Epidemiology incidence and geographical distribution of Pertussis using GIS and its incidence prediction in Iran in 2021

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Abstract
Background: Pertussis is a respiratory tract infection caused by Bordetella pertussis, which causes inflammation of the lungs and respiratory tract. The purpose of this study was to investigate the incidence and geographical distribution of pertussis using the geographic information system (GIS) and to predict its incidence in Iran in 2021.

Methods: This was a descriptive analytical study. Information on pertussis was obtained from the Center for Communicable Diseases Control during 2009-2015. In the next step, the ArcGIS 9.3 was used to prepare geographic maps of the disease incidence and frequency. Therefore, the disease prediction map was drawn.
using the Raster Calculator tool.

Results: The results showed that the highest incidence of pertussis during 2009-2015 was in Zanjan, Qom, Mazandaran, and Qazvin provinces. The incidence of pertussis in Iran increased from 0.74 in 2009 to 1.53 in 2015. Based on the modeling results for Iran, Qom, Mazandaran, Tehran, Qazvin, and Zanjan provinces, with 76.76%, 73.69%, 66.32%, 30.94% and 24.18% of their areas (Km2), are at high risk for pertussis in the coming years, respectively.

Conclusion: The incidence of the disease has been increasing in recent years, indicating the emergence of the disease in Iran. The modeling maps show that the Iranian provinces of Qom, Tehran, Zanjan, and Qazvin are at risk of the disease incidence in the coming years, indicating the need for planning, appropriate interventions and more precise implementation of the vaccination program against the disease.

Keywords: Incidence, Prediction, Pertussis, GIS, Iran

Introduction
Pertussis is a highly contagious acute respiratory disease caused by the pathogen of Bordetella pertussis. The disease is diagnosed in children by whooping coughs and vomiting. In adults, the symptoms are atypical in the form

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↑*What is "already known" in this topic:*
The number of cases with pertussis has been reduced considerably. It is indicated a remarkable success of Iran in preventing pertussis.

→*What this article adds:*
Some of the provinces in the country will be facing with higher risk of developing the disease by 2021. Accordingly, appropriate planning for prevention, interventional programs, and also a more accurate implementation of the vaccination programs against the disease in these provinces are necessary.

of long coughs. It is one of the major causes of child mortality worldwide (1). The disease declined by more than 90% following the implementation of widespread vaccination programs in the 1950s and 1960s. However, between 20 and 40 million cases of pertussis are annually reported worldwide, with 90% being in the developing countries (1, 2).

Therefore, despite widespread vaccination and underreporting, there is an increase in the incidence of the disease in neonates, children, and adults worldwide. Also, despite a relatively high vaccination coverage, the disease has been one of the emerging diseases in recent years (3). In the United States in 2012, the diagnosed cases of B. Pertussis was more than that in 1955 (4). In the UK in 2013, there was a significant increase in the incidence of the disease compared to the 1970s and 1980s. The 2 hypotheses raised for the increase in the incidence of the disease in recent years could be low vaccination coverage and susceptibility to infection despite vaccination (5). In a study performed in Iran in 2015, most confirmed cases of pertussis were in Tehran (59 cases), Mazandaran (45 cases), East Azerbaijan (28 cases), and Ilam (18 cases) provinces (6).

Studies conducted in Iran and around the world have examined pertussis from different angles. The evidence shows that, in terms of the efficacy and immunogenicity of pertussis vaccine, passive and normal immunity and sources of infection for neonates as well as severity of injury to this group indicate that the incidence of pertussis needs special attention.

Based on the evidence cited, it can be stated that pertussis is an endemic disease in Iran or perhaps even in most countries. The reported cases of pertussis based on the status and nature of the disease care system across the Iranian provinces in different years show significant fluctuations and variations that can make it difficult to understand the annual incidence trend or even incidence in different regions of Iran. Therefore, it should be examined continuously (7, 8).

As the incidence of the disease varies in different Iranian provinces, understanding the geographical pattern of its incidence and prevalence can be very important for interventions and disease management. Disease mapping using the geographic information system (GIS) has been performed around the world for many years. It is now considered as a first step in the development of disease warning systems and its importance is increasing day by day (8-10).

It is important to use the GIS to manage health systems and infrastructure. The GIS is a powerful set of tools for storing and retrieving data and converting and displaying spatial data from the real world (11). Therefore, the purpose of this study was to investigate the incidence and geographical distribution of pertussis using the GIS and to predict its incidence in Iran in 2021.

Methods

This was a descriptive analytical study with applied results. The research uses spatial and climatic information and incidence rate of typhoid in Iran. Initially, the infor-

mation on pertussis was obtained from the Center for Communicable Diseases Control during 2005-2015. The incidence and frequency table for pertussis was prepared for each year and the incidence rate was calculated for 100,000 people in Iran. In the next step, the GIS was used to prepare geographic maps of the disease incidence and frequency. To prepare the spatial database for the disease, the vector map of Iran's administrative divisions for 2017 used by the National Mapping Organization was used to link the descriptive information about the disease to the spatial data in the GIS environment. The geographical locations were verified through Google Earth. When the geographic database of the disease was developed, descriptive information, such as incidence and frequency of the disease, was added to the GIS descriptive table using Excel. Next, a spatial analysis was prepared to map the incidence and frequency distribution of disease during 2005-2015 in the GIS environment through symbology functions. With the information of each province, the incidence and frequency map of the disease was prepared for the whole country. To plot the disease prediction map, it was assumed that the probability of disease occurrence was higher in regions with the highest incidence and the highest recurrence of disease in a statistical period. Therefore, using the Raster Calculator tool, the fuzzy map of the disease over a given period was multiplied by the disease recurrence map and the disease prediction map was eventually drawn (12). The map shows the most likely areas for disease incidence in red.

With the information of each province available, the incidence and frequency of the disease was developed for the whole country. To plot the map of interpolation, the inverse distance interpolation method was used (13).

High-risk Points Analysis

The Getis-Ord-Gi* statistic was used for appropriate spatial distribution of hot and cold spots. A disease is recognized as a hot spot when its figures and those of its surrounding conditions are fairly high. When the Getis-Ord-Gi* statistic is calculated to be 1, 2, and 3, the CI is estimated at 99%, 95%, 90%, respectively (14).

As the incidence data are obtained based on the findings of routine healthcare system, the difference in incidence that was observed in different provinces can be largely dependent on the sensitivity of the healthcare system to record and report cases in these provinces.

Results

The results showed that 51.6% of pertussis patients were men, and 70.8% were urban dwellers. It also showed that 77% of the cases recovered without any complication (Table 1).

The results of the study showed that most pertussis cases reported between 2008 and 2015 were in 2013 with 1443 cases (Fig. 1).

The results show that most pertussis cases during 2009-2015 were reported in April and June (Fig. 2).

The results showed that the highest incidence of pertussis during 2009-2015 was in Zanjan, Qom, Mazandaran, and Qazvin provinces (Table 2).

Table 1. Demographic information of patients with Pertussis in Iran during 2009-2015

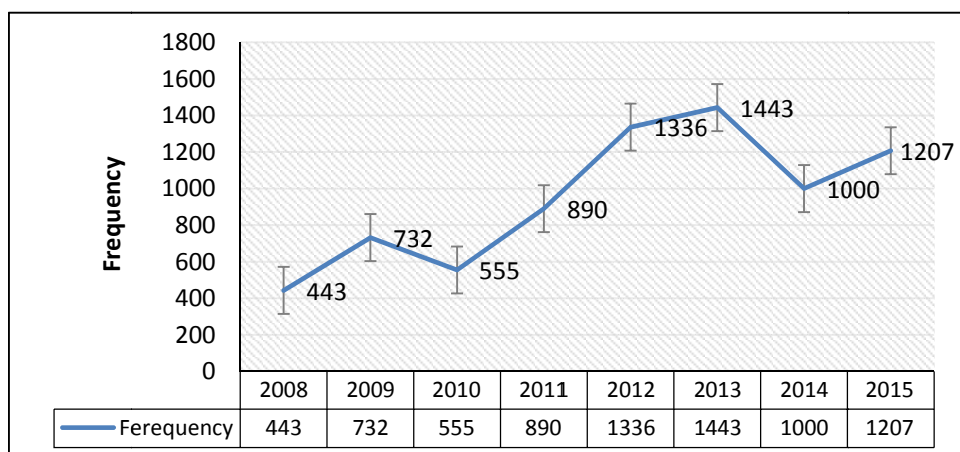| Variable		Frequency (%)
Sex	Female	3684 (48.4)
	Male	3897 (51.6)
Place of residence	City	5380 (70.8)
	Village	2226 (29.2)
	Recovery with complication	316 (4.2)
	Recovery without complication	5860 (77)
Status	Death	22 (0.3)
	Unknown	1408 (18.5)

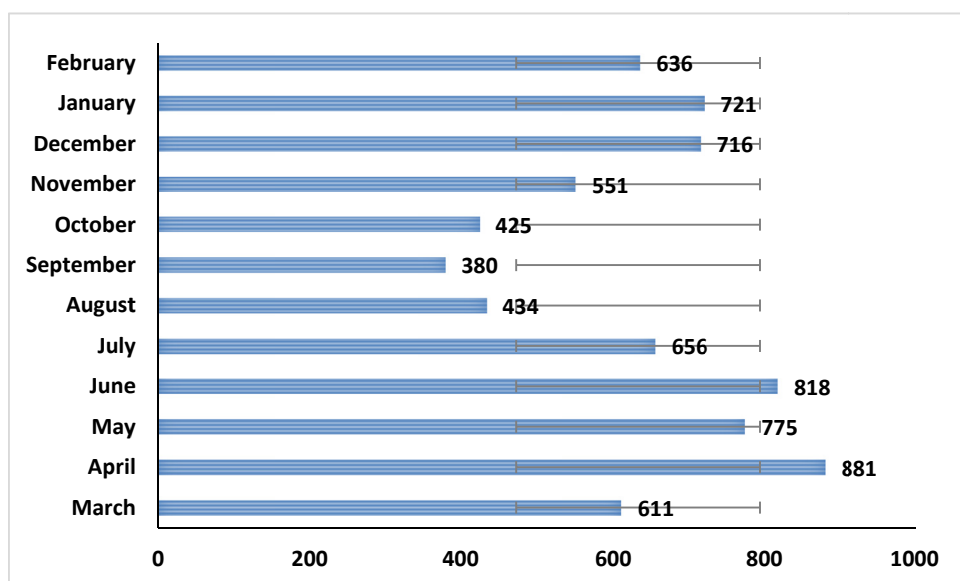*Fig. 1.* Frequency of reported cases of pertussis during 2008-2015

Fig. 2. Pertussis frequency according to the months reported

The results indicated that the incidence of pertussis in Iran increased from 0.74 in 2009 to 1.53 in 2015 (Fig. 3).

The prepared GIS maps show the incidence of pertussis in different provinces during 2009-2015 (Fig. 4).

According to the latest information on the incidence of the disease (incidence in 2015), Mazandaran, Qazvin, Qom, and Zanjan provinces had the highest incidence in 2015.

Based on the GIS maps of the whole country, 5.04% of the total area of Iran (83022.79 km^2) comprising parts of Isfahan, Alborz, Ilam, East Azarbaijan, Tehran, Khorasan Razavi, Zanjan, Semnan, Fars, Qazvin, Qom, Kurdistan, Kermanshah, Golestan, Gilan, Mazandaran, Markazi, Hormozgan, Hamedan, and Yazd provinces are at high risk for pertussis in the coming years (2021). Based on the modeling results in Iran, Qom, Mazandaran, Tehran, Qazvin, and Zanjan provinces with, 76.76%, 73.69%, 66.32%, 30.94% and 24.18% of their areas (Km^2), respectively, are at high risk for pertussis in the coming years (Fig. 5).

Table 2. Incidence of Pertussis per 100,000 population in Iran during 2009-2015

| Row	Province	2009	2010	2011	2012	2013	2014	2015
1	East Azerbaijan	0.24	0.51	1.13	2.00	3.94	2.84	3.23
2	West Azerbaijan	0.00	0.33	0.10	0.51	0.35	0.28	0.22
3	Ardebil	0.00	0.16	0.24	0.64	0.63	0.63	0.23
4	Isfahan	0.04	0.46	0.49	0.98	0.87	0.78	1.72
5	Alborz	0.00	0.26	1.08	1.51	1.48	1.45	1.66
6	Ilam	0.00	1.08	1.08	3.20	2.11	1.39	1.55
7	Bushehr	0.41	0.60	0.29	0.47	0.74	1.27	1.78
8	Tehran	0.73	0.91	1.37	1.84	2.30	1.11	1.91
9	Chaharmahal va Bakhtiari	1.48	1.47	1.68	0.77	1.64	1.84	3.86
10	Southern Khorasan	2.30	3.04	0.90	3.78	1.87	3.16	1.17
11	Khorasan Razavi	0.53	0.24	0.72	0.53	0.73	0.67	1.02
12	Northern Khorasan	0.12	0.23	1.50	2.16	1.13	0.22	0.88
13	Khuzestan	0.79	0.78	0.73	0.74	1.80	1.12	1.29
14	Zanjan	0.30	0.30	3.94	7.02	8.29	4.11	4.82
15	Semnan	2.61	0.80	0.95	0.94	2.61	0.76	1.49
16	Sistan and Baluchestan	0.36	0.36	0.63	0.15	0.11	0.22	0.11
17	Fars	0.40	0.18	0.33	0.19	0.28	0.21	0.08
18	Qazvin	2.04	1.43	5.41	3.79	4.57	4.52	5.12
19	Qom	7.04	0.80	4.43	6.66	4.19	4.86	4.29
20	Kurdistan	0.75	0.34	1.34	4.06	2.84	2.30	2.80
21	Kerman	0.07	0.07	0.20	0.17	0.59	0.81	0.32
22	Kermanshah	1.41	0.52	1.54	1.69	4.03	1.32	0.76
23	Kohgiloyeh and Boyerahmad	0.31	0.15	0.30	1.49	0.59	0.14	0.00
24	Golestan	0.29	0.69	0.62	1.38	1.79	0.27	0.84
25	Gilan	0.20	0.16	0.44	0.40	0.36	0.55	0.24
26	Lorestan	0.06	0.57	0.97	0.68	0.73	0.56	0.11
27	Mazandaran	2.66	4.53	5.34	10.35	7.42	4.94	5.41
28	Markazi	1.51	0.93	0.35	0.56	0.69	0.27	0.27
29	Hormozgan	0.13	0.91	0.06	0.31	0.18	0.48	0.23
30	Hamedan	1.56	1.09	1.88	2.09	1.80	1.06	1.56
31	Yazd	1.44	0.66	1.12	3.12	1.91	1.59	0.64
	Whole country	0.74	0.74	1.18	1.75	1.88	1.28	1.53
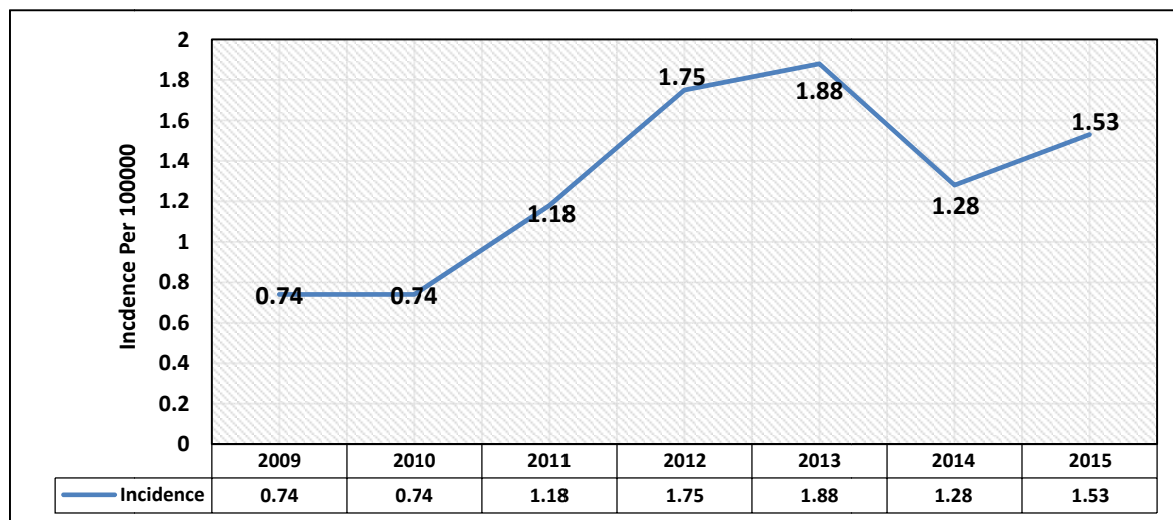
Fig. 3. Trend of pertussis incidence in Iran during 2009-2015

Discussion

Despite high vaccination coverage in most countries, the increase in cases of pertussis in infants, adolescents, and adults in recent years has attracted many countries' attention. As a result, it is considered as a recurring disease that threatens public health (15, 16).

The results of this study showed that the highest incidence of pertussis during 2009-2015 was in Zanjan, Qom, Mazandaran, and Qazvin provinces. The incidence of pertussis in Iran increased from 0.74 in 2009 to 1.53 in 2015. Based on the modeling results for Iran, Qom, Mazandaran, Tehran, Qazvin, and Zanjan provinces, with 76.76%,

73.69%, 66.32%, 30.94% and 24.18% of their areas, are at high risk for pertussis in the coming years, respectively.

The results of our study showed that Zanjan, Qom, Mazandaran, and Qazvin provinces had the highest incidence of the disease during 2009-2015. A cross-sectional study in Zanjan investigated 123 people with coughing symptoms for more than 2 weeks without any other disease, from which 23 cases (18.7%) were diagnosed with pertussis (17).

In a study by Ghorbani et al, out of 9613 suspected cases of pertussis reported from Iranian provinces, laboratory results were positive in 6.6% of cases. Most suspected
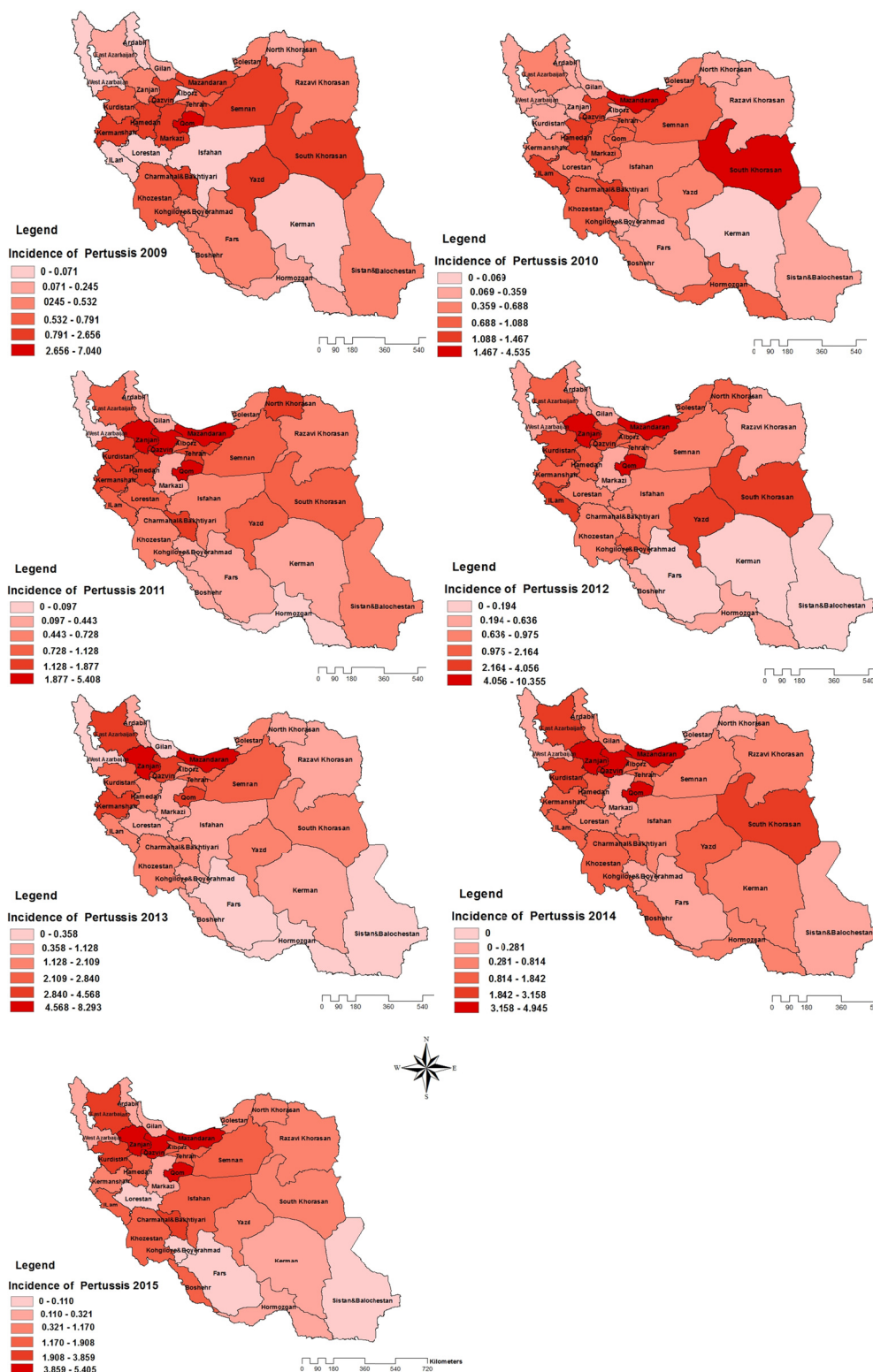
Fig. 4. Pertussis incidence in Iran during 2009-2015

cases of pertussis were reported from Mazandaran and Tehran provinces, but the ratio of confirmed cases was higher in Alborz and South Khorasan than in other Iranian provinces (18). In the study of Bellettini et al, 222 suspected pertussis patients were studied from September 2011 to January 2013, 72.5% of the cases were positive and 60.9% were under the age of 1 (19). In a study in Mexico, of 147 suspected patients, 59 (40.1%) were positive(18). In a South Korean study of 490 patients, 34 (6.9%) cases were positive (19).
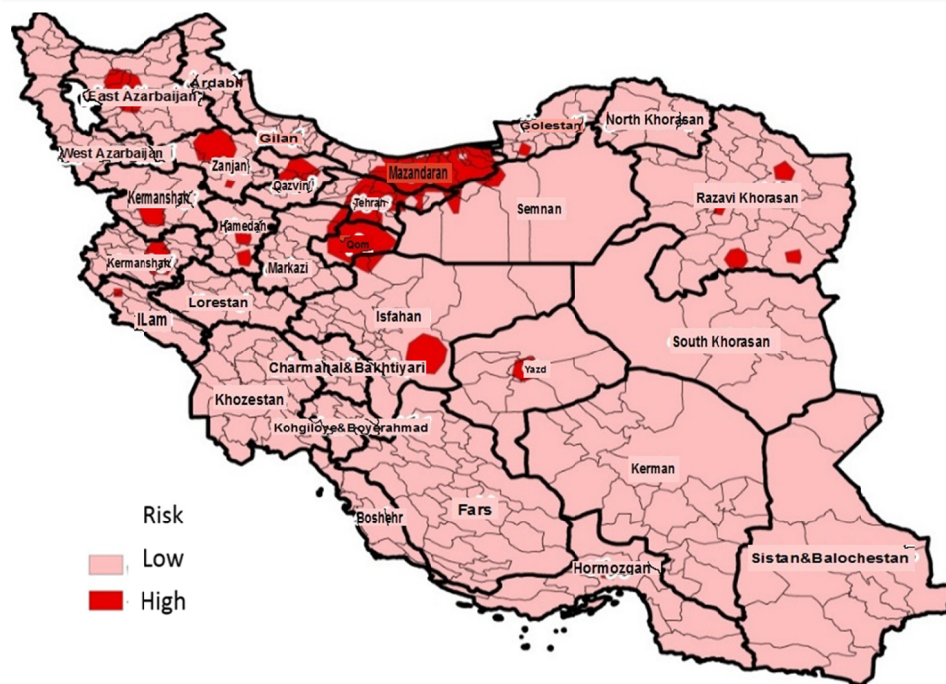
Fig. 5. Prediction of high risk areas for pertussis in Iran in 2021

The reasons for these differences may be in the sensitivity and specificity of the pertussis disease care systems, the definitions used in the care systems for suspected and probable cases, sampling and its transportation, the resources available for testing, the status of immunization coverage, and the endemic conditions of the disease in different regions. In recent decades, there has been an increase in the prevalence of the disease, which indicates that pertussis is one of the recurrent diseases worldwide. In the United States, the prevalence of the disease was 63.4% in the 1980s, 88.7% in the 1990s, and the highest incidence was during 2001-2003 (20).

The incidence of pertussis in Iran increased from 0.74 in 2009 to 1.53 in 2015. There are several reasons for this increased trend, including decreased immunity after vaccination over time, failure in complete vaccination, source of infection for infants, source of infection for adults, presence of polymorphism strains due to gene mutations in vaccine-associated antigens or ineffective vaccines, and improvements in disease diagnosis and infection reporting. In recent years in Iran, the collaboration between the Center for Disease Management and the Pasteur Institute of Iran, as a national laboratory for pertussis, the laboratory diagnosis of the disease has made significant progress, which may justify the increased incidence of disease dbecause of the progress in diagnosis.

Based on the statistics of the Ministry of Health's Center for Communicable Diseases Management, nowadays, the vaccination coverage in Iran is 99%. However, our modeling results showed that Qom, Mazandaran, Tehran, Qazvin, and Zanjan provinces with 76.76%, 73.69%, 66.32%, 30.94%, and 24.18% of their areas, respectively, are at high risk for pertussis in the coming years.

The factors that may be a risk for these provinces include incomplete vaccination, genetic variation of strains, possibility of the difference in recent pathogenic strains, and adult carriers transmitting the disease. Therefore, proper implementation of the vaccination program, identification of pathogenic strains and treatment of carrier individuals in these provinces can prevent the incidence of the disease in the coming years.

Conclusion

Based on the results, the incidence of the disease has been increasing in recent years, indicating the emergence of the disease in Iran. The modeling maps show that the Iranian provinces of Qom, Tehran, Zanjan, and Qazvin are at risk of the disease incidence in the coming years, indicating the need for planning and more precise implementation of the vaccination programs against the disease. Proper interventions can help prevent the disease from occurring in the years to come and minimize its incidence.

Acknowledgment

Conflict of Interests

The authors declare that they have no competing interests.

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