Effects of Humidity Variation on the Hantavirus Infection and Hemorrhagic Fever with Renal Syndrome Occurrence in Subtropical China

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Abstract. Infection rates of rodents have a significant influence on the transmission of hemorrhagic fever with renal syndrome (HFRS). In this study, four cities and two counties with high HFRS incidence in eastern Hunan Province in China were studied, and surveillance data of rodents, as well as HFRS cases and related environmental variables from 2007 to 2010, were collected. Results indicate that the distribution and infection rates of rodents are closely associated with environmental conditions. Hantavirus infections in rodents were positively correlated with temperature vegetation dryness index and negatively correlated with elevation. The predictive risk maps based on multivariate regression model revealed that the annual variation of infection risks is small, whereas monthly variation is large and corresponded well to the seasonal variation of human HFRS incidence. The identification of risk factors and risk prediction provides decision support for rodent surveillance and the prevention and control of HFRS.

INTRODUCTION

Hemorrhagic fever with renal syndrome (HFRS) is a rodent-borne disease caused by a group of hantaviruses (HVs). It is an important public health problem in China, with 40,000–50,000 cases reported annually, accounting for 90% of human cases reported globally over the last 10 years.¹ Hantaan virus (HTNV) and Seoul virus (SEOV) are the main two causative agents of HFRS in China, associated with *Apodemus agrarius* and *Rattus norvegicus*, respectively. Humans usually get infected with HV by contact or inhalation of aerosols and secretions from infected rodent hosts.² The number of cases of diseases caused by HVs varies both geographically and among years.^{3,4} The causes of these fluctuations are presumed in general to be due to changes in contacts between infectious mice and humans,^{3–5} and the greater the density of infectious rodents, the greater the contact chances between humans and infectious rodents.^{6,7} Thus, infected peridomestic rodents can significantly increase human infection risks⁸; the infection rates in rodents can directly influence the frequency of HFRS cases in humans.⁹

The abundance of rodents is statistically associated with infection rates of rodent hosts.⁴ The distribution, population density, and infection rates of rodent hosts, which are largely influenced by environmental conditions, determine the incidence and geographical distribution of HFRS among humans.⁵ Previous studies found that variations in meteorological factors, temperature, and precipitation significantly influenced rodent population cycles.^{10,11} Landscape elements, including normalized difference vegetation index (NDVI), land use and elevation, were closely associated with the distribution of

infected rodents. The probability of infected rodents varies with NDVI and elevation, and infection rates for HV in rodents were also significantly associated with rice agriculture.^{12,13} In addition, as the incidence of HFRS is affected by environmental conditions, HFRS cases in China mostly occurred in districts with low elevation, high humidity, and cultivated land.¹⁴ Seasonal variation of HFRS incidence was closely associated with meteorological factors, including precipitation, humidity, and temperature.¹⁵

Since the first HFRS case was detected in 1963, it has become a serious public health problem in China with Hunan Province being one of the most severe endemic areas, with more than 90% of cities reporting cases over this period.^{16,17} Changsha, Xiangtan, Zhuzhou, Hengyang, Shuangfeng, and Shaodong, subtropical cities in Hunan Province, are main epidemic areas of HFRS. During a 4-year period (2007–2010), nearly 850 cases were reported in three cities. SEOV is now the main HV type in study area, and various types of rodents are distributed, including *A. agrarius*, *R. norvegicus*, *Mus musculus*, and *Rattus flavipectus*.¹⁸ Rodents with large population and high infection rates are mainly *A. agrarius* (the most important host of HTNV) outdoors and *R. norvegicus* (the most important host of SEOV) peridomestically.

In this study, we combined principal component analysis (PCA) with logistic regression analysis to identify environmental risk factors and predict the risk of HV infection in rodents in Shuangfeng, Shaodong, Changsha, Xiangtan, Zhuzhou, and Hengyang of Hunan Province, aiming to provide decision support for rodent surveillance and the prevention and control of HFRS.

MATERIALS AND METHODS

Study sites. The study area covers Changsha, Xiangtan, Zhuzhou, and Hengyang cities and Shuangfeng and Shaodong counties of eastern Hunan, located in a transition zone between tropical and temperate areas with abundant water, an elevation lower than 500 m, and many hills. A temperate, subtropical rainy climate in these cities provides a

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moist environment for rodents, which is also conducive to the stability and infectivity of HV.¹⁹ Because subtropical double-harvest rice is the main crop, and most farmers reside less than 50 m from their fields, traditional farming methods provide an opportunity for wild rodent propagation, offering suitable living conditions and sufficient food resources to increase transmission of HFRS between rodents and from rodents to humans. To prevent and control HFRS, Ningxiang, Yanling, Shuangfeng, and Shadong counties were chosen as surveillance sites to monitor HFRS host animals. Ningxiang County included within Changsha city and Yanling County included within Zhuzhou city are located in southeast of the study area with subtropical humid monsoon climate and abundant water. Shadong and Shuangfeng counties are located in northwest of study area with lower altitudes, flat land.

Data collection. Surveillance of HV infections among rodent hosts from 2007 to 2010 was carried out in Ningxiang, Yanling, Shuangfeng, and Shadong counties (Figure 1), according to the protocol established by Chinese Centers for Disease Control and Prevention. Representative villages were selected for rodent surveillance, according to the distribution of HFRS epidemics and landscape elements. At least 300 medium-sized steel traps with peanuts were set peridomestic and outdoors at night and recovered in the morning in spring (March–April) and autumn (September–October). The traps were placed about 1 km away from villages in locations where rodents were most likely found, such as the edges of rivers and roads, on ridges, and in yards. More than 100 traps per patch were placed in peridomestic environments at approximately 12- to 15-m intervals for three consecutive nights and more than 200 traps baited with peanuts were placed outdoors in rows with 50 m between consecutive rows, and every 5 m along each row. After identification of species and sex, captured rodents were directly killed by using diethyl ether, and their sera and lungs were collected and stored in a portable liquid nitrogen freezer.

The antigens of HV in lung tissues (frozen sections) were detected by direct immunofluorescence assay. Detailed procedures can be found in published articles.²⁰

Data on reported HFRS cases in the study area from 2007 to 2010 were obtained from the Hunan Notifiable Disease Surveillance System (HNDSS). All of the cases were initially diagnosed based on clinical symptoms according to diagnostic criteria from the Ministry of Health of the People's Republic of China.²¹ The data include information about sex, age, residential address of each patient, and onset date of symptoms for each case. The HNDSS HFRS data do not differentiate HTNV from SEOV infections.

Environmental variables from 2007 to 2010, which include monthly NDVI, monthly temperate vegetation dryness index (TVDI), annual mean temperature, annual precipitation, and elevation, were collected and processed in ArcGIS 10.0 (ESRI Inc., Redlands, CA) (Table 1). Data for each variable were converted to the same geographic projection (Gauss-Kruger-Xian, 1980, Shaanxi Province, Xianyang city, Jingyang County, Yongle town) and clipped to the study area. NDVI is generated from a transformation of the near-infrared and red wavelengths, correlated with land surface vegetation coverage. Vegetation index provides green vegetation growth status and coverage information and the surface temperature reflects the soil moisture condition, the information of both is complementary, offering the potential for regional soil moisture monitoring. Land surface temperature (LST) is closely negatively correlated with NDVI. Spatial relations consist of the scatterplot of LST and NDVI, which represent triangular relationship. The TVDI has been widely used in soil moisture estimation because it based on the empirical interpretation of the NDVI- T_s triangle space.²² The TVDI is estimated using NDVI and LST. TVDI is higher for dry condition and lower for wet condition and varies between 0 and 1. The average monthly values of both NDVI and TVDI were calculated from 2007 to 2010. All environmental

FIGURE 1. Location of study area and sampling sites of rodents.

TABLE 1
Resources and classifications of environmental variables

Variables	Source	Classification
Elevation	WorldClim (http://www.worldclim.org/)	< 100; 100–200; 200–300; > 300 (m)
Temperature	WorldClim (http://www.worldclim.org/)	< 17; 17–18; > 18 (°C)
Precipitation	WorldClim (http://www.worldclim.org/)	< 1,200; 1,200–1,400; 1,400–1,600; 1,600–1,800; > 1,800 (mm)
NDVI	National Aeronautics and Space Administration (http://landsweb.nascom.nasa.gov/data/)	< 0.5; 0.5–0.6; 0.6–0.7; > 0.7
LST	National Aeronautics and Space Administration (http://landsweb.nascom.nasa.gov/data/)	–
TVDI	Calculated using Function (1)	< 0.25; 0.25–0.5; 0.5–0.75; > 0.75

LST = land surface temperature; NDVI = normalized difference vegetation index; TVDI = temperate vegetation dryness index.

variables were resampled to raster data with a spatial resolution of 0.00833° (nearly 1 km) and classified according to local geographical conditions (Table 1).

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$

$$\text{TVDI} = \frac{T_s - T_{s\min}}{a + b\text{NDVI} - T_{s\min}}$$

where NIR is the near-infrared band; RED is the red wavelengths band; T_s is the observed LST at a given pixel; NDVI is the observed NDVI; $T_{s\min}$ is the minimum LST for a given NDVI, defining the wet edge; a and b are the intercept and slope of the dry edge, modeled as a linear fit to data that represent the entire range of surface moisture ($T_{s\max} = a + b\text{NDVI}$).

Statistical analysis. Environmental conditions of surveillance sites from 2007 to 2010 were collected to identify risk factors by using PCA. Biplots of the first two principal components were used to visualize the associations among the rodent population and environmental variables and their relationship with HV infection. PCA was conducted in R software version 2.7.2 (Lucent Technologies, Murray Hill, NJ).

Univariate and multivariate logistic analysis were conducted to analyze the associations between infection rates of rodents and environmental variables from 2007 to 2010. Relative classification values of environmental variables in each surveillance sites were collected. To develop a risk map for HFRS, we used the average monthly and annual environmental variable values from 2007 to 2010 to apply the logistic regression model across the coverage area using a raster calculator. The model was evaluated by overlaying human HFRS case localities from 2007 to 2010 onto each risk map. The average area under the receiver operating characteristic (ROC) curve (AUC) was used to evaluate predictive accuracy of the model. Evaluation data were merged with 10,000 randomly selected background points and entered into an ROC analysis to

derive the AUC. All statistical analyses were performed using SPSS software (SPSS Inc., Chicago, IL).

RESULTS

Rattus norvegicus and *M. musculus* were the primary rodent species in Yanling County, and *A. agrarius* and *R. flavipectus* were concentrated in Shuangfeng County. A total of 1,542 rodents were captured by 35,760 traps from 2007 to 2010, and 25 rodents were positive for HV (11 were *R. norvegicus*, nine were *M. musculus*, two were *A. agrarius*, and two were *R. flavipectus*). In Ningxiang County, 823 rodents were captured from 2007 to 2010; in Yanling County, 380 rodents were captured in 2009 and 2010; in Shuangfeng County, 205 rodents were captured in 2007 and 2010; and in Shaodong County, 134 rodents were captured in 2009. Among which, 496 were *R. norvegicus*, 460 were *M. musculus*, 351 were *A. agrarius*, and 191 were *R. flavipectus*; male rats capture outdoors were more likely to be infected with HV than animals captured indoors or female rats or other rodents captured outdoors (Table 2). Results of PCA showed the first 3 principal components (PCs) accounted for 85.5% of the total variation. PC1 indicates negative correlations with precipitation and NDVI, positive correlations with TVDI and temperature. PC2 indicates a significant positive correlation with elevation. PC3 shows a negative correlation with NDVI and temperature (Table 3). Results of biplots showed that surveillance sites are concentrated relatively, indicating a similar geographical environment conditions between surveillance sites. Both PC1 and PC2 successfully separated many sites that are positive for HV (Figure 2).

Univariate logistic analysis showed that HV infections in rodents decrease with the increase of elevation. High annual temperature (> 18°C) and precipitation are conducive to the rodent infection, while excessive precipitation reduces infection rates.²³ High-risk areas for HVs in rodents are in districts where NDVI is low or TVDI is greater than 0.75, and

TABLE 2
The numbers of rodents of each species captured and the numbers positive, by county

	<i>Rattus norvegicus</i>		<i>Mus musculus</i>		<i>Rattus flavipectus</i>		<i>Apodemus agrarius</i>		Other species		Total	
	Caught	Positive	Caught	Positive	Caught	Positive	Caught	Positive	Caught	Positive	Caught	Positive
Ningxiang	220	5	210	3	185	2	176	1	32	1	823	12
Yanling	179	4	201	5	0	0	0	0	0	0	380	9
Shuangfeng	6	0	35	1	0	0	152	1	12	0	205	2
Shaodong	91	2	14	0	6	0	23	0	0	0	134	2
Total	496	11	460	9	191	2	351	2	44	1	1,542	25

TABLE 3
Results of principal components analysis

	Component				
	1	2	3	4	5
Importance of components					
Standard deviation	1.541	1.036	0.908	0.680	0.513
Proportion of variance	0.475	0.215	0.165	0.092	0.053
Cumulative proportion	0.475	0.690	0.855	0.947	1.000
Loadings					
NDVI	-0.479	0.000	-0.639	-0.328	0.504
Elevation	0.000	0.931	-0.232	0.000	-0.277
Temperature	0.423	-0.299	-0.714	0.000	-0.466
Precipitation	-0.560	-0.176	0.129	-0.443	-0.665
TVDI	0.525	0.115	0.109	-0.830	0.101

NDVI = normalized difference vegetation index; TVDI = temperate vegetation dryness index.

HV infections in rodents hardly occurred in areas where TVDI is low (Table 4). Multivariate logistic regression showed that elevation and TVDI had a significant effect on the HV infections in rodents; the infection risks are high in regions with low elevation and high TVDI (Table 5). The average AUC was 0.80, indicating that multivariate logistic regression model was satisfactory.

The annual and monthly risk maps of rodents from 2007 to 2010 were produced based on the multivariate logistic regression model. According to the model results, predicted risks were divided into three levels: low (< 0.15), moderate ($0.15-0.30$), and high (> 0.30), and the mean relative risks of HV infection of rodents in study area.¹³ Annual prediction maps showed high-risk areas always focused on the southwest of the study area (Hengyang city), and sporadically scattered in Changsha city, Shaodong County, and Zhuzhou city; however, low-and moderate-risk of infections always occurred in northwest and east region, north and middle of the study area, respectively. In 2010, high infection risk areas decreased and low infection risk areas appeared in southwest (Figure 3). Not surprisingly, our results showed that risk

areas varied seasonally. In detail, high-risk areas were always distributed southwest of the study area during autumn and winter. However, the area of infection risk changed during spring and summer, and high-risk areas sporadically scattered in Hengyang city, Shaodong County, and Zhuzhou city (Figure 4). Prediction maps of all months except in December showed good performance (Table 6). High infection risk areas varied monthly. Specifically, the area of infection risk was limited in June while high-risk areas occurred in January–April, August–December and were mainly distributed southwest of the study area, and October showed statistically significantly higher risk than in other months. High infection risk areas in May and July were mainly concentrated in Hengyang and Changsha cities, and sporadically scattered in Shuangfeng County and Zhuzhou city. High-risk areas always appeared southwest of the study area, whereas the northwest and east were low infection risk areas all of the time. The north regions of the study area were moderate infection risk regions except in February, whereas the west and east were low infection risk areas all the time (Figure 4).

DISCUSSION

In this study, we combined geographic information system and remote sensing with traditional mathematical statistics analysis methods to identify the risk factors of HV infections in rodents and predict the risk. These approaches will provide methods and reference for rodent surveillance and study on HFRS transmission in other subtropical areas. Results of PCA showed that the distribution and infection rates of rodents are closely associated with a few easily monitored environmental conditions. Logistic regression analysis showed that TVDI and elevation are main risk factors influencing the distribution of HV-infected rodents, and their distribution could be well predicted. The close association between TVDI and rodent infections helps to resolve the challenges associated with the uncertainty and accessibility of traditional precipitation variables, and could have great significance on the future analysis of HFRS and rodents.

Numerous studies have found that the transmission of HFRS was associated with NDVI.²⁴ NDVI is correlated with the amount and productivity of vegetation and crops, which is a good indicator of food and living conditions for rodents.²⁵ Most rodent species responded directly to fluctuations in food availability, and population densities are driven by changes in food resources.^{26,27} Vegetation also provides shelter and safety and keeps rodents from predators. Meanwhile, meteorological factors, especially temperature and precipitation, were also closely associated with the transmission of HFRS.^{15,23,28} The appropriate precipitation leads to increased rodent food resources, affects the transmission of HFRS by influencing the living conditions and food supplies of rodents and the transmission between rodents and from rodents to humans; temperature affects the population of rodents by influencing the pregnancy numbers, litter size, birthrates, and survival rates, and appropriate temperatures were correlated to increased survival and recruitment, which lead to greater rodent population densities; the infectivity of HV is also influenced by temperature and precipitation.^{11,13,15,29} But the higher the temperature, the shorter the survival of the HV outside the host. However, our results showed that TVDI and elevation were the main risk factors,

FIGURE 2. Biplot of first two principal components of five environmental variables of 27 sampling locations of rodents from 2007 to 2010 in subtropical China; red solid circles indicate hantavirus (HV) detection were positive and hollow squares indicate HV detection were negative. The length and direction of each environmental variable vector reflects its influence on principal components 1 and 2.

TABLE 4
Results of univariate logistic regression analysis for HV infection

Variable	OR (95% CI)	P	Variable	OR (95% CI)	P
Elevation (m)		0.00	NDVI		0.00
< 100	4.92 (4.08–5.94)	0.00	< 0.5	11.03 (8.71–13.96)	0.00
100–200	1.74 (1.41–2.15)	0.00	0.5–0.6	1.16 (0.95–1.41)	0.15
200–300	0.00	0.99	0.6–0.7	0.59 (0.48–0.74)	0.00
> 300	1.00		> 0.7	1.00	
Temperature (°C)		0.00	TVDI		0.00
17–18	0.33 (0.28–0.37)	0.00	0.25–0.50	0.00	0.98
> 18	1.00		0.50–0.75	0.46 (0.40–0.52)	0.00
Precipitation (mm)		0.00	> 0.75	1.00	
< 1,200	8.99 (7.65–10.57)	0.00			
1,200–1,400	4.54 (3.89–5.29)	0.00			
1,600–1,800	1.00				

CI = confidence interval; HV = hantavirus; NDVI = normalized difference vegetation index; OR = odds ratio; TVDI = temperate vegetation dryness index.

and therefore temperature, precipitation, and NDVI were not included in the final logistic regression model. There are two main reasons for explanations: first, TVDI is calculated using NDVI and LST and NDVI, and it is a complex variable, which reflects the moisture condition, temperature, and lushness of the vegetation; second, previous studies mainly used time-series precipitation data that are almost site data, supposing the whole study area is a homogeneous space. Results of these studies usually showed the temporal relationship between precipitation and HFRS occurrence, but not the relationship between heterogeneity of precipitation and HFRS occurrence in the study area. The abundant rainfall in subtropical regions plays an important role in the transmission of HV in rodent hosts. TVDI, a combination of NDVI and LST, provides complete information of soil moisture conditions. Considering the impact mechanism of meteorological factors on rodents varies with climatic regions,^{9,11,30} and the accessibility of accurate meteorological data, the attempt to use TVDI to predict HV infections in this study provides effective support for future analysis of HFRS and rodents.

The TVDI had proven to be a good indicator of vegetation status because LST can raise water stress of vegetation rapidly and NDVI represent long-time effects. The combination of LST and NDVI can provide complete information on vegetation, water stress, and the moisture conditions at the surface. TVDI is a relative indicator of soil moisture, representing the differences of soil moisture in a given region. Results of logistic regression showed that HV infections in rodents are high in districts where TVDI is greater than 0.75, lower in areas where TVDI is between 0.5 and 0.75, and is close to zero in places where TVDI is between

0.25 and 0.5 (Tables 3 and 4). The study area is located in south of China, where the climate is temperate and rainy. The soil conditions are relatively wet, areas where TVDI is less than 0.25 are almost water body and areas where TVDI is between 0.25 and 0.5 are of high-moisture soil conditions. High infection risks in areas where TVDI is greater than 0.75 probably associated with human activities. Building lands are widely distributed in these areas, which are an indicator of the intensity of human activities. Up to some extent, the ecological environment, affected by land reclamation, irrigation, deforestation, and road construction, modulates HFRS incidence.³¹ And the intensive human activities provide suitable living conditions for rodents, as well as the transmission of HV.³² Infection risks in districts where TVDI is between 0.25 and 0.5 ($P = 0.98$) may result from concentrated sampling sites. The likely reasons for high infection risks in areas with low elevation may possibly reflect the geographical conditions and land use types in these regions. Cultivated and building lands, which are suitable for the existence and distribution of rodents, are widely distributed in areas with low elevation.^{32,33} The cultivated land environment

TABLE 5

Results of multivariate logistic regression analysis for HV infection

Variable	OR (95% CI)	P
Elevation (m)		0.00
< 100	4.69 (3.86–5.71)	0.00
100–200	1.16 (0.92–1.48)	0.22
200–300	0.00	0.99
> 300	1.00	—
TVDI		0.00
0.25–0.5	0.00	0.98
0.5–0.75	0.50 (0.43–0.58)	0.00
> 0.75	1.00	—

CI = confidence interval; HV = hantavirus; OR = odds ratio; TVDI = temperate vegetation dryness index.

FIGURE 3. Comparison of the four predicted hantavirus risk maps overlaid with human hemorrhagic fever with renal syndrome (HFRS) cases in subtropical China from 2007 to 2010.

FIGURE 4. Monthly predicted map of hantavirus-infected rodents overlaid with human hemorrhagic fever with renal syndrome (HFRS) cases in subtropical China from 2007 to 2010.

TABLE 6
Percentages of the human cases and the related AUC value in low, moderate, and high predicted risk areas in 2007–2010

Year	Low (< 0.15)		Moderate (0.15–0.30)		High (> 0.30)		AUC
	Cases (%)	Area (%)	Cases (%)	Area (%)	Cases (%)	Area (%)	
2007	44.8	61.5	26.3	16.4	29.0	22.1	0.614 ± 0.019
2008	28.5	56.8	30.3	19.4	41.2	23.8	0.719 ± 0.016
2009	16.2	53.6	38.1	17.8	45.7	28.6	0.743 ± 0.015
2010	50.3	71.2	33.1	17.3	16.6	11.5	0.650 ± 0.018
January	19.5	54.8	46.0	22.6	34.5	22.6	0.736 ± 0.024
February	35.1	57.8	15.6	17.4	49.4	24.8	0.635 ± 0.035
March	22.9	61.5	41.7	16.4	35.4	22.1	0.725 ± 0.030
April	31.1	64.3	36.1	14.9	32.8	20.8	0.736 ± 0.026
May	37.6	65.5	32.3	17.2	30.1	17.3	0.701 ± 0.025
June	55.1	80.9	33.3	15.2	11.5	3.9	0.677 ± 0.032
July	35.2	62.7	27.8	15.9	37.0	21.4	0.686 ± 0.035
August	31.7	68.9	31.7	16.6	36.6	14.5	0.746 ± 0.035
September	37.8	55.3	24.4	16.1	37.8	28.6	0.668 ± 0.034
October	13.2	46.6	24.5	14.2	62.3	39.2	0.761 ± 0.033
November	29.1	54.6	32.7	18.3	38.2	27.1	0.684 ± 0.023
December	41.4	58.8	30.7	20.1	27.9	21.1	0.598 ± 0.027

AUC = area under curve.

of most villages in China is suitable for rodent survival and development, and high rodent densities persist in many fields and villages.³⁴ The relatively high population density that focused on the building land also increases rates of contacts between rodents and humans.

The monthly and annual prediction maps from 2007 to 2010 based on logistic regression model showed the spatial-temporal changes of the HV infections in rodents. High-risk areas were concentrated in southwest regions of the study area (Hengyang city), and low-risk areas were in east regions (Zhuzhou city). The annual variation of infection risks is small, while the high infection risk areas predicted in 2010 was significantly less than in other years (Figure 3), which may be due to the excessive rainfall in 2010. TVDI is influenced by rainfall, and the excessive rainfall in 2010 reduced the rodent population and contractions between rodents by destroying their living conditions. Finally, infection risks vary with month, and predicted high-risk areas in June are significantly less than in other months (Figure 4). Seasonal variations of rodent infection risks corresponded to the seasonal variations of human HFRS incidence. The rate of HFRS incidence is small in summer, but large in autumn and winter.³⁵ The risk maps provide theoretical support for rodent surveillance and the prevention and control of HFRS.

This study also has some limitations. First, environmental variables used are primarily abiotic factors, but in all likelihood, they act indirectly on biotic factors that impact the existence and distribution of rodents. Second, surveillance sites are set according to the distribution of epidemic and landscape elements, and surveillance data are collected in specific times, and therefore lack the overall spatial-temporal distribution of population density and infection rates of rodents. For example, low infection risk in areas where TVDI is between 0.25 and 0.75 may have resulted from the concentrated sampling sites. Finally, considering that TVDI plays an important role in the rodent infections, TVDI combined with surveillance data and HFRS cases can be used for further study on the distribution and infection of rodents and the transmission of HFRS.

Received July 1, 2015. Accepted for publication October 31, 2015.

Published online December 28, 2015.

Note: Supplemental table and figures appear at www.ajtmh.org.

Financial support: This work was supported by the Key Discipline Construction Project in Hunan Province (2008001), National Natural Science Foundation (40971038), Scientific Research Fund of the Hunan Provincial Education Department (11K037), Hunan Provincial Natural Science Foundation of China (11JJ3119), Science and Technology Planning Project of Hunan Province of China (2010SK3007), and Key Subject Construction Project of Hunan Normal University (geographic information systems).

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