, in accordance with our results, the HAD of Shaoxing city has developed a targeted EID surveillance system and taken control measures to reduce the risk of future infection outbreaks. The surveillance of influenza-like illnesses (ILIs) and severe acute respiratory infections (SARIs) have been strengthened in local health centers and hospitals to prevent and control SARS outbreaks, and the surveillance of diarrhea patients has also been strengthened by implementing diarrheal disease outpatient services in hospitals annually from May to November to prevent and control cholera outbreaks. The government of Shaoxing city has provided increased funding and strong policy support to guarantee improvements in the care of HIV/AIDS patients, research on drugs and vaccines, programs to fight poverty in areas of high HIV prevalence, and the provision of stronger societal support for AIDS prevention.

There have been many successful instances associated with risk assessments of infectious diseases. A study by Gallagher et al. (14), which evaluated the risk of foot and mouth disease (FMD) in Europe, is an example of the consensus method in veterinary medicine. That particular study applied the Delphi method; specifically,

the experts attending a workshop were repeatedly administered questionnaires regarding the countries where FMD was most likely to occur. Another example is a study that was also conducted in Europe and intended to assist national public health authorities in the European Union with assessing the risks associated with the transmission of infectious agents on aircraft; this study was initiated by the European Centre for Disease Prevention and Control (ECDC) in 2007 and titled the RAGIDA project (Risk Assessment Guidance for Infectious Diseases transmitted on Aircraft) (15). The Delphi method-based study by Gallagher and colleagues and the ECDC's RAGIDA project utilized expert panel consultations and provided examples of the qualitative risk assessment method. The use of qualitative methods to assess the risk of infectious disease transmission is not always easy and often relies on individual expert opinions.

AHP is a social science technique used in an attempt to organize complex relationships between elements into a structure or system based on subjective judgments, such as experience. AHP is perhaps the most well-known and widely used multicriteria-based method. This method has firm theoretical underpinnings and has been successfully used to help people make better decisions in a wide variety of complex circumstances such as systems for evaluating bovine spongiform encephalopathy surveillance, raw milk-associated foodborne infections, the risk of airborne infectious diseases in aircraft cabins, and an index system of the risk of infectious diseases at ports (16–19). An infectious disease risk assessment was conducted by AHP during the Shanghai Expo, and a prime infectious disease was identified, thus providing scientific materials for health management policy establishment (20). The main strength of AHP is that it is both methodologically sound and user friendly. The pairwise comparisons technique used in AHP is generally considered to be among the best methods for eliciting judgments from people. The output is easily understood because it is based on simple scales derived from the pairwise comparisons. A good example of the use of pairwise comparisons to determine the relative weights of each of the compared attributes was presented clearly in a paper by McCaffrey (21). A built-in measure of the consistency of the determined judgments exists; this both evaluates the reliability of the analysis and reduces the likelihood of a procedural mistake (22).

Although AHP has been the subject of many research papers and the general consensus is that this technique is both technically valid and practically useful, this method does have limitations. Firstly, there are many risk assessment methods, including AHP, and these are only valuable supplements to other objective and subjective methods. Second, there is substantial disparity among experts in terms of the level of understanding regarding AHP; therefore, it may be difficult to reach an agreement through the approach used herein. It is possible that the cases and policies experienced in China might influence the evaluation and cause biases with respect to the awareness of issues. Finally, the EID situation is continuously evolving with respect to hitherto unknown and novel EIDs (e.g., MERS coronavirus, avian influenza A/H7N9); regarding such EIDs, we pos-

sess only limited information that cannot meet the needs of the risk assessment model. For example, new avian influenza A (H7N9) viral infections in humans were first reported in China in 2013 (4), and this occurrence was too recent to be included in the assessment. To date, however, infection sources other than birds and contaminated environments in live poultry markets remain elusive. It is unclear how the emerging avian influenza A (H7N9) virus is spreading in China and what underlying risk factors and mechanisms are involved in cross-species transmission (23). This lack of knowledge has made it difficult to perform a timely quantitative risk assessment on this novel EID. In the future, we will perform a risk assessment that includes avian influenza A (H7N9) virus according to the risk assessment model developed in this study; this will allow us to determine a summary score for the novel avian influenza A (H7N9) virus and thus to compare this novel EID with the other EIDs assessed in this study. However, we can quickly collect and explore information on novel EIDs to perform periodic risk assessments and can therefore refine our prevention and control strategies using the results of these risk assessments.

The risk assessment model developed in this study can be used to establish a list of low, moderate, and high-risk EIDs, thus allowing resources to be made available for the development of prevention and control measures. The availability of this rating model will further allow the development of rapid detection assays and controls for highly rated pathogens associated with the most important EIDs. Furthermore, this expansion of EID risk analysis is of important practical significance because it can provide a reference for the verification of EID model simulations and could potentially benefit EID monitoring and prediction. This analysis can also increase the public awareness of the risks of an EID outbreak, the causes of an outbreak, and preparing for an outbreak. An understanding of the future degree of the EID risk is very important when designing an early warning system.

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Conflict of interest None to declare.

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