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# LEPTOSPIROSIS IN VIETNAM

**N.K. Tokarevich, O.V. Blinova**

*St. Petersburg Pasteur Institute, St. Petersburg, Russian Federation*

**Abstract.** Leptospirosis poses a serious public health problem in many countries because about 1 million people suffer annually from this severe, often fatal, infection. At present, its importance has been increasing due to development of integration processes, globalization and intensification of economic activities, inevitable anthropogenic transformation of landscapes as well as rise in number of people with occupational risk of pathogen exposure. The burden of human leptospirosis is expected to rise with demographic shifts and climate change that result in heavy rainfall and flooding. Regarding leptospirosis, Southeast Asia, including Vietnam, is among the most vulnerable global regions. The objective of the review was to analyze available published data on the spread of leptospirosis in Vietnam. More than 100 research articles were analyzed allowing to state that in Vietnam synanthropic rodents (rats), agricultural (buffaloes, cattle, pigs) and domestic animals (cats, dogs) are the main sources of leptospirosis infection in humans. It is essential that rats (cats and dogs also) in Vietnam are used for food. Among all farm animals, pigs are of maximal importance as a source of infection in humans. In Vietnam, Leptospira prevalence in pigs varies widely, up to 73%. It depends significantly on the location, farm size, age and gender of animals, etc. A large variety of Leptospira serovars have been identified in pigs in Vietnam: Tarassovi, Bratislava, Australis, Javanica, Autumnalis, Grippotyphosa, and some others. Official Vietnam reporting of leptospirosis cases based on clinical data does not reflect the real-life incidence rate in humans. However, the available seroprevalence studies reveal that, on average, about 10% of the Vietnamese population are infected with Leptospira. Work in agriculture is the dominant risk factor for acquiring this infection. The highest Leptospira seroprevalence rates were detected in farmers, 63.2%. Serovar diversity is typical for pathogenic Leptospira circulating in Vietnam. In humans, the most frequent are antibodies to Hebdomadis, Wolffi and Icterohaemorrhagiae, but the frequency varied markedly across the country depending on the site, possibly with relation to the environment, as well as with economic activity of the local population. In Vietnam, geographic, climatic and social differences between northern, central and southern regions contribute to the specificity of local leptospirosis epidemiology. This emphasizes the advisability of developing special measures for leptospirosis prevention taking into account regional peculiarities.

***Key words:*** *leptospirosis, Leptospira, Leptospira serovars, morbidity, rats, buffalo, cattle, seroprevalence, antibodies.*

## ЛЕПТОСПИРОЗ ВО ВЬЕТНАМЕ

**Токаревич Н.К., Блинова О.В.**

*ФБУН НИИ эпидемиологии и микробиологии имени Пастера, Санкт-Петербург, Россия*

**Резюме.** Лептоспироз представляет серьезную проблему для здравоохранения многих стран, так как в мире ежегодно около 1 млн людей болеют этой тяжелой инфекцией, часто оканчивающейся летальным исходом. В настоящее время значение этой проблемы возрастает, что связано с развитием интеграционных процессов, обусловленных глобализацией экономики, интенсификацией хозяйственной деятельности, приводящей к антропогенной трансформации ландшафтов и расширению контингента лиц, входящих в угрожаемые профессии, а также глобальными климатическими изменениями. Юго-Восточная Азия, включая Вьетнам, относится к числу самых неблагополучных в отношении лептоспироза регионов мира. Целью работы является

**Адрес для переписки:**
Токаревич Николай Константинович
197101, Россия, Санкт-Петербург, ул. Мира, 14,
ФБУН НИИ эпидемиологии и микробиологии имени Пастера.
Тел.: 8 (812) 232-21-36.
E-mail: zoonoses@mail.ru

**Contacts:**
Nikolay K. Tokarevich
197101, Russian Federation, St. Petersburg, Mira str., 14,
St. Petersburg Pasteur Institute.
Phone: +7 (812) 232-21-36.
E-mail: zoonoses@mail.ru

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современный анализ литературных данных о распространении лептоспирозной инфекции во Вьетнаме. В ходе данной работы было проанализировано более 100 научных статей. Это позволило констатировать, что основными источниками лептоспирозной инфекции во Вьетнаме являются синантропные грызуны (крысы), сельскохозяйственные (буйволы, крупный рогатый скот, свиньи) и домашние (кошки и собаки) животные. Существенной особенностью заражения жителей Вьетнама является употребление ими в пищу крыс, кошек и собак. Из сельскохозяйственных животных в качестве источника инфекции наибольшее значение имеют свиньи. Показатели инфицированности этих животных лептоспирами колеблются в широких пределах, достигая 73%. Значение этих показателей существенно различаются в зависимости от территории обитания животных, от размера фермы, возраста, пола свиней, от количество осадков и ряда других факторов. У свиней во Вьетнаме было выявлено большое разнообразие сероваров лептоспир среди которых преобладали Tarassovi, Bratislava, Australis, Javanica, Autumnalis, Grippotyphosa и другие. Официальная отчетность о заболеваниях лептоспирозом, основанная на клинических данных, не отражает реальное количество больных во Вьетнаме. В среднем около 10% жителей Вьетнама инфицировано лептоспирами. Работа в сельском хозяйстве является доминирующим фактором риска заражения. Наиболее высокие показатели серопревалентности к лептоспирам были выявлены у фермеров — 63,2%. Для Вьетнама характерно большое разнообразие сероваров циркулирующих лептоспир. Наиболее часто у людей выявляются антитела к лептоспирам сероваров Hebdomadis, Wolffi и Icterohaemorrhagiae, но частота их встречаемости существенно различалась между собой в разных регионах, что, можно полагать, связано с ландшафтно-климатическим своеобразием территории, а также обусловлено хозяйственной деятельностью людей. Географические, климатические и социальные различия северной, центральной и южной части Вьетнама в значительной степени определяют эпидемиологические особенности лептоспироза. Это усиливает целесообразность разработки конкретных мер профилактики этой инфекции для каждой территории с учетом их специфики.

***Ключевые слова:*** *лептоспироз, лептоспиры, серовары лептоспир, заболеваемость, крысы, буйволы, крупный рогатый скот, серопревалентность, антитела.*

## Introduction

Leptospirosis is a globally widespread disease, largely due to the wide range of reservoir hosts of pathogenic Leptospira and animals susceptible to them [9]. Thus, according to the Leptospirosis Burden Epidemiology Reference Group (LERG), the number of severe leptospirosis cases in humans exceeds 500 000 per year, though real incidence may be even much higher due to insufficient attention to this infection and difficulties of its diagnostics [78]. Some other researchers emphasize that leptospirosis is among the main global zoonoses, and it accounts for the number of deaths that exceeds mortality due to other causes of hemorrhagic fever. The annual number of leptospirosis cases exceeds one million, and 58 900 of fatal outcomes are recorded worldwide annually [26].

The highest leptospirosis incidence rate in humans is reported in subtropical and tropical climatic zones (e.g., in Seychelles, Malaysia, New Caledonia, Suriname), with 20.0–100.0 per 100 thousand population [4, 31, 46, 86]. Vietnam is a country in Southeast Asia that is one of the most vulnerable regions in the world with regard to leptospirosis. The region ranks second in the world (next to Oceania), both for leptospirosis morbidity and mortality [26]. Moreover, it was possibly in Southeast Asia, under conditions of high humidity and swampiness, long before the appearance of humans, that certain species of Leptospira adapted to parasitizing the bodies of animals, primarily rodents [5]. Currently, leptospirosis poses a significant public health problem in many countries, including Russia [9]. However, Southeast Asia, Vietnam particularly, provides the most favorable conditions for the survival of Leptospira as the pathogen prefers a warm and humid climate. The essential social significance of leptospirosis lies in the occupational risk of infection to which people are exposed in connection with the work they perform [15]. The Government of Vietnam has recognized the priority of five zoonotic diseases, including leptospirosis, and established a framework to investigate and respond to these diseases through the One Health program [63]. The socio-economic importance of leptospirosis is increasing due to a number of drivers. The most important of them are as follows.

1. Integration is proceeding and developing through: globalization of the economy; international economic cooperation; and trade, including export/import of animals (agricultural, domestic, wild), food, and feed [60]. All this favors the introduction of pathogenic Leptospira into virgin territories [2, 3]. Development of international tourism entails growth in the number of patients infected with Leptospira abroad [14, 45, 57]. Several cases of leptospirosis (including fatal) have been reported in Russian tourists that had acquired the infection in Vietnam [6, 7, 10].

2. Intensification of economic activity is leading to anthropogenic transformation of landscapes and a growth in the number of the threatened workers. More than 50% of the Vietnamese population is employed in the agricultural sector [24]. In the previous century, it was noted that the cultivation of rice provides favorable conditions both for survival of Leptospira in the environment and for the habitat of the pathogen's potential carriers [1]. Rice is the main agricultural crop

in Vietnam; its production and export increase steadily. According to the Ministry of Agriculture and Rural Development of the Socialist Republic of Vietnam, the country's rice output in 2021 reached over 43.86 million tons, up 1.1 million tons compared to 2020 [85]. In 2020, Vietnam exported $2.74 billion worth of rice to many countries, making it the third largest rice exporter in the world [66]. Leptospirosis in Vietnam (in the Mekong Delta, first of all) may be considered an environmentally linked disease.

Obviously, the spread of leptospirosis is underestimated in Southeast Asia and, possibly, in other rice-growing countries [81]. Animal husbandry is an important sector of the Vietnamese national economy, and livestock is potentially an important reservoir for pathogenic Leptospira [36]. Significant changes have recently taken place in this sector in Vietnam. These resulted both in a notable increase in the number of farm animals (pigs alone about 29 million heads) and in an improvement in technologies of meat processing and trade in supermarkets. However, infection with some Leptospira serovars may reduce one live pig born per litter, equivalent to 8% loss of production [18].

3. Global climate change may soon transform Vietnam into one of the countries most affected by weather [31, 53]. This means more extensive flooding of agricultural land during the rainy season and increased salinization during the dry season as a result of sea level rise and higher river flooding. In the Mekong Delta, about 590 000 hectares of rice land would be lost due to flooding and salinization; that is about 13 percent of rice growing fields in the region [87]. Leptospirosis is commonly considered a flood-related infection [47]. Some findings support the hypothesis that soils may be the original habitat of the genus Leptospira and a possible environmental reservoir, or at least a temporary carrier, of pathogenic strains [23, 76, 77]. Rains wash the surface of the soil, transferring particles including Leptospira into suspension [70, 75]. Thus, Leptospira penetrate freshwater bodies, where it survives even under unfavorable conditions [74], potentially infecting people on rice plantations. On the other hand, during the dry season, salinity will grow due both to sea level rise and higher river flooding.

The objective of this review was to analyze the literature data on the spread of leptospirosis infection in Vietnam.

## Materials

Articles were sought from Web of Science and international databases: Medline (through PubMed), Science Direct, and Google Scholar. We used a combination of the following search terms: [Leptospirosis AND Vietnam]. The total number of references exceeded 100, but we excluded those non-essential and added a number of important references (mostly in Russian) not available in those databases.

## Geography

Vietnam is situated at the southeastern tip of the Indochinese Peninsula. On the east side, Vietnam contacts the South China Sea. The geographical position of Vietnam has a pronounced, elongated meridional character. The nation stretches along the 105th meridian in a narrow strip. This specific feature of Vietnamese geography, together with alternation of highlands and lowlands, results in a significant variety of climatic conditions.

Vietnam has both a tropical climate zone and a temperate climate zone, with all of the country experiencing the effects of the annual monsoon. Rainy seasons correspond to monsoon circulations, which bring heavy rainfall in the north and south from May to October, and in the central regions from September to January. In the northern regions, average temperatures range from 22–27.5°C in summer to 15–20°C in winter. The southern areas have a narrower range of 28–29°C in summer to 26–27°C in winter. Vietnam's climate is also impacted by the El Niño Southern Oscillation (ENSO), which influences monsoonal circulation, and drives complex shifts in rainfall and temperature patterns which vary spatially at a sub-national level. Due to such different geographical and climatic features, which to a certain extent determine socio-economic characteristics, Northern, Central and Southern Vietnam are usually considered separately. This has prompted researchers to analyze the impact of abiotic, biotic, and social factors on the spread of leptospirosis infections in those different regions of Vietnam [55].

## Leptospira reservoirs

Small synanthropic mammals, rats first of all, are the most important reservoirs of pathogenic Leptospira. The principal feature of their behavior is living close to humans, in residential premises or commercial facilities (livestock farms, enterprises for the processing of animal raw materials, warehouses, etc.). Moreover, rats penetrate natural foci, easily contact wild animals, and can exchange Leptospira. Infection in rodents proceeds mostly in chronic, non-fatal forms, but causes very long, often lifelong, excretion of the pathogen in the animal urine. In Vietnam, the risk of human infection with Leptospira from those animals is especially high, since rats, including those imported from abroad, are traditionally used for food [41]. In 1962 in the south of Vietnam (Saigon, currently Ho Chi Minh City), Leptospira were isolated from Rattus norvegicus. Those Leptospira were assigned to *L. bataviae* by the cross agglutination lysis and cross absorption tests, although they were not antigenically identical to the reference strain or its variant subserotype [40]. Those synanthropic mammals serve as an important source of human infection in the cities of Vietnam, as Leptospira prevalence in rats is high.

Thus, in January 2011 in northern Vietnam (urban areas of Hanoi and Hai Phong), 22% of 100 studied rats were found to have antibodies to *L. interrogans* [44]. In a later study, another group of researchers in Vietnam not only confirmed such high infection prevalence in rats, but also isolated Leptospira from 3 rats [43] and from 144 rats (135 *R. norvegicus*, 8 *R. rattus*, 1 *R. argentiventer*) captured in Vietnam. In total, 17 *L. interrogans* were isolated, of which 16 isolates belonged to the Bataviae serogroup [42]. More recent studies conducted in southwestern Vietnam used not only serological, but also molecular genetic methods (using RT-PCR for the lipL32 gene, confirmed by 16S rRNA, as well as by the microscopic agglutination test-MAT). The results also bear witness to a high prevalence of Leptospira in those synanthropic animals. Antibodies to Leptospira were detected in 18.3% of rats, namely in Rattus norvegicus (33.0%), Bandicota indica (26.5%), Rattus tanezumi (24.6%), Rattus exulans (14.3%), and Rattus argentiventer (7.1%). The most common serovars, in descending order, were: Javanica (4.6% of rats), Louisiana (4.2%), Copenhageni (4.2%), Cynopterie (3.7%), Pomona (2.9%), and Icterohaemorrhagiae (2.5%). A total of 16 rats (5.8%) tested positive by RT-PCR. There was considerable agreement between the MAT and PCR, although significantly more rats were positive by MAT. Leptospira seroprevalence in rats caught during the rainy season was higher than in those caught in the dry season [52].

The results of a study performed by a Russian-Vietnamese group of researchers in seven northern provinces of Vietnam (Dien Bien, Laitiau, Lao Cai, Ha Giang, Lang Son, Cao Bang, Quang Ninh) confirmed the high infection of small wild mammals with Leptospira. PCR-based study of lung and kidney suspensions of 158 animals revealed 16S rRNA of pathogenic Leptospira in 22 (13.9%) samples [8]. Another Russian-Vietnamese group investigated by real-time PCR 133 rodents (of 25 species) trapped in 2010, 2013, 2014, and 2018 in three provinces of northern Vietnam (Ha Giang, Cao Bang, Lao Cai); 24 rodents (18%) were positive for Leptospira. Those were: *Callosciurus erythraeus, Bandicota savilei, Berylmys bowersi, Niviventer fulvescens, Rattus nitidus, Rattus* cf. *rattus*, and *Rattus tanezumi*. The Tanezumi rat *(Rattus tanezumi)*, also known as the Asian rat or Asian house rat, dominated: 11 of 44 animals (33.1%) were infected [12]. When comparing the results of a study on sera of 156 rats from different provinces of Vietnam, it was found that Leptospira seroprevalence in the southern province (Can Tho) was higher than in the central (Ha Tinh) or in the northern (Tai Binh): 24.6%, 10.0%, and 11.4%, respectively. The average value was 16.0% [55]. Therefore, Leptospira prevalence in rats was close to those obtained in earlier studies conducted in the Mekong Delta region [52, 58, 17]. Their findings were at the level of those for other countries of Southeast Asia, such as Thailand, Lao PDR and Cambodia; the mean prevalence was about 7.1% [25].

However, it should be mentioned that in Southeast Asia, Vietnam included, the prevalence of Leptospira in rats was found to be rather low as compared to other southern countries. The highest Leptospira prevalence in rats (> 70%) was reported in Brazil [62, 29, 26, 27], Mexico [59], Egypt [69], and some other countries [17]. The study conducted in three provinces of Vietnam [55] revealed that the seroprevalence in animals other than rats was much higher: 44.2% in buffalo (n = 52), 32.9% in dogs (n = 219), 24.9% in cattle (n = 233), while only 12.2% in cats (n = 164), and 10.2% in pigs (n = 381). In total, it means that Leptospira seroprevalence in animals in the northern province (Tai Binh) was higher than in the central (Ha Tinh) or the southern (Can Tho): 25.9%, 13.3%, and 19.8%, respectively. However, consideration of seroprevalence in individual animal species clarifies significantly our knowledge about the infection of animals with Leptospira in different regions of Vietnam.

It should be noted that the sera of buffaloes, in the samples of which antibodies to Leptospira were found more often than in other animal species, were not examined in Can Tho, as buffalo are not common in this province. Naturally, the lack of data on those animals in the southern Vietnam had an impact on the total seroprevalence in animals of the region. Moreover, it was found that in Can Tho Leptospira seroprevalence in cattle (n = 69) was higher than in Tai Binh (n = 80) or Hatin (n = 84): 30.4%, 22.5%, and 22.6%, respectively. Leptospira seroprevalence in dogs, cats and pigs in Tai Binh exceeded that in both other provinces. Thus, in dogs it was 46.7% in Tai Binh (n = 60), 15.2% in Hatin (n = 79), and 40.0% in Can Tho (n = 32). The same figures for cats were 25.0% in Tai Binh (n = 60), 4.8% in Hatin (n = 42), and 4.8% in Can Tho (n = 62). Leptospira seroprevalence in pigs was 20.5% in Tai Binh (n = 122), 3.3% in Hatin (n = 121), and 7.2% in Can Tho (n = 138).

Hebdomadis, Louisiana, and Javanica were the most common serovars detected in buffalo, while in pigs it was Castelloni, and in rats Louisiana. In cattle, 15 different serovars were detected, Hebdomadis and Canicola being the most frequent. Thirteen serovars were identified in dogs, but Hardjobovis was the most frequently detected. Six serovars were detected in cats; Louisiana, Hebdomadis, and Castellonis dominated.

Using a low dilution threshold for sera containing antibodies to Leptospira (1:100), 17 Leptospira serovars were detected in the studied animals, of which Hebdomadis (2.3%), Molasses (1.6%), Castelloni (1.5%), and Javanika (1.4%) were the most frequent. Panama, Tarassovi, Australis, and Autumnalis were found in all three provinces, while Bratislava was found only in Can Tho. It should be pointed out that all 17 Leptospira serovars were present in Can Tho, while only 12 and 8 serovars were found in Taibin and Hatin, respectively [55].

In Vietnam, infection of humans with Leptospira occurs not only through direct contacts with dogs and cats (or the use of water or food contaminated by them), but also through consumption of their meat, as those animals are used for food [11, 13]. Pigs are of great importance in Vietnam because of their contribution to human nutrition, their role in agricultural production systems, and their economic function. Vietnam's pig herd is the largest in Southeast Asia [51]. In 2020 it exceeded 27 million head, and about 7 million Vietnamese people were involved in pigs raising in 2016 [34]. Therefore, pigs are considered the main source of leptospirosis in humans. In addition, leptospirosis in pigs leads to large economic losses due to abortion and infertility of animals [49].

In Vietnam, Leptospira seroprevalence in pigs ranged up to 73% among sows (n = 424) in the Mekong Delta, where leptospirosis is endemic [18]. High Leptospira prevalence in pigs was also confirmed by pathogen detection in pig kidneys. Thus, in the Mekong Delta (south Vietnam), Leptospira were detected by immunofluorescence in 22 of 32 pigs (69%), and Leptospira serovar Bratislava was isolated from the kidney of one pig [19]. A serological survey was conducted among sows in the Mekong Delta in southern Vietnam in 1999 to investigate variations in Leptospiral seroprevalence over a one-year period. In this region, leptospirosis is endemic, and a high Leptospiral seroprevalence has been shown in the pig population [20].

However, a rather low prevalence (8.17%) was detected in a seroprevalence study of pigs (n = 1959) randomly selected in five provinces (Son La, Hanoi, Nghe An, Dak Lak, An Giang) [49]. The low Leptospira prevalence, according to those authors, was due to a number of reasons, as follows. Serum was sampled during dry or early wet seasons, when seroprevalence is likely to be lower than in the rainy season [71]. Most of other studies were conducted in the Mekong Delta of southern Vietnam, relatively close to riverine areas, which provide more exposure to contaminated water and hence higher levels of Leptospira prevalence. Sera were sampled at slaughterhouses, from rather young animals (aged 6–9 months), while older pigs are more likely to be infected with Leptospira [18]. Animals chosen for slaughter usually look healthy and probably are less infected with Leptospira.

However, some other researchers do not share the conclusion about favorable conditions for infection of pigs with Leptospira in the Mekong Delta. Thus, in a study of 2000 sera from 10 provinces, the average Leptospira seroprevalence was 21.05%, while that of the samples from three provinces lying in the Mekong Delta was much lower: 10.0% in Soc Trang and 11.5% in Dong Thap. The highest detected seroprevalence values were 37.5% in Quang Ngai (Central region), 32.5% in Binh Duong (South), and 30.5% in Bac Giang (North) [50]. There is probably some impact from the amount of precipitation, as has already been proven for Brazil [68], India [71], and Korea [39]. In addition to the aforementioned drivers of Leptospira prevalence in pigs, it is likely that animal gender should be taken into account as well [49]. The size of the farms involved into the study is also important, including possible herd movements [48].

Some downtrend in Leptospira prevalence in pigs may be due to co-infection and reduction in the number of those animals due to the outbreak of African swine fever in 2019, which led to culling and death of approximately 5.9 million pigs (about 22%) [22, 88]. In 2021, ASF outbreaks were ongoing in 48 out of 63 provinces in Vietnam, resulting in the death and culling of nearly 280 000 pigs with a total weight of about 11 678 metric tons, about 3.6-fold higher than the culled numbers in the same period of 2020 [21].

A wide variety of Leptospira serovars were identified in pigs: Tarassovi, Bratislava, Australis, Javanica, Autumnalis, Grippotyphosa, etc. [18, 19, 20]. In particular, Pyogenes and Panama serovars were isolated [50] that already had been detected in cattle in some other countries [33, 56, 61]. It should be noted that the Pyrogenes serovar was detected in Quang Ngai, the province known for its large herd of cattle. One may assume the cattle to be a source of Leptospira in local pigs. In addition, it has been suggested that since Leptospira of Bratislava and Tarasovi serovars are common in wild boars [37, 80], those animals may also contribute to pathogen transmission to farm pigs [48].

## Leptospirosis in humans

Leptospirosis was first identified in Vietnam in 1930 [28, 82]. At the end of the twentieth century, prevalence in humans was rather high: 18.8% of the inhabitants in the Mekong Delta aged 15–60 years had antibodies to Leptospira [81]. Moreover, it should be highlighted that even now leptospirosis is underdiagnosed in many countries, Vietnam included. Due to significant polymorphism of its clinical course and shortcomings in laboratory diagnostics, leptospirosis is often misdiagnosed as some other febrile illnesses such as dengue, scrub typhus, or chikungunya [30, 32, 38, 65]. In Vietnam, nationwide reporting on infectious diseases is carried out by the General Department of Preventive Medicine of the Ministry of Health. Their statistics are built on the basis of clinical information, resulting in significant underdiagnosis of leptospirosis. Therefore, in 2014–2017, the Vietnamese Ministry of Health reported roughly less than 20 cases nationwide per year. In 2018, both morbidity and mortality due to leptospirosis were reported to be zero [35, 84].

However, some scientific publications on Leptospira seroprevalence in humans contradict the official statistics on leptospirosis in Vietnam [46, 83]. In 2019 (November-December), a serological examination of 600 practically healthy residents of three

provinces (representing North, Central North and South Vietnam) revealed antibodies to Leptospira in 9.5% of them. Antibodies to Leptospira serovars Hebdomadis (14.0%), Pomona (14.0%), Saxkoebing (12.3%), and Panama (8.8%) were most frequently detected. Leptospira seroprevalence varied significantly: from 5.5% in Can Tho City, to 9.0% in Thai Binh, and 14% in Ha Tinh province. The highest rate of Leptospira seroprevalence, 63.2%, was found in farmers [79]. The seropositivity in Vietnam seemed rather low compared to other Southeast Asian countries.

For instance, in Malaysia the seroprevalence of Leptospiral antibodies in high-risk groups was up to 28.6% (in planters) and 33.6% (wet market workers) [64, 67]. However, the difference may be related to the choice of humans under study. The difference in prevalence might be due to the fact that in Malaysia the occupationally high-risk group was examined, while in Vietnam they "randomly" selected healthy residents aged above four, and the highest rate of seroprevalence to Leptospira (63.2%) was revealed in farmers [79].

In our opinion, the detection of antibodies to Leptospira in almost 10% of healthy humans in three different provinces clearly indicates that the official data on the registration of leptospirosis do not reflect the real spread of this infection in Vietnam. This is confirmed by the results of a study of sera sampled from 3815 patients with suspected leptospirosis. The patients were examined in 11 public hospitals from three provinces (Thai Binh, Ha Tinh, Can Tho), representing three different geographical and climatic zones of Vietnam. The result proved that the conclusions of the authors about the unsatisfactory diagnosis of leptospirosis were valid not only for individual territories, but for the whole of Vietnam [54]. Surveillance revealed that in 68 (1.8%) and 248 (6.5%) cases, a leptospirosis diagnosis was confirmed, or regarded as likely, according to the microscopic agglutination test (MAT) or enzyme immunoassay (ELISA-IgM), respectively. In addition, more than 30% of patient serum samples contained IgM antibodies (according to ELISA data) to Leptospira. The number of laboratory-confirmed leptospirosis cases was highest in Thai Binh (2.3%), while somewhat lower in Ha Tinh (2.0%) and Can Tho (1.0%). Laboratory values considered "probable for leptospirosis" were even higher: 8.5% in Ha Tinh, 7.1% in Can Tho, and 7.0% in Thai Binh.

In three provinces, 20 different serovars (with a titer threshold of 1:100 to 1:400) were detected using MAT, indicating diversification of Leptospira serovars circulating in Vietnam. Of those 20 serovars, 17 were found in Hatin, 16 in Taibin, and 12 in Can Tho. In general, the serovars Wolffi (14.2%), Hebdomadis (13.8%), and Icterohaemorrhagiae (12.6%) prevailed, but their incidence varied significantly in the three provinces. Castellonis (12.3%), Djasiman (12.3%), and Wolffi (12.3%) dominated in Taibin. Icterohaemorrhagiae (19%) and Wolffi (15%) dominated in Khatin. Hebdomadis (23.6%) and Wolffi (15.3%) prevailed in Can Tho.

According to aggregate findings in those three provinces, leptospirosis was more common in women (57.9%) than in men (42.1%). It is not typical for most countries and may be explained by the fact that 85.9% of women in Vietnam are employed in agriculture. Of the probable and confirmed cases of leptospirosis, approximately two-thirds were farmers, and most of them were involved in raising agriculture or domestic animals. Working in agriculture is probably the main risk factor for contracting leptospirosis in Vietnam. Thus, 53.5% and 83.2% of patients with probable or confirmed leptospirosis were farmers in Taibin and Hatin, respectively.

About two thirds of patients with leptospirosis were people of working age, 24 to 60 years [54]. Although adults are more frequently infected with Leptospira due to their professional activities, children also acquire this pathogen. Thus, a serological study of children in the south of Vietnam revealed an average Leptospira prevalence of 12.8% [72]. It ranged from 11% in 7 years-old up to 25% in 12-year-old children [73]. It is possible that walking barefoot in the mud, swimming in polluted water, etc., may cause Leptospira infection in children [54]. There is evidence that virulent Leptospira survive in the environment for several months [16].

## Conclusion

The main sources of leptospirosis infection in Vietnam are synanthropic rodents (rats), agricultural animals (buffaloes, cattle, pigs) and domestic animals (cats, dogs). Among all farm animals, pigs are the most important source of Leptospira in Vietnam, as about 7 million of the country's population work in the pig breeding sector. The seroprevalence of leptospirosis in pigs is up to 73% in some locations (Mekong Delta), though it varies significantly depending on the territory, farm size, animal age and gender, amount of precipitation, etc. A specific and essential feature of the infection in Vietnam is human consumption of cats, dogs, and rats.

Official reporting of leptospirosis cases based on clinical data does not reflect the actual number of patients in Vietnam. On average, about 10% of the population was found to be infected with Leptospira. Work in the agriculture sector is the dominant risk factor for acquiring the infection. The highest Leptospira seroprevalence was detected in farmers. Women are infected more often than men. About two thirds of patients with leptospirosis were people of working age (24 to 60 years), but antibodies to Leptospira were also detected in 12.8% of children. A very wide variety of pathogenic Leptospira serovars was detected in Vietnam. The list of pathogenic

Leptospira varies significantly depending on the region. This is due to variation of environment, landscape and climatic features of the territory, as well as the economic profile of the province. Geographic, climatic and social differences in the northern, central and southern regions of Vietnam largely determine the epidemiological features of leptospirosis within the territory. This argues for the advisability of developing measures to prevent this infection in each region, taking into account their specifics.

## References


1. Лептоспирозы людей и животных / Под ред. проф. В.В. Ананьина. М.: Медицина, 1971. 352 с. [Leptospirosis in humans and animals. Ed. Prof. V.V. Ananyin. *Moscow: Medicine, 1971. 352 p. (In Russ.)*]
2. Ананьина Ю.В. Природно-очаговые бактериальные зоонозы: современные тенденции эпидемического проявления // Журнал микробиологии, эпидемиологии и иммунобиологии. 2002. № 6. С. 86–90. [Ananyina Ju.V. Bacterial zoonoses with natural focality: current trends in epidemic manifestation. *Zhurnal mikrobiologii, epidemiologii i immunobiologii = Journal of Microbiology, Epidemiology and Immunobiology, 2002, no. 6, pp. 86–90. (In Russ.)*]
3. Ананьина Ю.В. Лептоспирозы людей и животных: тенденции распространения и проблемы профилактики // Эпидемиология и вакцинопрофилактика. 2010. № 2 (51). С. 13–16. [Ananyina Ju.V. Human and animal leptospiroses: prevalence trends and preventive measures. *Epidemiologiya i vaktsinoprofilaktika = Epidemiology and Vaccinal Prevention, 2010, no. 2 (51), pp. 13–16. (In Russ.)*]
4. Бренева Н.В., Балахонов С.В. Вопросы эндемичности и энзоотичности лептоспирозов // Журнал микробиологии, эпидемиологии и иммунобиологии. 2019. № 5. С. 118–125. [Breneva N.V., Balakhonov S.V. Endemicity and enzooticity aspects of leptospirosis. *Zhurnal mikrobiologii epidemiologii i immunobiologii = Zhurnal Mikrobiologii, Epidemiologii i Immunobiologii, 2019, no. 5, pp. 118–125. (In Russ.)*] *doi: 10.36233/0372-9311-2019-5-118-125*
5. Жданов В.М. Эволюция заразных болезней человека. М.: Медицина, 1964. 375 с. [Zhdanov V.M. The evolution of human infectious diseases. *Moscow: Medicine, 1964. 375 p. (In Russ.)*]
6. Киселева Е.Ю., Бренева Н.В., Лемешевская М.В., Бурданова Т.М. Завозной случай лептоспироза с летальным исходом из Вьетнама в Иркутскую область // Инфекционные болезни. 2014. Т. 12, Вып. 3. С. 95–99. [Kiseleva E.Yu., Breneva N.V., Lemeshevskaya M.V., Burdanova T.M. An imported case of leptospirosis with a lethal outcome from Vietnam to the Irkutsk region. *Infektsionnye bolezni = Infectious Disease, 2014, vol. 12, no. 3, pp. 95–99. (In Russ.)*]
7. Никулина М.А., Гранитов В.М., Танашкин С.Ф., Волчкова Е.В., Немилостива Е.А. Проблемы диагностики завозного случая лептоспироза (анализ клинического наблюдения) // Эпидемиология и инфекционные болезни. 2017. Т. 22, Вып. 1. С. 36–41. [Nikulina M.A., Granitov V.M., Tanashkin S.F., Volchkova E.V., Nemilostiva E.A. Problems finding imported case leptospirosis (clinical observation). *Epidemiologiya i infektsionnye bolezni = Epidemiology and Infectious Diseases, 2017, vol. 22, no. 1, pp. 36–41. (In Russ.)*] *doi: 10.17816/EID40969*
8. Поршаков А.М., Чумачкова Е.А., Касьян Ж.А., Оглодин Е.Г., Лыонг Тхи Мо, Во Вьет Кыонг, Чинь Ван Тоан, Буй Тхи Тхань Нга. Результаты эпизоотологического обследования на чуму и другие зоонозы в северных провинциях Социалистической Республики Вьетнам весной 2019 г. // Проблемы особо опасных инфекций. 2020. Т. 1. С. 133–138. [Porshakov A.M., Chumachkova E.A., Kas'yan Z.A., Oglodin E.G., Mo L., Cuong V., Toan C., Nga B. Results of epizootiological survey on plague and other zoonotic infections in the northern provinces of the Socialist Republic of Vietnam during spring months of 2019. *Problemy osobo opasnykh infektsii = Problems of Particularly Dangerous Infections, 2020, vol. 1, pp. 133–138. (In Russ.)*] *doi: 10.21055/0370-1069-2020-1-133-138*
9. Стоянова Н.А., Токаревич Н.К., Ваганова А.Н., Грачева Л.И., Майорова С.О. Лептоспирозы: пособие для врачей / Под ред. Ю.В. Ананьиной. СПб.: НИИЭМ им. Пастера, 2010. 116 с. [Stoyanova N.A., Tokarevich N.K., Vaganova A.N., Gracheva L.I., Mayorova S.O. Leptospirosis. A guide for medical doctors. Ed. Yu.V. Anan'ina. *St. Petersburg: St. Petersburg Pasteur Institute, 2010. 116 p. (In Russ.)*]
10. Шаракшанов М.Б., Бренева Н.В., Лемешевская М.В., Бурданова Т.М., Муляр Н.Ф., Путилова Е.А., Белых К.А., Котова И.В., Киселева Е.Ю., Балахонов С.В. Клинико-эпидемиологический анализ случаев лептоспироза в Иркутской области в 2011–2015 гг. // Инфекционные болезни. 2016. Т. 14, Вып. 1. С. 73–79. [Sharakshanov M.B., Breneva N.V., Lemeshevskaya M.V., Burdanova T.M., Mulyar N.F., Putilova E.A., Belykh K.A., Kotova I.V., Kiseleva E.Y., Balakhonov S.V. Clinical and epidemiological analysis of cases of leptospirosis in the Irkutsk region in 2011–2015. *Infektsionnye bolezni = Infectious Diseases, 2016, vol. 14, no. 1, pp. 73–79. (In Russ.)*] *doi: 10.20953/1729-9225-2016-1-73-79*
11. A summary report on dog and cat meat consumption in Vietnam. Research conducted by Market Strategy and Development Co, Ltd. January 2021. *URL: https://media.4-paws.org/f/d/7/f/fd7fa3dec78bdccc150f917132cfec8f8d576725/FOURPAWS_Vietnamese_Consumer_Summary_Report_GB_V4.pdf*
12. Anh L.T.L., Balakirev A.E., Chau N.V. Investigation of multiple infections with zoonotic pathogens of rodents in northern Vietnam. *J. Vector. Borne Dis., 2021, vol. 58, no. 1, pp. 47–53. doi: 10.4103/0972-9062.321750*
13. Avieli N. Dog meat politics in a Vietnamese town. *Ethnology, 2011, vol. 50, pp. 59–78. URL: https://www.researchgate.net/publication/289953306_Dog_meat_politics_in_a_Vietnamese_town*
14. Bandara M., Ananda M., Wickramage K., Berger E., Agampodi S. Globalization of leptospirosis through travel and migration. *Global Health, 2014, vol. 10: 61. doi: 10.1186/s12992-014-0061-0*
15. Bharti A.R., Nally J.E., Ricaldi J.N., Matthias M.A., Diaz M.M., Lovett M.A., Levett P.N., Gilman R.H., Willig M.R., Gotuzzo E. Leptospirosis: a zoonotic disease of global importance. *Lancet Infect. Dis., 2003, vol. 3, pp. 757–771. doi: 10.1016/s1473-3099(03)00830-2*
16. Bierque E., Thibeaux R., Girault D., Soupe-Gilbert M.-E., Goarant C. A systematic review of Leptospira in water and soil environments. *PLoS One, 2020, vol. 15, no. 1: e0227055. doi: 10.1371/journal.pone.0227055*
17. Boey K., Shiokawa K., Rajeev S. Leptospira infection in rats: a literature review of global prevalence and distribution. *PLoS Negl Trop. Dis., 2019, vol. 13, no. 8: e0007499. doi: 10.1371/journal.pntd.0007499*

18. Boqvist S., Chau B.L., Gunnarsson A., Olsson Engvall E., Vågsholm I., Magnusson U. Animal- and herd-level risk factors for leptospiral seropositivity among sows in the Mekong delta, Vietnam. *Prev. Vet. Med., 2002, vol. 53, no. 3, pp. 233–245. doi: 10.1016/s0167-5877(01)00263-x*
19. Boqvist S., Montgomery J.M., Hurst M., Thu H.T., Engvall E.O., Gunnarsson A., Magnusson U. Leptospira in slaughtered fattening pigs in southern Vietnam: presence of the bacteria in the kidneys and association with morphological findings. *Vet. Microbiol., 2003, vol. 93, no. 4, pp. 361–368. doi: 10.1016/s0378-1135(03)00042-7*
20. Boqvist S., Ho Thi V.T., Magnusson U. Annual variations in Leptospira seroprevalence among sows in southern Vietnam. *Trop. Anim. Health Prod., 2005, vol. 37, no. 6, pp. 443–449. doi: 10.1007/s11250-005-0300-8*
21. Bui N. Vietnam Livestock Market Update Report Number: VM2021–0109, Hanoi: USDA, 2021. *URL: https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Vietnam%20Livestock%20Market%20Update_Hanoi_Vietnam_12-13-2021.pdf (12.05.2022)*
22. Bui N., Gilleski S. Vietnam African swine fever update, in GAIN report VM9027. Hanoi: USDA, 2019. *URL: https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Vietnam%20African%20Swine%20Fever%20Update_Hanoi_Vietnam_11-30-2019 (12.05.2022)*
23. Casanovas-Massana A., Pedra G.G., Wunder E.A. Jr., Diggle P.J., Begon M., Ko A.I. Quantification of Leptospira interrogans survival in soil and water microcosms. *Appl. Environ. Microbiol., 2018, vol. 84, no. 13: e00507-18. doi: 10.1128/AEM.00507-18*
24. Chu D.T., Ngoc T.U., Chu-Dinh T., Ngoc V.T.N., Van Nhon B., Pham V.H., Nghia L.L., Anh L.Q., Van Pham T.H., Truong N.D. The possible zoonotic diseases transferring from pig to human in Vietnam. *Eur. J. Clin. Microbiol. Infect. Dis., 2019, vol. 38, no. 6, pp. 1003–1014. doi: 10.1007/s10096-018-03466-y*
25. Cosson J.F., Picardeau M., Mielcarek M., Tatard C., Chaval Y., Suputtamongkol Y., Buchy P., Jittapalapong S., Herbreteau V., Morand S. Epidemiology of Leptospira transmitted by rodents in southeast Asia. *PLoS Negl Trop. Dis., 2014, vol. 8, no. 6: e2902. doi: 10.1371/journal.pntd.0002902*
26. Costa F., Porter F.H., Rodrigues G., Farias H., de Faria M.T., Wunder E.A., Osikowicz L.M., Kosoy M.Y., Reis M.G., Ko A.I., Childs J.E. Infections by Leptospira interrogans, Seoul virus, and Bartonella spp. among Norway rats (Rattus norvegicus) from the urban slum environment in Brazil. *Vector Borne Zoonotic Dis., 2014, vol. 14, no. 1, pp. 33–40. doi: 10.1089/vbz.2013.1378*
27. De Faria M.T., Calderwood M.S., Athanazio D.A., McBride A.J., Hartskeerl R.A., Pereira M.M., Ko A.I., Reis M.G. Carriage of Leptospira interrogans among domestic rats from an urban setting highly endemic for leptospirosis in Brazil. *Acta Trop., 2008, vol. 108, no. 1, pp. 1–5. doi: 10.1016/j.actatropica.2008.07.005*
28. De Lajudie P., Brygoo Er. Les leptospiroses au Viet-Nam [Leptospirosis in Viet-Nam]. *Med. Trop. (Mars), 1953, vol. 13, no. 4, pp. 466–481. (In French).*
29. De Oliveira D., Figueira C.P., Zhan L., Pertile A.C., Pedra G.G., Gusmão I.M., Wunder E.A., Rodrigues G., Ramos E.A., Ko A.I., Childs J.E., Reis M.G., Costa F. Leptospira in breast tissue and milk of urban Norway rats (Rattus norvegicus). *Epidemiol. Infect., 2016, vol. 144, no. 11, pp. 2420–2429. doi: 10.1017/S0950268816000637*
30. De Vries S.G., Visser B.J., Nagel I.M., Goris M.G., Hartskeerl R.A., Grobusch M.P. Leptospirosis in Sub-Saharan Africa: a systematic review. *Int. J. Infect. Dis., 2014, vol. 28, pp. 47–64. doi: 10.1016/j.ijid.2014.06.013*
31. Douchet L., Goarant C., Mangeas M., Menkes C., Hinjoy S., Herbreteau V. Unraveling the invisible leptospirosis in mainland Southeast Asia and its fate under climate change. *Sci. Total. Environ., 2022, vol. 832: 155018. doi: 10.1016/j.scitotenv.2022.155018*
32. Dunay S., Bass J., Stremick J. Leptospirosis: a Global Health Burden in Review. *Emerg. Med. (Los Angel), 2016, vol. 6, 5 p. doi: 10.4172/2165-7548.1000336*
33. Feresu S.B., Bolin C.A., Korver H., Terpstra W.J. Classification of leptospires of the pyrogenes serogroup isolated from cattle in Zimbabwe by cross-agglutinin absorption and restriction fragment length polymorphism analysis. *Int. J. Syst. Bacteriol., 1994, vol. 44, no. 3, pp. 541–546. doi: 10.1099/00207713-44-3-541*
34. General Statistic Office. Results of the rural, agricultural and fishery census 2016. Hanoi: Statistic Publishing House, 2018. *URL: https://www.gso.gov.vn/wp-content/uploads/2019/03/TDT-NTNNTS-2016.pdf (12.05.2022)*
35. General Statistic Office. Statistical Summary Book of Viet Nam 2020. Date of issue: 30/06/2021. *URL: https://www.gso.gov.vn/en/data-and-statistics/2021/07/statistical-summary-book-of-viet-nam-2020 (12.05.2022)*
36. Hassan L. Emerging zoonoses in domesticated livestock of Southeast Asia. Ed.: N.K. Van Alfen. Encyclopedia of agriculture and food systems. *Academic Press, 2014, pp. 68–81. doi: 10.1016/B978-0-444-52512-3.00216-3*
37. Jansen A., Luge E., Guerra B., Wittschen P., Gruber A.D., Loddenkemper C., Schneider T., Lierz M., Ehlert D., Appel B., Stark K., Nöckler K. Leptospirosis in urban wild boars, Berlin, Germany. *Emerg. Infect. Dis., 2007, vol. 13, no. 5, pp. 739–742. doi: 10.3201/eid1305.061302*
38. Jeffree M.S., Mori D., Yusof N.A., Atil A.B., Lukman K.A., Othman R., Hassan M.R., Suut L., Ahmed K. High incidence of asymptomatic leptospirosis among urban sanitation workers from Kota Kinabalu, Sabah, Malaysian Borneo. *Sci. Rep., 2020, vol. 10, no. 1: 19442. doi: 10.1038/s41598-020-76595-0*
39. Kim S.H., Jang J.Y. Correlations between climate change-related infectious diseases and meteorological factors in Korea. *J. Prev. Med. Public Health, 2010, vol. 43, no. 5, pp. 436–444. (In Korean). doi: 10.3961/jpmph.2010.43.5.436*
40. Kitaoka M., Duong H.M., Mori M., Mo D.H. Identification of Leptospira strains isolated from rats in Saigon as Leptospira bataviae or its subserotype. *Int. J. Zoonoses, 1977, vol. 4, no. 1, pp. 45–47.*
41. Koizumi N., Morita M., Pheng V., Wann C., Masuoka H., Higa Y., Wada T., Hirayama K., Ohnishi M., Miura K. Rat trade and leptospirosis: Molecular epidemiology of Leptospira species in rats exported from Cambodia to Vietnam. *Transbound Emerg. Dis., 2022, vol. 69, no. 3, pp. 1641–1648. doi: 10.1111/tbed.14077*
42. Koizumi N., Miura K., Sanai Y., Takemura T., Ung T.T.H., Le T.T., Hirayama K., Hasebe F., Nguyen H.L.K., Hoang P.V.M., Nguyen C.N., Khong T.M., Le M.T.Q., Hoang H.T.T., Ohnishi M. Molecular epidemiology of Leptospira interrogans in Rattus norvegicus in Hanoi, Vietnam. *Acta Trop., 2019, vol. 194, pp. 204–208. doi: 10.1016/j.actatropica.2019.02.008*
43. Koizumi N., Izumiya H., Mu J.J., Arent Z., Okano S., Nakajima C., Suzuki Y., Mizutani Muto M., Tanikawa T., Taylor K.R., Komatsu N., Yoshimatsu K., Thi Thu Ha H., Ohnishi M. Multiple-locus variable-number tandem repeat analysis of Leptospira interrogans and Leptospira borgpetersenii isolated from small feral and wild mammals in East Asia. *Infect. Genet. Evol., 2015, vol. 36, pp. 434–440. doi: 10.1016/j.meegid.2015.08.013*

44. Koma T., Yoshimatsu K., Yasuda S.P., Li T., Amada T., Shimizu K., Isozumi R., Mai L.T., Hoa N.T., Nguyen V., Yamashiro T., Hasebe F., Arikawa J. A survey of rodent-borne pathogens carried by wild Rattus spp. in Northern Vietnam. *Epidemiol. Infect., 2013, vol. 141, no. 9, pp. 1876–1884. doi: 10.1017/S0950268812002385*
45. Kutsuna S., Kato Y., Koizumi N., Yamamoto K., Fujiya Y., Mawatari M., Takeshita N., Hayakawa K., Kanagawa S., Ohmagari N. Travel-related leptospirosis in Japan: a report on a series of five imported cases diagnosed at the National Center for Global Health and Medicine. *J. Infect. Chemother., 2015, vol. 21, no. 3, pp. 218–223. doi: 10.1016/j.jiac.2014.10.004*
46. Laras K., Cao B.V., Bounlu K., Nguyen T.K., Olson J.G., Thongchanh S., Tran N.V., Hoang K.L., Punjabi N., Ha B.K., Ung S.A., Insisiengmay S., Watts D.M., Beecham H.J., Corwin A.L. The importance of leptospirosis in Southeast Asia. *Am. J. Trop. Med. Hyg., 2002, vol. 67, no. 3, pp. 278–286. doi: 10.4269/ajtmh.2002.67.278*
47. Lau C., Smythe L., Craig S., Weinstein P. Climate change, flooding, urbanisation and leptospirosis: Fuelling the fire? *Trans. R. Soc. Trop. Med. Hyg., 2010, vol. 104, pp. 631–638. doi: 10.1016/j.trstmh.2010.07.002*
48. Lee H.S., Bui V.N., Nguyen H.X., Bui A.N., Hoang T.D., Nguyen-Viet H., Grace Randolph D., Wieland B. Seroprevalences of multi-pathogen and description of farm movement in pigs in two provinces in Vietnam. *BMC Vet. Res., 2020, vol. 16, no. 1: 15. doi: 10.1186/s12917-020-2236-7*
49. Lee H.S., Khong N.V., Xuan H.N., Nghia V.B., Nguyen-Viet H., Grace D. Sero-prevalence of specific Leptospira serovars in fattening pigs from 5 provinces in Vietnam. *BMC Vet Res., 2017, vol. 13, no. 1: 125. doi: 10.1186/s12917-017-1044-1*
50. Lee H.S., Thanh T.L., Ly N.K., Nguyen-Viet H., Thakur K.K., Grace D. Seroprevalence of leptospirosis and Japanese encephalitis in swine in ten provinces of Vietnam. *PLoS One, 2019, vol. 14, no. 8: e0214701. doi: 10.1371/journal.pone.0214701*
51. Lemke U., Mergenthaler M., Roessler R., Le Thi Thanh H., Herold P., Kaufmann B., Zárate A. Pig production in Vietnam — a review. *CAB Reviews Perspectives in Agriculture Veterinary Science Nutrition and Natural Resources, 2008, vol. 23, 15 p. doi: 10.1079/PAVSNNR20083023*
52. Loan H.K., Van Cuong N., Takhampunya R., Kiet B.T., Campbell J., Them L.N., Bryant J.E., Tippayachai B., Van Hoang N., Morand S., Hien V.B., Carrique-Mas J.J. How important are rats as vectors of leptospirosis in the Mekong Delta of Vietnam? *Vector Borne Zoonotic Dis., 2015, vol. 15, no. 1, pp. 56–64. doi: 10.1089/vbz.2014.1613*
53. Lu L.C., Chiu S.Y., Chiu Y.H., Chang T.H. Sustainability efficiency of climate change and global disasters based on greenhouse gas emissions from the parallel production sectors — a modified dynamic parallel three-stage network DEA model. *J. Environ. Manage, 2022, vol. 317: 115401. doi: 10.1016/j.jenvman.2022.115401*
54. Mai L.T.P., Dung L.P., Mai T.N.P., Hanh N.T.M., Than P.D., Tran V.D., Quyet N.T., Hai H., Ngoc D.B., Hai P.T., Hoa L.M., Thu N.T., Duong T.N., Anh D.D. Characteristics of human leptospirosis in three different geographical and climatic zones of Vietnam: a hospital-based study. *Int. J. Infect. Dis., 2022, vol. 120, pp. 113–120. doi: 10.1016/j.ijid.2022.04.011*
55. Mai L.T.P., Dung L.P., Than P.D., Dinh T.V., Quyet N.T., Hai H., Mai T.N.P., Hanh N.T.M., Ly N.K. Leptospira infection among human-close-contact animals in different geographical areas in Vietnam. *Sci. Prog., 2021, vol. 104, no. 3: 368504211031747. doi: 10.1177/00368504211031747*
56. Martins G., Loureiro A.P., Hamond C., Pinna M.H., Bremont S., Bourhy P., Lilenbaum W. First isolation of Leptospira noguchii serogroups Panama and Autumnalis from cattle. *Epidemiol. Infect., 2015, vol. 143, no. 7, pp. 1538–1541. doi: 10.1017/S0950268814002416*
57. Mishima N., Tabuchi K., Kuroda T., Nakatani I., Lamaningao P., Miyake M., Kanda S., Koizumi N., Nishiyama T. The first case in Japan of severe human leptospirosis imported from Vietnam. *Trop. Med. Health, 2013, vol. 41, no. 4, pp. 171–176. doi: 10.2149/tmh.2013-04*
58. Muoi N.T.B., Thu H.T.V. Survey on Leptospira infection rate in rats (Rattus norvegicus and Rattus rattus) in Kien Giang province. *Sci. J. Cantho Univ., 2016, vol. 2: 4.*
59. Panti-May J.A., De Andrade R.R.C., Gurubel-González Y., Palomo-Arjona E., Sodá-Tamayo L., Meza-Sulú J., Ramírez-Sierra M., Dumonteil E., Vidal-Martínez V.M., Machaín-Williams C., De Oliveira D., Reis M.G., Torres-Castro M.A., Robles M.R., Hernández-Betancourt S.F., Costa F. A survey of zoonotic pathogens carried by house mouse and black rat populations in Yucatan, Mexico. *Epidemiol. Infect., 2017, vol. 145, no. 11, pp. 2287–2295. doi: 10.1017/S0950268817001352*
60. Pappas G., Papadimitriou P., Siozopoulou V., Christou L., Akritidis N. The globalization of leptospirosis: worldwide incidence trends. *Int. J. Infect. Dis., 2008, vol. 12, no. 4, pp. 351–357. doi: 10.1016/j.ijid.2007.09.011*
61. Patel J.M., Vihol P.D., Prasad M.C., Kalyani I.H., Raval J.K., Patel K.M., Thirumalesh S.R.A., Balamurugan V. Seroepidemiological pattern of leptospirosis in bovine of South Gujarat, India. *Veterinary World, 2014, vol. 7, no. 11, pp. 999–1003. doi: 10.14202/vetworld.2014.999-1003*
62. Pellizzaro M., Conrado F.O., Martins C.M., Joaquim S.F., Ferreira F., Langoni H., Biondo A.W. Serosurvey of Leptospira spp. and Toxoplasma gondii in rats captured from two zoos in Southern Brazil. *Rev. Soc. Bras. Med. Trop., 2017, vol. 50, no. 6, pp. 857–860. doi: 10.1590/0037-8682-0138-2017*
63. Pham-Thanh L., Nhu T.V., Nguyen T.V., Tran K.V., Nguyen K.C., Nguyen H.T., Hoa N.T., Padungtod P. Zoonotic pathogens and diseases detected in Vietnam, 2020–2021. *One Health, 2022, vol. 14: 100398. doi: 10.1016/j.onehlt.2022.100398*
64. Rahman M.H.A.A., Hairon S.M., Hamat R.A., Jamaluddin T.Z.M.T., Shafei M.N., Idris N., Osman M., Sukeri S., Wahab Z.A., Mohammad W.M.Z.W., Idris Z., Daud A. Seroprevalence and distribution of leptospirosis serovars among wet market workers in northeastern, Malaysia: a cross sectional study. *BMC Infect. Dis., 2018, vol. 18, no. 1: 569. doi: 10.1186/s12879-018-3470-5*
65. Ricaldi J.N., Vinetz J.M. Leptospirosis in the tropics and in travelers. *Curr. Infect. Dis. Rep., 2006, vol. 8, no. 1, pp. 51–58. doi: 10.1007/s11908-006-0035-3*
66. Rice. The Observatory of Economic Complexity (OEC). *URL: https://oec.world/en/profile/hs/rice (12.05.2022)*
67. Ridzuan J.M., Aziah B.D., Zahiruddin W.M. Study on seroprevalence and leptospiral antibody distribution among high-risk planters in Malaysia. *Osong Public Health Res. Perspect, 2016, vol. 7, no. 3, pp. 168–171. doi: 10.1016/j.phrp.2016.04.006*
68. Romero E.C., Bernardo C.C., Yasuda P.H. Human leptospirosis: a twenty-nine-year serological study in São Paulo, Brazil. *Rev. Inst. Med. Trop. Sao Paulo, 2003, vol. 45, no. 5, pp. 245–248. doi: 10.1590/s0036-46652003000500002*
69. Samir A., Soliman R., El-Hariri M., Abdel-Moein K., Hatem M.E. Leptospirosis in animals and human contacts in Egypt: broad range surveillance. *Rev. Soc. Bras. Med. Trop., 2015, vol. 48, no. 3, pp. 272–277. doi: 10.1590/0037-8682-0102-2015*

70. Schneider A.G., Casanovas-Massana A., Hacker K.P., Wunder E.A. Jr., Begon M., Reis M.G., Childs J.E., Costa F., Lindow J.C., Ko A.I. Quantification of pathogenic Leptospira in the soils of a Brazilian urban slum. *PLoS Negl Trop. Dis., 2018, vol. 12, no. 4: e0006415. doi: 10.1371/journal.pntd.0006415*
71. Sethi S., Sharma N., Kakkar N., Taneja J., Chatterjee S.S., Banga S.S., Sharma M. Increasing trends of leptospirosis in northern India: a clinico-epidemiological study. *PLoS Negl Trop. Dis., 2010, vol. 4, no. 1: e579. doi: 10.1371/journal.pntd.0000579*
72. Thai K.T., Binh T.Q., Giao P.T., Phuong H.L., Hung le Q., Van Nam N., Nga T.T., Goris M.G., de Vries P.J. Seroepidemiology of leptospirosis in southern Vietnamese children. *Trop. Med. Int. Health, 2006, vol. 11, no. 5, pp. 738–745. doi: 10.1111/j.1365-3156.2006.01619.x*
73. Thai K.T., Nga T.T., Phuong H.L., Giao P.T., Hung le Q., Binh T.Q., Van Nam N., Hartskeerl R.A., de Vries P.J. Seroepidemiology and serological follow-up of anti-leptospiral IgG in children in Southern Vietnam. *Acta Trop., 2008, vol. 106, no. 2, pp. 128–131. doi: 10.1016/j.actatropica.2008.02.005*
74. Thibeaux R., Bierque E., Soupé-Gilbert M.E., Girault D., Guentas L., Goarant C. Leptospira interrogans retains direct virulence after long starvation in water. *Curr. Microbiol., 2020, vol. 77, no. 10, pp. 3035–3043. doi: 10.1007/s00284-020-02128-7*
75. Thibeaux R., Geroult S., Benezech C., Chabaud S., Soupé-Gilbert M.E., Girault D., Bierque E., Goarant C. Seeking the environmental source of Leptospirosis reveals durable bacterial viability in river soils. *PLoS Negl Trop. Dis., 2017, vol. 11, no. 2: e0005414. doi: 10.1371/journal.pntd.0005414*
76. Thibeaux R., Girault D., Bierque E., Soupé-Gilbert M.E., Rettinger A., Douyère A., Meyer M., Iraola G., Picardeau M., Goarant C. Biodiversity of environmental Leptospira: improving identification and revisiting the diagnosis. *Front. Microbiol., 2018, vol. 1, no. 9: 816. doi: 10.3389/fmicb.2018.00816*
77. Thibeaux R., Iraola G., Ferrés I., Bierque E., Girault D., Soupé-Gilbert M.E., Picardeau M., Goarant C. Deciphering the unexplored Leptospira diversity from soils uncovers genomic evolution to virulence. *Microb. Genom., 2018, vol. 4, no. 1: e000144. doi: 10.1099/mgen.0.000144*
78. Tonin A.A., Krawczak F. da S., Noll J.C.G., Tochetto C., Martins J.L.R., Badke M.R.T., Labruna M.B., Silva A.S.D. Leptospira seroprevalence in capybaras from a brazilian urban area. *Acta Scientiae Veterinariae, 2016, vol. 44, no. 1: 5. doi: 10.22456/1679-9216.81100*
79. Tran V.D., Mai L.T.P., Thu N.T., Linh B.K., Than P.D., Quyet N.T., Dung L.P., Mai T.N.P., Hanh N.T.M., Hai H., Duong T.N., Anh D.D. Seroprevalence and serovar distribution of Leptospirosis among healthy people in Vietnam: results from a multi-center study. *Clin. Epidemiol. Glob. Health, 2021, vol. 10: 100700. doi: 10.1016/j.cegh.2021.100700*
80. Vale-Gonçalves H.M., Cabral J.A., Faria M.C., Nunes-Pereira M., Faria A.S., Veloso O., Vieira M.L., Paiva-Cardoso M.N. Prevalence of Leptospira antibodies in wild boars (Sus scrofa) from Northern Portugal: risk factor analysis. *Epidemiol. Infect., 2015, vol. 143, no. 10, pp. 2126–2130. doi: 10.1017/S0950268814003331*
81. Van C.T., Thuy N.T., San N.H., Hien T.T., Baranton G., Perolat P. Human leptospirosis in the Mekong delta, Viet Nam. *Trans. R. Soc. Trop. Med. Hyg., 1998, vol. 92, no. 6, pp. 625–628. doi: 10.1016/s0035-9203(98)90787-8*
82. Vaucel M. Le serodiagnostic de Martin et Pettit au Tonkin. Resultats de 800 sero-agglutinations. *Bull. Soci. Patholog. Exotique, 1936, vol. 29, pp. 251–257.*
83. Victoriano A.F., Smythe L.D., Gloriani-Barzaga N., Cavinta L.L., Kasai T., Limpakarnjanarat K., Ong B.L., Gongal G., Hall J., Coulombe C.A., Yanagihara Y., Yoshida S., Adler B. Leptospirosis in the Asia Pacific region. *BMC Infect. Dis., 2009, vol. 9: 147. doi: 10.1186/1471-2334-9-147*
84. Vietnam Health Statistics Yearbook 2018. Hanoi, Viet Nam: Ministry of Health (Vietnam), 2020. *URL: https://moh.gov.vn/documents/176127/0/NGTK+2018+final_2018.pdf/29980c9e-d21d-41dc-889a-fb0e005c2ce9 (12.05.2022)*
85. Vietnam's rice production in 2021 increased by 1.1 million tons. Ministry of Agriculture and Rural Development of the Socialist Republic of Vietnam. Ed.: Ngo The Hien. 05.01.2022. *URL: https://www.mard.gov.vn/en/Pages/vietnam%E2%80%99s-rice-production-in-2021-increased-by-1-1-million-tons.aspx (12.05.2022)*
86. Villanueva S.Y., Saito M., Baterna R.A., Estrada C.A., Rivera A.K., Dato M.C., Zamora P.R., Segawa T., Cavinta L.L., Fukui T., Masuzawa T., Yanagihara Y., Gloriani N.G., Yoshida S. Leptospira-rat-human relationship in Luzon, Philippines. *Microbes Infect., 2014, vol. 16, no. 11, pp. 902–910. doi: 10.1016/j.micinf.2014.07.001*
87. Yuen K.W., Hanh T.T., Quynh V.D., Switzer A.D., Teng P., Lee J.S.H. Interacting effects of land-use change and natural hazards on rice agriculture in the Mekong and Red River deltas in Vietnam. *Nat. Hazards Earth Syst. Sci., 2021, vol. 21, pp. 1473–1493. doi: 10.5194/nhess-21-1473-2021*
88. Yun C.H. Editorial — Unforeseen enemy: African swine fever. *Asian-Australas J. Anim. Sci., 2020, vol. 33, no. 1, pp. 1–3. doi: 10.5713/ajas.2020.0001ED*



**Авторы:**

**Токаревич Н.К.**, д.м.н., профессор, зав. лабораторией зооантропонозных инфекций ФБУН НИИ эпидемиологии и микробиологии имени Пастера, Санкт-Петербург, Россия;
**Блинова О.В.**, к.х.н., младший научный сотрудник лаборатории зооантропонозных инфекций ФБУН НИИ эпидемиологии и микробиологии имени Пастера, Санкт-Петербург, Россия.

**Authors:**

**Tokarevich N.K.**, PhD, MD (Medicine), Professor, Head of the Laboratory of Zoonoses, St. Petersburg Pasteur Institute, St. Petersburg, Russian Federation;
**Blinova O.V.**, PhD (Chemistry), Junior Researcher, Laboratory of Zoonoses, St. Petersburg Pasteur Institute, St. Petersburg, Russian Federation.



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