Space-time analysis of Peste des petits ruminants in Benin, 2009-2018

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Keywords

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Abstract

Background: Peste des petits ruminants (PPR), a viral disease that affects sheep and goats, has been endemic in Benin for several decades. ***Aim***: Our purpose was to determine the space-time distribution of PPR in Benin. ***Methods***: This work draws on ten years of passive surveillance data at the national level (2009 to 2018), provided by the Ministry of Agriculture, Livestock and Fisheries in Benin. Data covered all 77 communes in Benin. Using the cumulative incidence of PPR per 10,000 animals at risk per commune, we conducted cluster and hotspot analyses and designed risk maps for each year of the study and for the entire 10-year period. ***Results***: We identified space-time clusters as follows: High-High, Low-Low, High-Low, Low-High and hotspots. This study revealed that over the period, 1,297 new outbreaks were recorded with 88,668 sick animals and 23,002 deaths. The PPR incidence and mortality rates were highest in 2010, 2011 and 2012. The departments of Ouémé, Plateau and Borgou were the most affected. The number of new PPR outbreaks recorded was higher in March, April and May, with more infected animals and a higher mortality rate. More outbreaks were reported in communes in the departments of Mono and Couffo. Overall, the study identified significant clusters of PPR across the 10-year period in 26 communes and 9 departments. ***Conclusions***: The results of this space-time analysis may help improve PPR risk assessment and forecasting in certain regions and make an important contribution to disease prevention and control measures.

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■ INTRODUCTION

Small ruminants represent a major component of animal production, with annual global production estimated at approximately 2.1 billion head (FAO & OIE, 2016). In 2021, the small ruminant population in Benin was estimated at 4,657,523 head (RNA, 2021), which reflects the socio-economic importance of this production sector. Sheep and goats not only provide a source of income, they also have an important cultural role, for example during weddings (Dossa *et al*., 2007). However, the sector faces numerous constraints, including lack of food resources, adverse climatic conditions, and diseases. It has also been neglected by development and research institutions (Gnanda *et al*., 2016; Djagba *et al*., 2020). Peste des petits ruminants (PPR), a highly contagious disease that causes high mortality, mainly affects sheep and goats. It is caused by a virus from the genus *Morbillivirus* from the Paramyxoviridae family (Baron & Bataille, 2022). Its major symptoms are fever, runny nose and eyes, stomatitis and acute diarrhea (Sen *et al*., 2010) Animals infected with PPR shed large amounts of virus through their ocular, nasal, oral and fecal secretions (Mariner *et al*., 2016). Viral transmission occurs when susceptible animals are in direct contact with infected animals (via respiratory mucosa) or when they ingest contaminated food or water. Levels of morbidity can reach 100% and mortality rate can exceed 90% (Banyard *et al*., 2010). The disease was first observed in Côte d'Ivoire in 1942

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(Diall & Dione, 2021) and has spread throughout Africa, the Middle East and Asia (FAO & OIE, 2016). In 2015, the international community set out to eradicate PPR by 2030. Since then, the Food and Agriculture Organization of the United Nations (FAO) and the World Organization for Animal Health (WOAH) have developed and are implementing a Global Control and Eradication Strategy (GCES) (Ilboudo *et al*., 2022). The control strategy involves mass vaccination with a vaccine known to be effective against PPR (Mariner *et al*., 2016). However, despite these initiatives, efforts to combat the disease are being hampered because breeders' lack knowledge and commitment. In addition, there is little or no control of animal movements between high-risk and disease-free areas. Therefore, a better understanding of risk areas and risk factors could help improve the control strategy. This study was launched to analyze the temporal and spatial distribution of PPR cases in Benin, based on passive surveillance data collected over 10 consecutive years.

■ MATERIAL AND METHODS

Study area

Benin is located in the tropical zone between the equator and the Tropic of Cancer in West Africa. It lies between the parallels 6°30' and 12°30' of latitude north and the meridians 1° and 30°40' of longitude east. It covers an area of 114,763 km^2 and shares borders with several countries. In the north, it has a border of 277 km with the Republic of Niger (including 120 km along the boundary formed by the Niger River). To the northwest, the border with Burkina Faso stretches across 386 km. In the west, there is a 651 km long border with Togo. To the east, the border with Nigeria covers 809 km, and the Atlantic Ocean lies to the south, with 121 km of coastline. In Benin, the administrative hierarchy has four levels: departments, communes, districts and villages. The country has a total of 12 departments, 77 communes, 546 districts and 5,290 villages (PNA, 2022). Two climate types are observed. In the south, the equatorial climate has alternating dry seasons (from November to March and from mid-July to mid-September) and rainy seasons (from April to mid-July and from mid-September to October). In contrast, the center and north have a tropical climate characterized by a dry season from November to April and a rainy season from June to September (PNA, 2022).

Statistical analysis

Descriptive statistics

Data were provided by the Benin's Livestock Directorate of the Ministry of Agriculture, Livestock and Fisheries. This study considered data relating to PPR in farms across Benin. We considered the number of new outbreaks recorded, the number of animals showing clinical signs of PPR, the number of dead animals, and the number of small ruminants (sheep and goats) in each of the 77 communes during the period from 2009 to 2018. Initially, data drawn from the database provided was entered into an Excel spreadsheet (number of new outbreaks, cases and deaths per commune, per month and per year). Subsequently, we used a Pivot Table to generate other databases in order to produce curves with R software and tables in Excel. Similarly, other databases were generated and introduced into QGIS and ArcGIS software to analyze the distribution in the different communes. Lastly, we designed the databases for the SaTScan software. Following the analysis at 50%, 40%, 30%, 20% and 10% of the population at risk in the SaTScan software, we loaded the shapefiles generated into QGIS software in order to visualize the clusters.

The descriptive analysis involved mapping the outbreaks recorded during the evaluation period (2009-2018). In addition, a graphic representation was developed, using the cumulative number of outbreaks recorded between 2009 and 2018, on a monthly basis. Lastly, the annual cumulative incidence rate (IR) of PPR for 10,000 sheep and goats between 2009 and 2018 was determined using the formula below:

$$\text{IR} = \frac{\text{Total number of cases recorded from 2009 to 2018}}{\text{(Average total number of small ruminants) x 10 years}} \times 10\,000$$

Space-time analysis

We conducted a spatial and temporal analysis of PPR in Benin, covering the period from 2009 to 2018.

Our spatial analysis focused on the cumulative incidence of PPR per commune for 10,000 small ruminants. A global cluster detection method (Moran's Index I) was used as the first step to determine if clusters were present in the study area. Then, three different methods (Local Indicators of Spatial Association, Getis, Ord and SaTScan) were applied to locate the clusters. The method involving Local Indicators of Spatial Association effectively detects spatial units (SU) with outliers or atypical values. The Getis and Ord method identifies SU, which are surrounded by a group of spatial units with high or low values. SaTScan detects clusters in both time and space.

Lastly, the Empirical Bayesian Kriging (EBK) method was used for geostatistical prediction and to produce risk maps (Geostatistical Analyst, Geostatistical Wizard, ArcGIS 10.8, Environmental System Research Institute, USA). Thus, risk maps were produced for each year in order to interpolate incidence of PPR across Benin.

A brief description of these methods is provided below.

■ Global cluster detection methods: Moran's I index

To identify unusual spatial structures, most statistical analyses include a proximity measure to evaluate the structure's presence. Several definitions of proximity are available, which may generate different results. Methods based on global statistics can be considered as tests of tendency to aggregation (clustering) over the entire study area. Moran's I index is a method that uses a classical spatial autocorrelation statistic. For each spatial unit (SU) SUi, a local autocorrelation coefficient I_i is estimated by:

$$I_i = \left[(Y_i - \overline{Y}) \sum_{j=1}^{k} w_{ij} (Y_j - \overline{Y}) \right] \left[\frac{K}{w + \sum_{i=1}^{k} (Y_i - \overline{Y})^2} \right]$$

where Yi = Oi/ni are proportions of cases of each SUi. (Oi is number of observed cases of SUi and ni number of SUi). K represents the average of proportions over all the K SU:

$$\overline{Y} = \sum_{i=1}^{k} Y_i$$

Moran's I index is an autocorrelation coefficient used to detect the existence of spatial structures, where high-risk and low-risk areas tend to be close together, which is the case particularly in the presence of clusters.

In statistics, Moran's I is a random variable whose distribution is determined by the distribution of cases with spatial similarities. The distribution of Moran's I index is known under the null hypothesis, assuming that the number of cases is a random variable following a normal distribution that is constant regardless of the spatial unit. Each spatial unit was considered independently of neighboring units.

Therefore, the Moran's I index measures the similarity between neighboring SU. If neighboring units are similar (i.e. existence of a structure in the shape of SU clusters), the index i is positive. If neighboring units are systematically different, i is negative. If there is no correlation between neighboring units, i tends to be close to zero.

■ Local cluster detection methods

Firstly, to detect local clusters, we implemented the Spatial statistics method of Getis and Ord. The Getis-Ord spatial statistics method belongs to a family of G-statistics that can be used to study the existence of groups of spatial units. Like the Moran's coefficient or index, the general statistic G is global. By studying the overall degree of spatial interdependence, we calculated a single index for the entire study area. The Moran's coefficient or index does not distinguish between high-risk and low-risk areas. Therefore, the Getis-Ord Gi* index is more suitable because it allows us to locate high-risk regions at the scale of the study area. It discerns the types of clusters at high or low risk under exact or asymptotic normal conditions.

The standardized Gi* index is essentially a Z-score and can therefore be associated with statistical significance. A Gi* value close to zero implies a random distribution of the event in spatial units. Conversely, positive and negative Gi* with high absolute values correspond to spatial units with high and low values of the event, respectively. The negative Gi* indicates a trend towards clusters where incidences of the event last for a short duration. In summary, if the calculated index values are above a statistically significant threshold, the location of a cluster is identified as a hotspot (high-risk area).

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}\, x_j - \overline{X} \sum_{j=1}^{n} w_{ij}}{s\sqrt{\frac{\left[n \sum_{j=1}^{n} w_{ij}^2 - \left(\sum_{j=1}^{n} w_{ij}\right)^2\right]}{n-1}}}$$

where xj is the attributed value for feature j, w_{ij} is the spatial weight between feature i and j, n is equal to the total number of features with:

$$\overline{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad \text{and} \quad s = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \left(\overline{X}\right)^2}$$

Secondly, we used the Kulldorff scanning method that uses a geographically moving window in order to group different neighboring spatial units into potential clusters. On a regular grid covering the study area, the algorithm uses superimposed circular windows, centered at each grid point, and with constant radii, depending on grid spacing. Potential clusters are defined for a radius varying from zero to a predefined limit, in general, up to the inclusion of 50% of the number of spatial units. Instead of using a predetermined grid, the windows can be centered on the observed spatial units, causing the geographical area to be scanned with an irregular grid. Using a rectangular window is also possible, but may give different results.

Space-time cluster analysis was performed using SaTScan Version 9.7 (http://www.satscan.org). We used a retrospective Poisson model to identify, detect and test the significance of spatio-temporal clusters of PPR in Benin. The analysis was carried out using circular spatial moving windows, ranging from 50% to 10% of the population at risk, and temporal windows, ranging in length from one month to 10 years. A cluster in space and time was defined when there were more observed cases (O) in the scan window than expected (E), and its statistical significance was assessed using the log-likelihood ratio statistic. The corresponding p-value was obtained via Monte Carlo simulations (n = 999).

Designing the risk map using the interpolation method

Empirical Bayesian kriging is an alternative method for modeling small databases that can define at-risk areas. This feature is important in the fight against communicable diseases as demonstrated by several studies. This method can be used to estimate the prevalence of the pathology at any points in a given territory, with minimal errors.

Empirical Bayesian Kriging (EBK) is a geostatistical interpolation method that automates the most difficult aspects of building a valid kriging model. It automatically calculates parameters through a process of sub-tuning and simulations, which means that the model's parameters do not have to be tuned manually. This kriging method is more efficient than other geostatic or deterministic interpolation methods. It generates an incidence prediction raster. Within the framework of the present study, the raster obtained was discretized into 6 classes according to the natural thresholds (Jenks).

■ RESULTS

Descriptive statistics

Table I presents the evolution of PPR outbreaks over time in Benin between 2009 and 2018. During the period 2009-2018, 1,297 new outbreaks were recorded with 88,668 sick animals and 23,002 deaths. The highest number of new outbreaks (188) was recorded in 2011. In comparison, 184 new outbreaks were recorded in 2012, with more affected animals (15,650) and deaths (5,061). In 2017 and 2018, a high number of new outbreaks was also recorded, although the number of deaths was relatively low compared to 2010, 2011 and 2012.

The PPR Incidence shown in Figure 1 reveals that the years 2010, 2011 and 2012 were marked by the highest PPR incidences.

Table I: Time trend of PPR outbreaks in Benin between 2009 and 2018 /// *Evolution temporelle des foyers de Peste des petits ruminants au Bénin entre 2009 et 2018*

Years	New outbreaks	Number of cases	Number of Deaths	Average number of cases per outbreak	Average number of deaths per outbreak
2009	102	7657	1956	75	19
2010	151	13672	3259	91	22
2011	188	11967	3254	64	17
2012	184	15650	5061	85	28
2013	70	9597	2143	137	31
2014	125	9846	2898	79	23
2015	24	1856	456	77	19
2016	97	9237	1495	95	15
2017	174	4736	1371	27	8
2018	182	4450	1109	24	6
Total	1297	88668	23002	68	18

Table II shows that the departments of Ouémé, Plateau and Borgou were the most affected throughout the entire study period.

The annual incidence rate was calculated using the cumulative number of cases, and the average total number of sheep and goats for the period 2009-2018. This yielded an incidence rate of 34 cases of PPR per 10,000 sheep and goats, per year.

Figure 2 shows the monthly trend of PPR during the same period, 2009-2018. The highest number of new PPR outbreaks, and the highest number of new cases were recorded in March, April and May, which corresponds to the main rainy season in the southern part of the country.

Figure 3 shows the spatial distribution of animals infected with PPR and the number of animals that died as a result. The number of cases of PPR and the number of deaths appear to be higher in communes in the departments of Ouémé and Plateau.

Figure 4 shows the spatial distribution of PPR outbreaks. The communes with the highest number of outbreaks were located in the departments of Mono and Couffo.

Table II: Distribution of cases of PPR in departments in Benin between 2009 and 2018 /// *Répartition des cas de Peste des petits ruminants dans les départements du Bénin entre 2009 et 2018*

Departments	Number of cases	Average number of small ruminants (2009 to 2010)	Cumulative incidence per 10,000 small ruminants	Relative frequency of number of cases (95% CI)
Alibori	10787	431220	250.15	12.17 (11.9-12.4)
Atacora	2097	379344	55.28	2.37 (2.3-2.5)
Atlantique	4231	246567	171.60	4.77 (4.6-4.9)
Borgou	18394	348204	528.25	20.74 (20.5-21.0)
Collines	8463	176576	479.28	9.54 (9.4-9.7)
Donga	2670	126823	210.53	3.01 (2.9-3.1)
Ouémé	17261	151373	1140.29	19.47 (19.2-19.7)
Plateau	13253	140030	946.44	14.95 (14.7-15.2)
Mono	4434	182353	243.15	5.00 (4.9-5.1)
Zou	3553	181307	195.97	4.01 (3.9-4.1)
Couffo	3359	227609	147.58	3.79 (3.7-3.9)
Littoral	166	18293	90.74	0.19 (0.1-0.2)

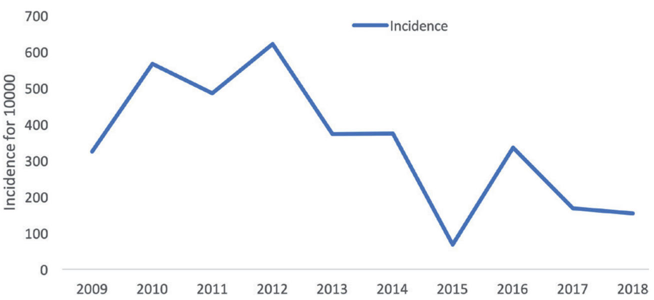

Figure 1: Annual incidence trend of PPR case between 2009 and 2018 /// *Évolution de l'incidence annuelle des cas de PPR entre 2009 et 2018*

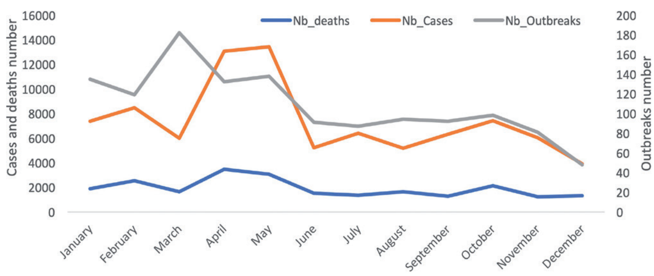

Figure 2: Monthly trend of number of PPR outbreaks, cases and deaths in Benin between 2009 and 2018 /// *Évolution mensuelle du nombre de foyers, de cas et de mortalité animale liés à la PPR au Bénin entre 2009 et 2018*

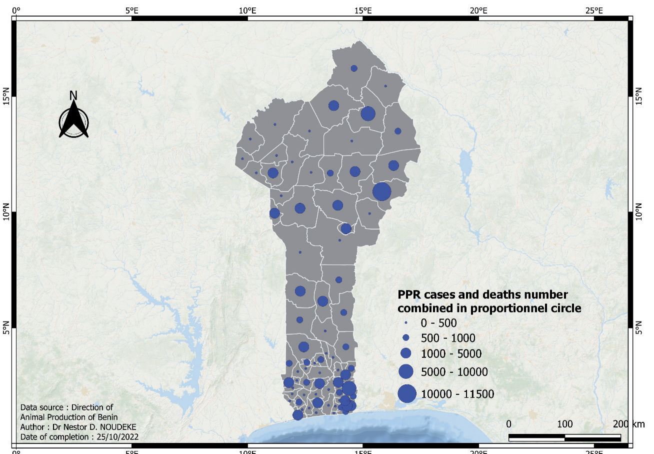

Figure 3: Space distribution of animals affected and dead from PPR in communes of Benin between 2009 and 2018 /// *Répartition spatiale des animaux atteints ou morts de la PPR dans les communes du Bénin entre 2009 et 2018*

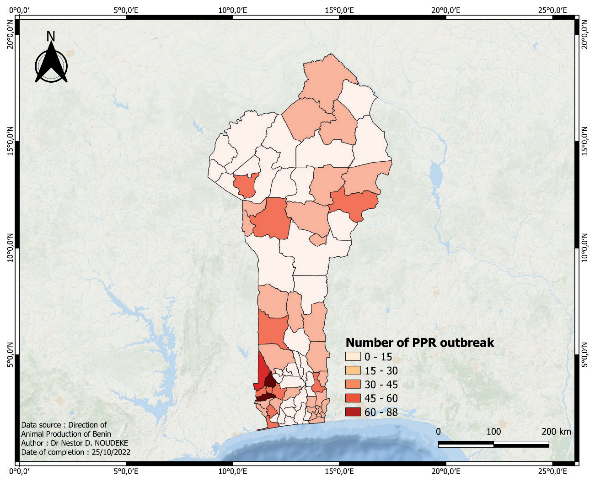

Figure 4: Spatial distribution of PPR outbreaks communes of Benin between 2009 and 2018 /// *Répartition spatiale des foyers de PPR dans les communes du Bénin entre 2009 et 2018*

Spatial analysis with cluster detection and risk prediction

At the 5% threshold, Moran's I index identified significant clusters of cases of PPR throughout the 10 years, with the exception of 2011, 2012, 2016 and 2017. The indices are as follows: 0.16 (Z-score = 3.47, P < 0.01) in 2009; 0.28 (Z-score = 5.18, P < 0.01) in 2010; 0.01 (Z-score = 1.58, P < 0 .11) in 2011; 0.03 (Z-score = 1.03, P < 0.30) in 2012; 0.37 (Z-score = 6.66, P < 0.01) in 2013; 0.12 (Z-score = 2.62, P < 0.01) in 2014; 0.08 (Z-score = 2.73, P < 0.01) in 2015; 0.09 (Z-score = 1,89, P < 0.06) in 2016; 0.01 (Z-score = 1.21, P < 0.23) in 2017 and 0.03 (Z-score = 2.09, P < 0.03) in 2018. It should be noted that all the Moran I indices obtained are positive, which confirms the existence of clusters.

The Figures 5 to 15 show High-High, Low-Low clusters, PPR hotspots, and predicted cumulative incidence per 10,000 small ruminants per year.

In total, 26 communes in 9 departments in Benin had at least one High-High PPR cluster (high number of cases in a given commune, with a high number of cases in surrounding communes): Toucountouna (Atacora), Toffo, Tori-Bossito (Atlantic), Bembèrèkè, N'Dali, Nikki (Borgou), Djakotomè, Lalo (Couffo), Djougou (Donga), Bopa, Houéyogbé (Mono), Adjarra, Adjohoun, Aguégués, Akpro-Missérété, Avrankou , Bonou, Dangbo, Porto-Novo (Ouémé), Adja-Ouèrè, Ifangni, Pobè, Sakété (Plateau), Covè, Djidja, Za-Kpota (Zou) (Figures 5A, 6A, 7A, 8A, 9A, 10A, 11A, 12A, 13A, 14A, 15A). The communes of Porto-Novo, Sakété, Adjarra and Aguégués frequently had High-High clusters (Figures 5A, 6A, 7A, 8A, 9A, 10A, 11A, 12A, 14A, 15A). The analysis also identified clusters featuring Low-Low PPR (low number of cases in a given commune, with a low number of cases in surrounding communes). These clusters occurred at least once in 31 communes: Banikoara, Gogounou, Kandi, Karimama, Malanville (Alibori), Allada, Kpomassè, Ouidah, So-Ava, Toffo, Tori-Bossito, Zè (Atlantic), Djakotomè, Klouékanmè, Lalo, Toviklin (Couffo), Lokossa, Comè, Dogbo, Grand-Popo, Houéyogbé (Mono), Adjohoun, Bonou, Dangbo (Ouémé), Ifangni (Plateau), Abomey, Agbangnizoun, Bohicon, Ouinhi, Za-Kpota and Zogbodomey (Zou) (Figures 5A, 6A, 7A, 8A, 9A, 10A, 12A, 13A, 14A).

An outlier or atypical value of High-Low PPR was detected in the following 13 communes: Natitingou (Atacora), Parakou, Sinendé (Borgou), Aplahoué, Lalo (Couffo), Ouaké (Donga), Dogbo, Grand-Popo, Lokossa (Mono), Bonou, Porto-Novo (Ouémé), Pobè (Plateau) and Agbangnizoun (Zou) (Figures 5A, 6A, 7A, 8A, 12A, 13A, 14A).

An outlier or atypical value of Low-High PPR (low number of cases in a commune with a high number of cases in the surrounding communes) was detected in 19 communes: So-Ava, Zè, Abomey-Calavi, Kpomassè Ouidah (Atlantic), Kalalé, Pèrèrè (Borgou), Cotonou (Littoral), Comè, Athiémé (Mono), Adjarra, Adjohoun, Aguégués, Akpro-Missérété, Avrankou, Dangbo (Ouémé), Adja-Ouèrè, Ifangni, Pobè (Plateau) (Figures 5A, 6A, 7A, 8A, 9A, 10A, 11A, 12A, 13A, 14A, 15A).

PPR hotspots were detected in 18 communes: Adja-Ouèrè, Adjohoun, Bonou, Dangbo, Sakété, Adjarra, Aguégués, Akpro-Missérété, Avrankou, Bantè, Grand-Popo, Ifangni, Kandi, Nikki, Pèrèrè, Pobè, Porto-Novo, Zé. The communes of Sakété, Ifangni, Pobè, Porto-Novo, Avrankou, Adjarra and Adjohoun were frequently identified as being hotspots (Figures 5B, 6B, 7B, 8B, 9B, 10B, 11B, 12B, 13B, 14B, 15B).

The annual risk maps of cumulative PPR incidence, hotspots and clusters were similar.

The disease risk predictions of the cumulative incidence of PPR were higher in the south-east and north-east of Benin overall for each year and for the 10-year period. In contrast, risk predictions were generally lower in the southwestern, central, and northwestern regions of Benin for each year, as well as for the 10-year period (Figures 5C, 6C, 7C, 8C, 9C, 10C, 11C, 12C, 13C, 14C, 15C).

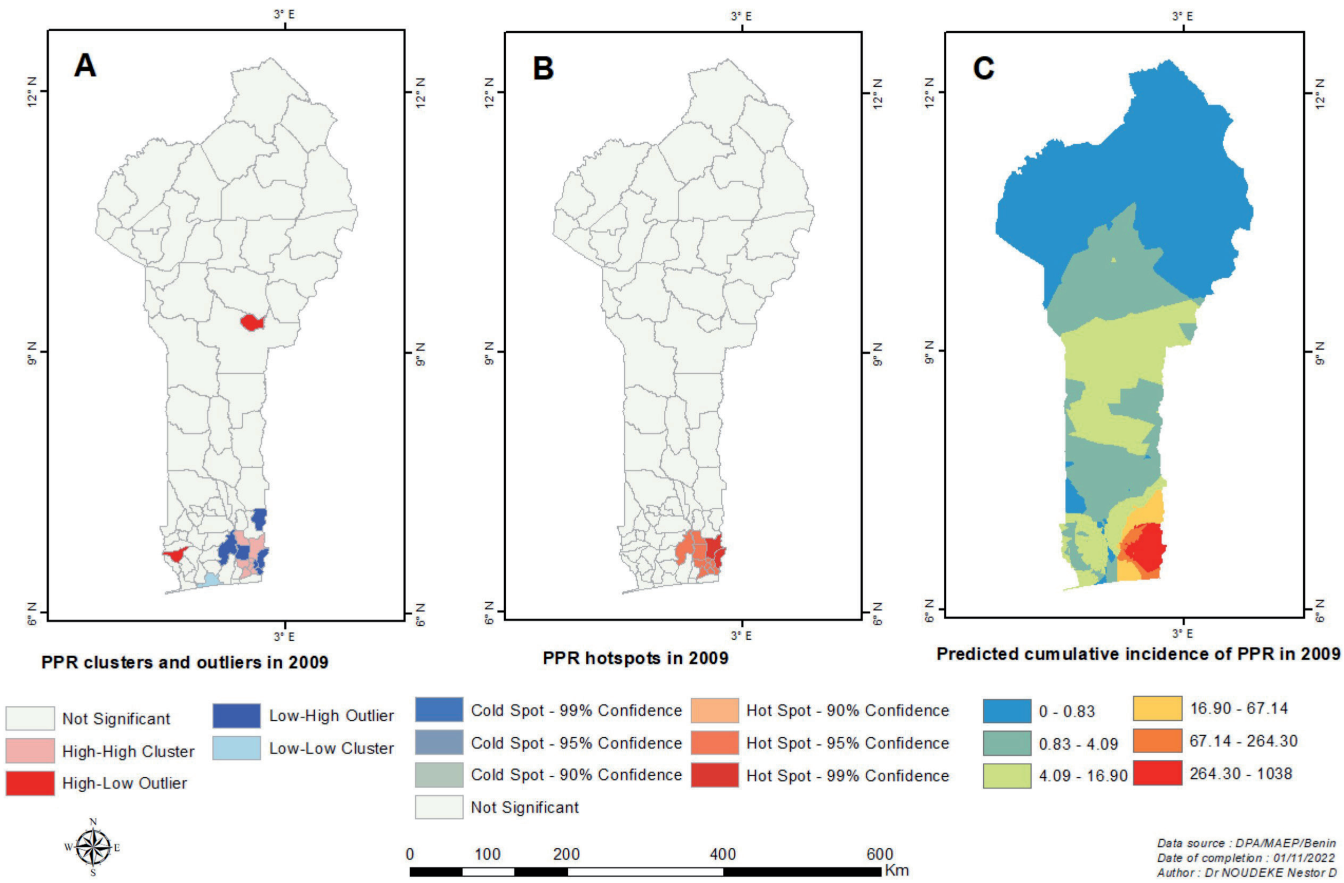

Figure 5: Clusters (A), hotspots (B) and risk map (C) of PPR in 2009 /// *Clusters (A), Hotspots (B) et carte des risques (C) de la PPR en 2009*

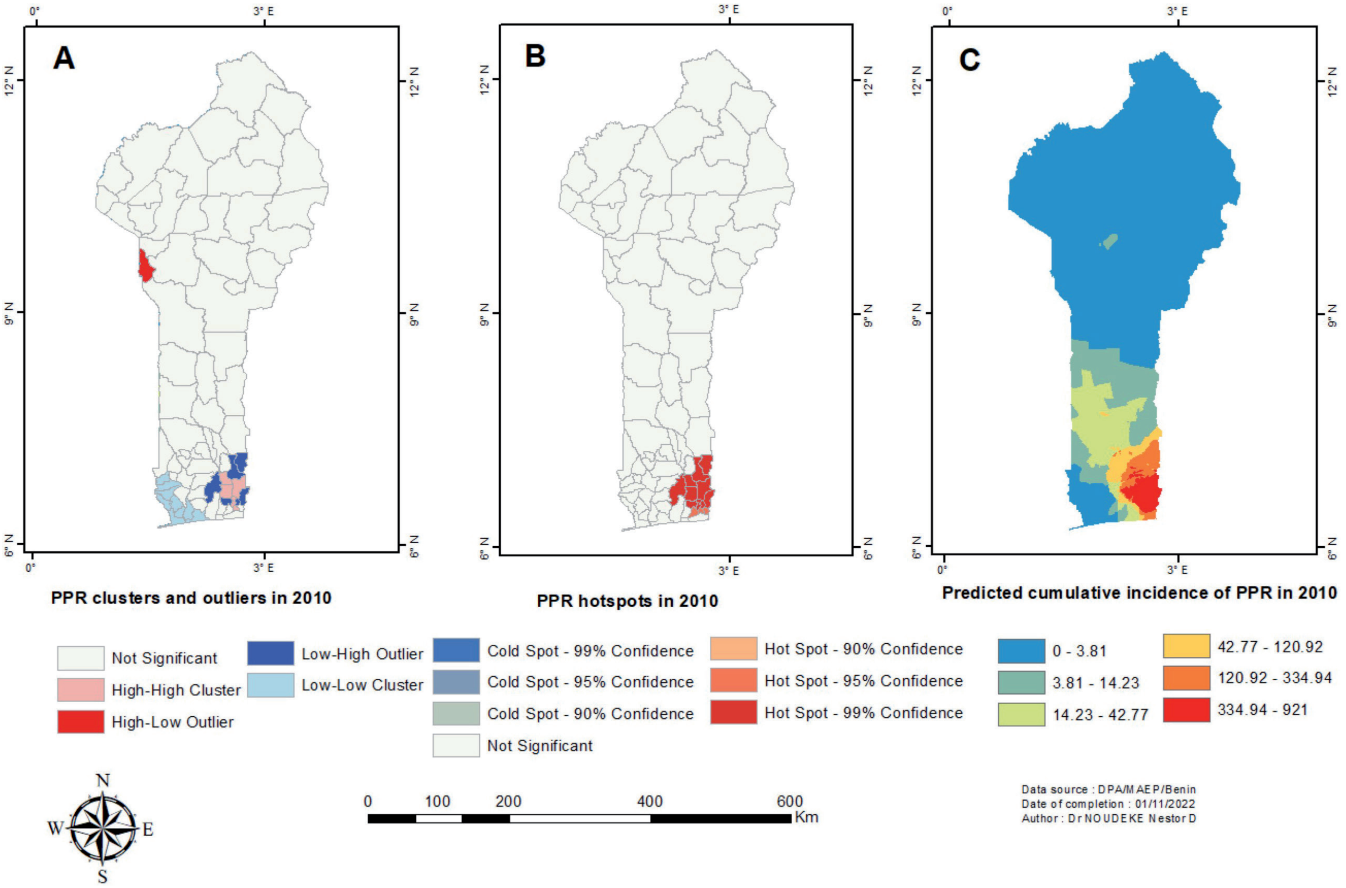

Figure 6: Clusters (A), hotspots (B) and risk map (C) of PPR in 2010 /// *Clusters (A), Hotspots (B) et carte des risques (C) de la PPR en 2010*

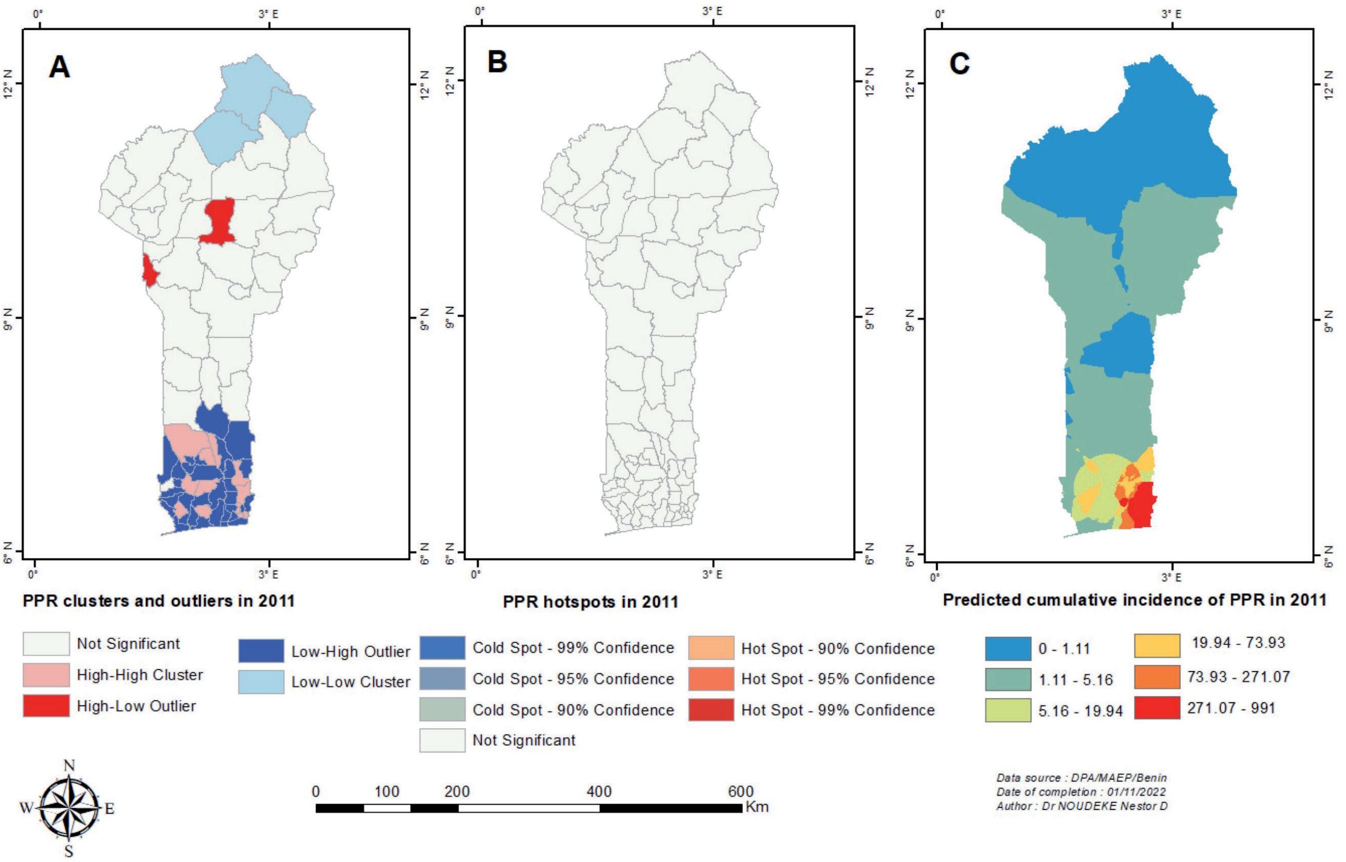

Figure 7: Clusters (A), hotspots (B) and risk map (C) of PPR in 2011 /// *Clusters (A), Hotspots (B) et carte des risques (C) de la PPR en 2011*

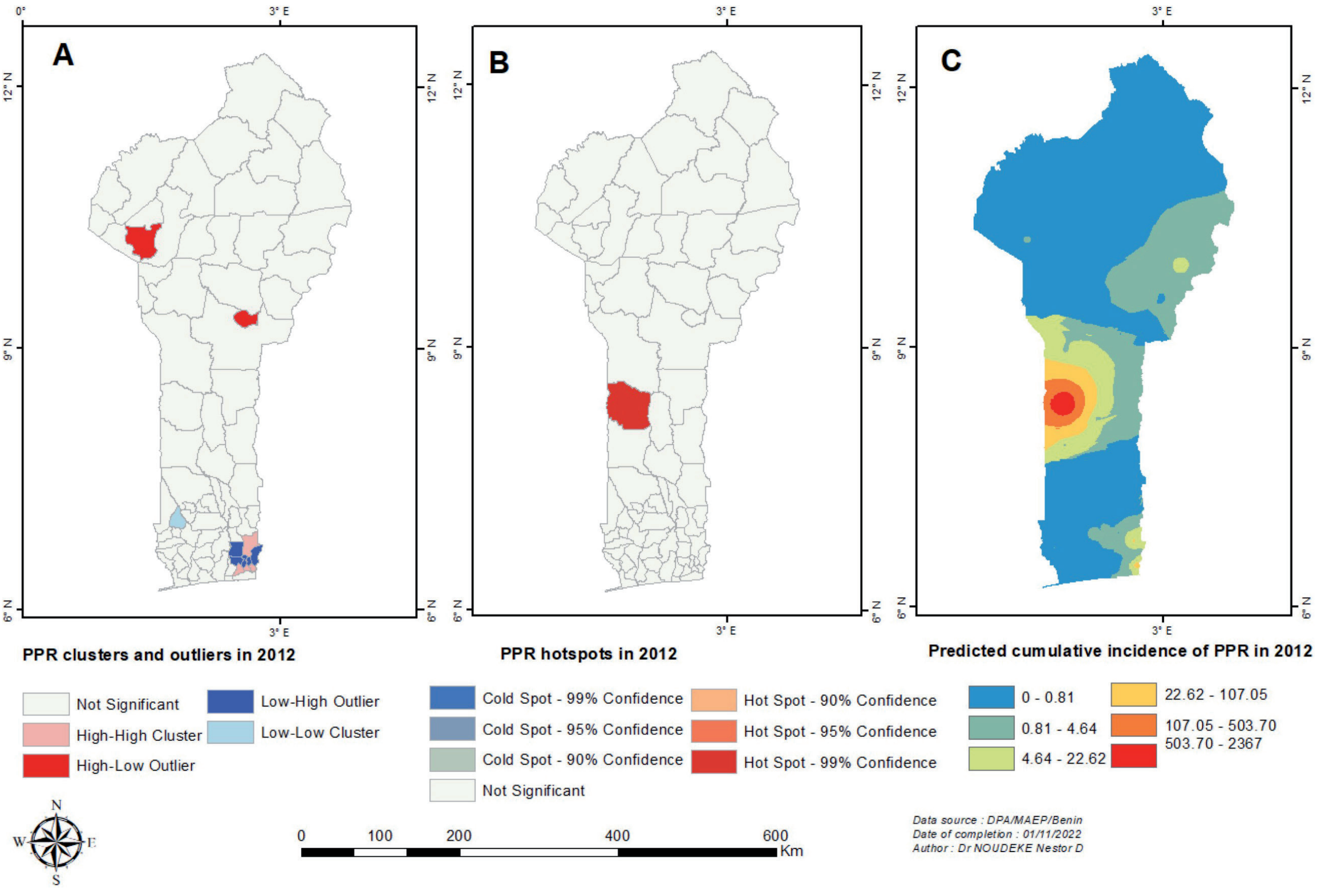

Figure 8: Clusters (A), hotspots (B) and risk map (C) of PPR in 2012 /// *Clusters (A), Hotspots (B) et carte des risques (C) de la PPR en 2012*

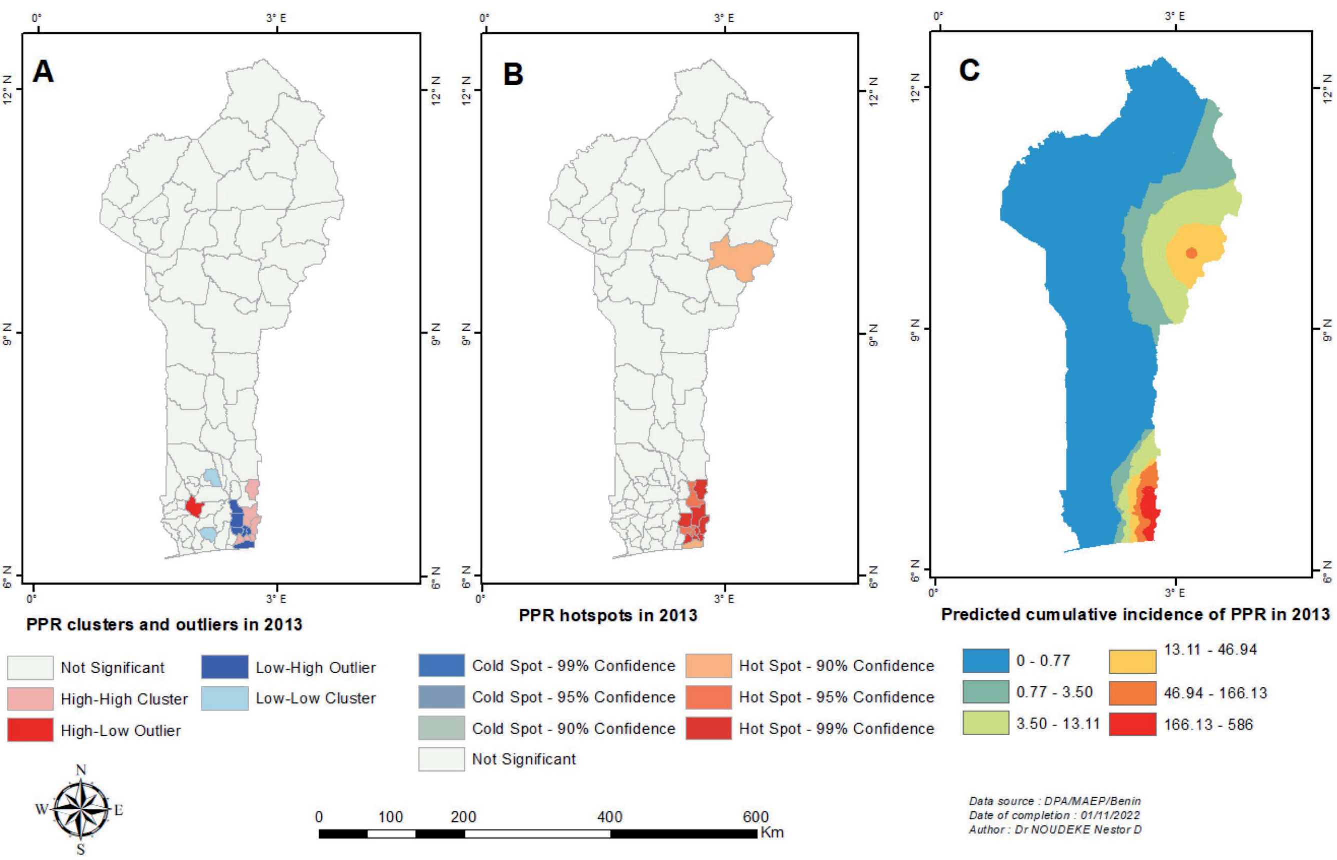

Figure 9: Clusters (A), hotspots (B) and risk map (C) of PPR in 2013 /// *Clusters (A), Hotspots (B) et carte des risques (C) de la PPR en 2013*

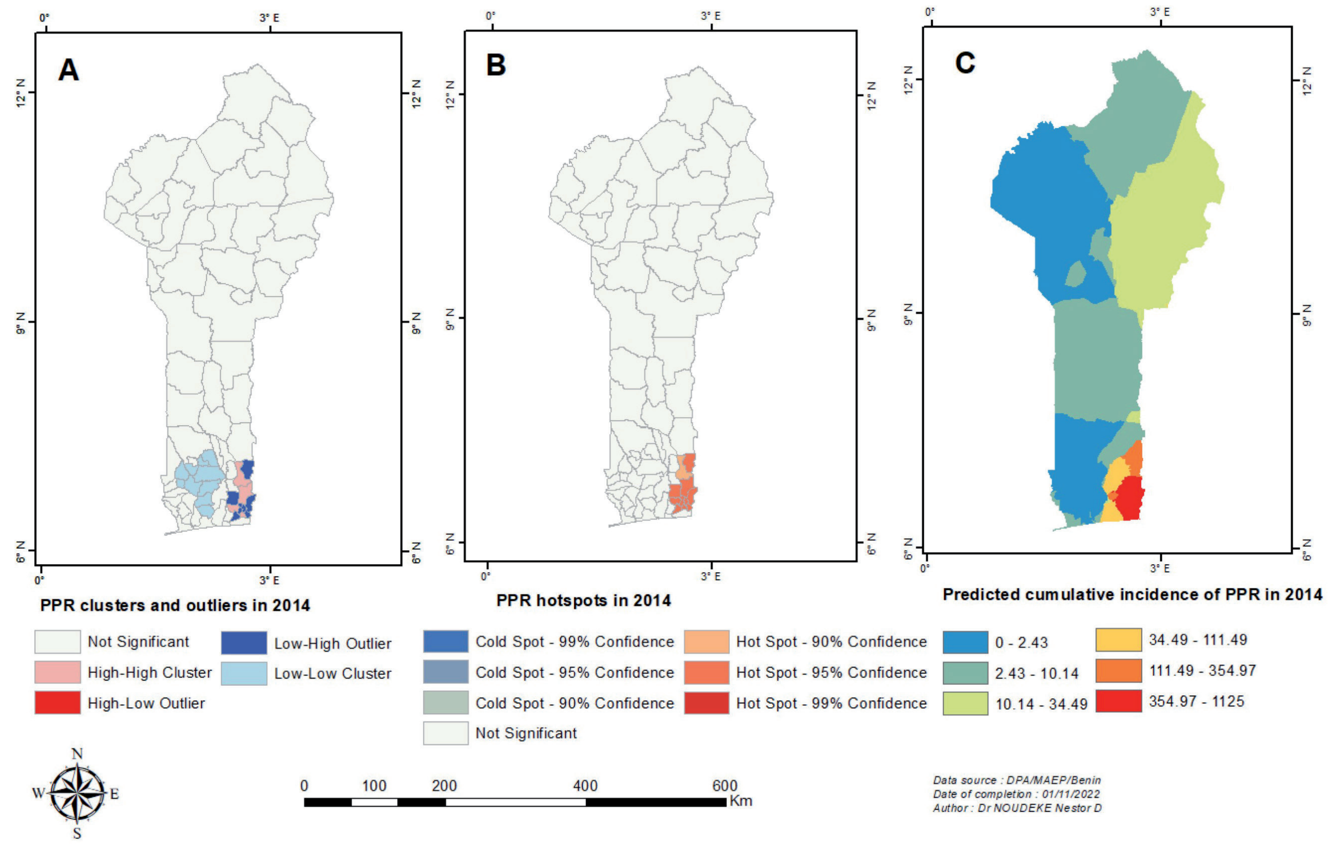

Figure 10: Clusters (A), hotspots (B) and risk map (C) of PPR in 2014 /// *Clusters (A), Hotspots (B) et carte des risques (C) de la PPR en 2014*

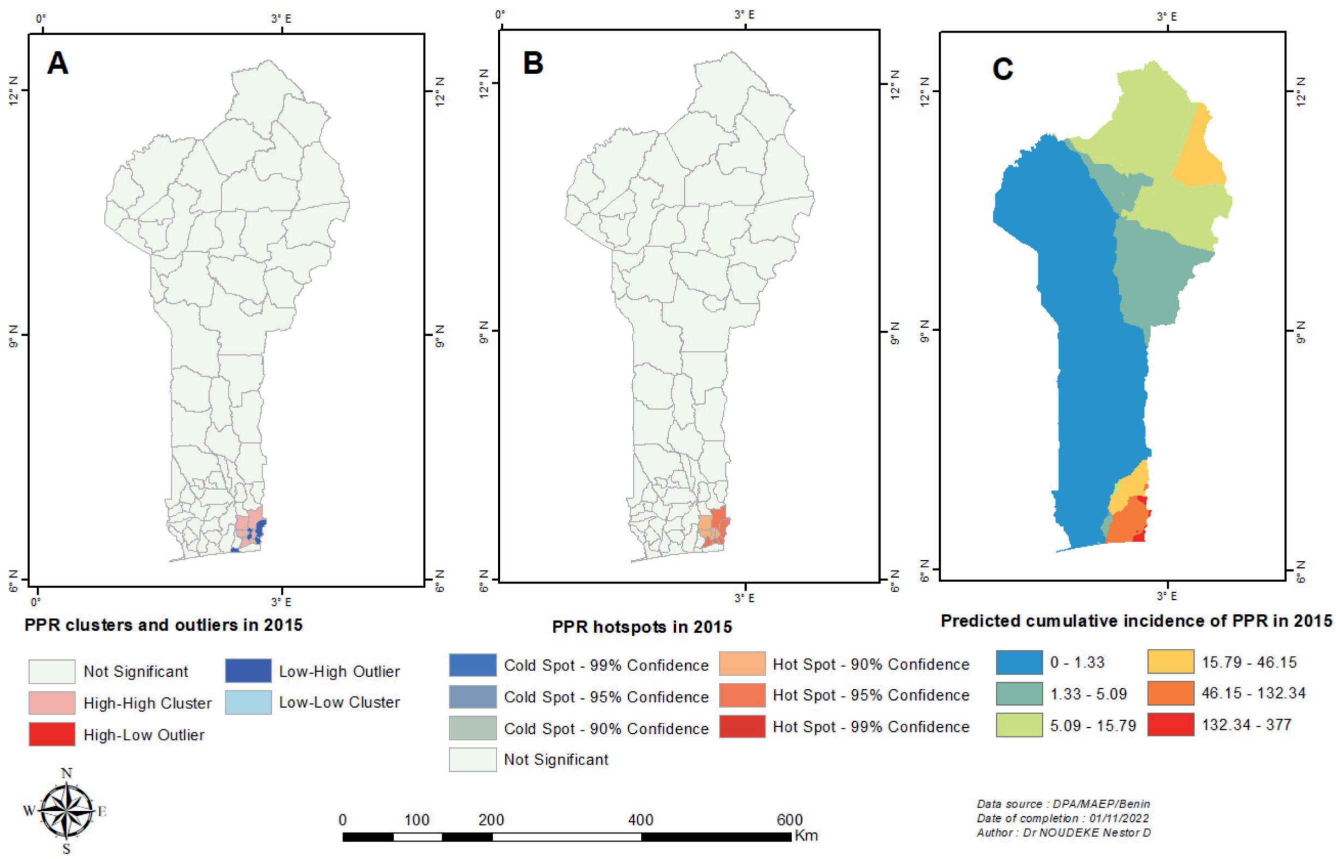

Figure 11: Clusters (A), hotspots (B) and risk map (C) of PPR in 2015 /// *Clusters (A), Hotspots (B) et carte des risques (C) de la PPR en 2015*

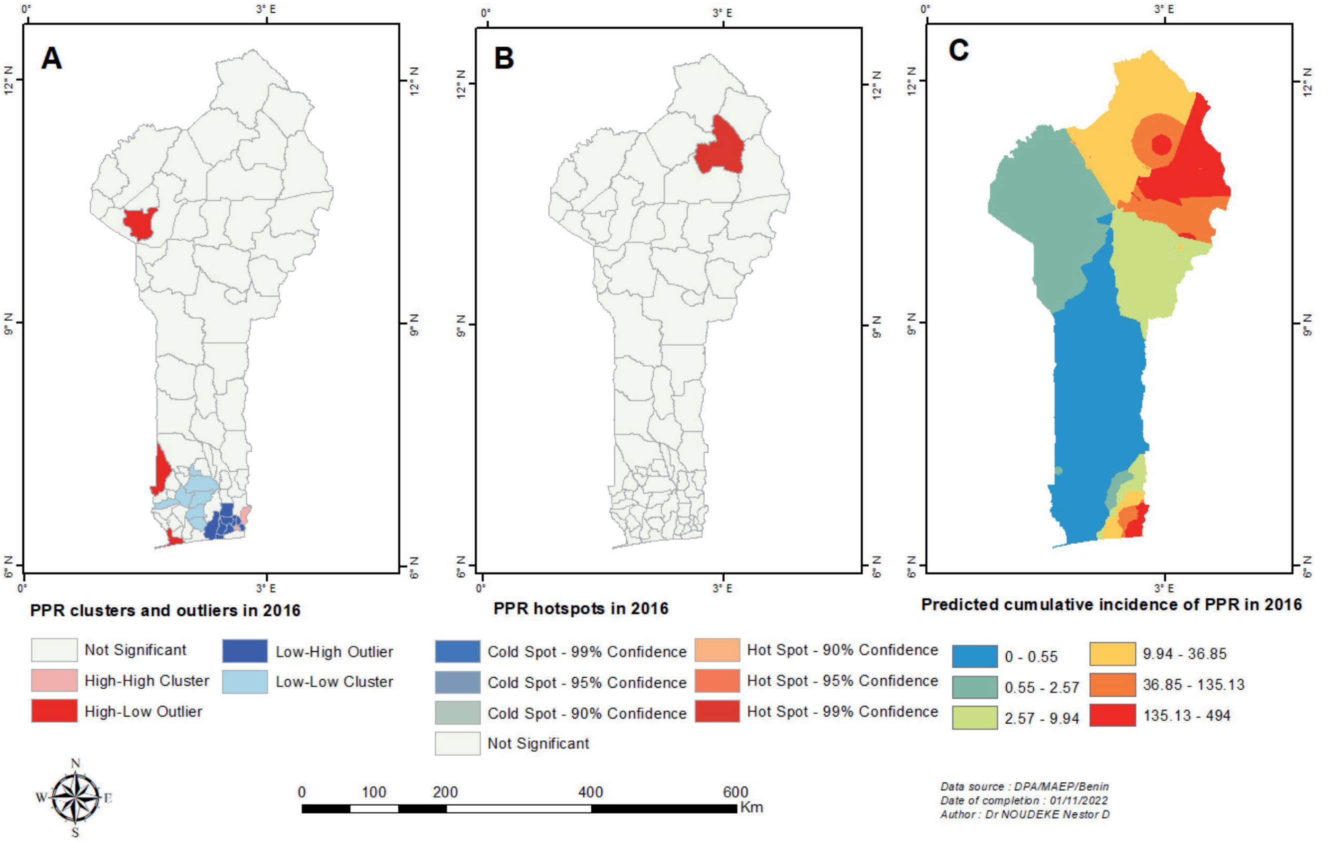

Figure 12: Clusters (A), hotspots (B) and risk map (C) of PPR in 2016 /// *Clusters (A), Hotspots (B) et carte des risques (C) de la PPR en 2016*

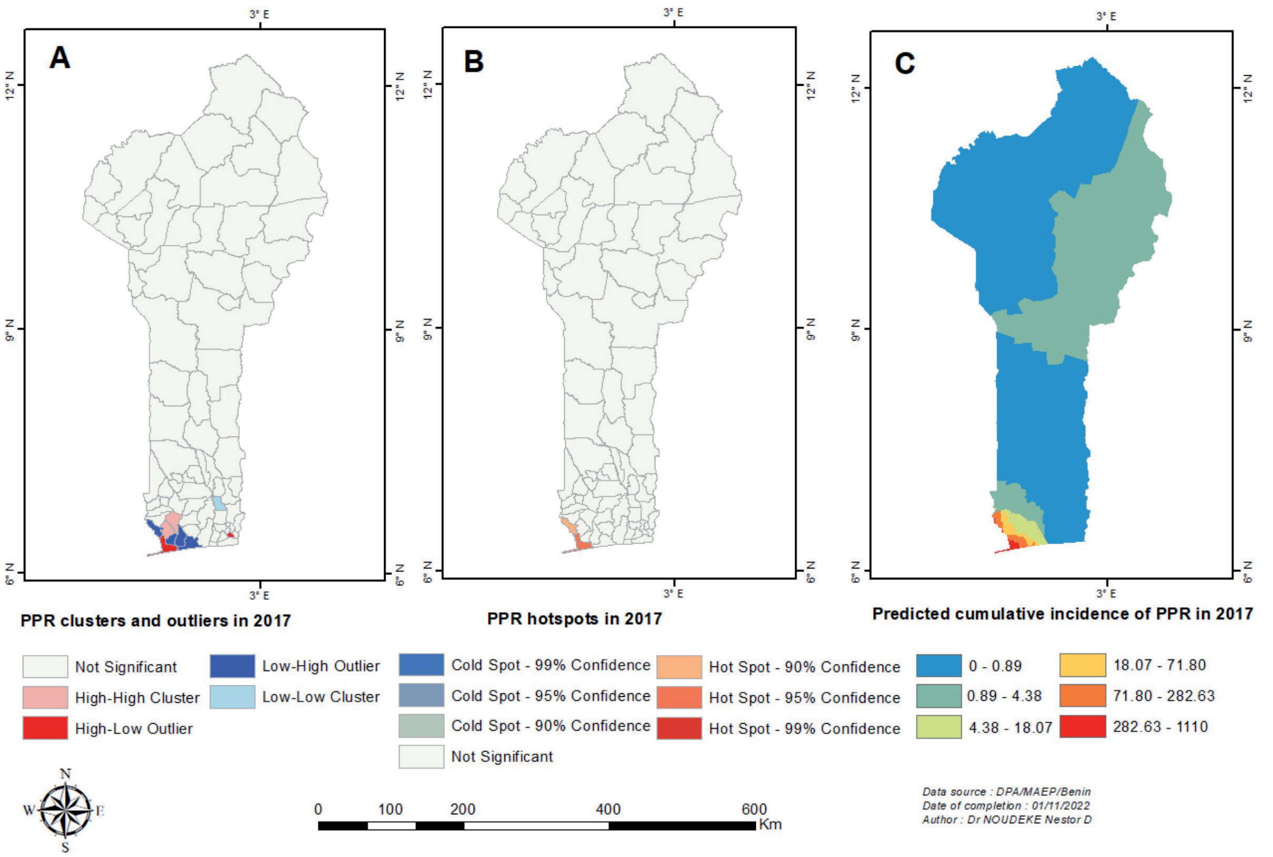

Figure 13: Clusters (A), hotspots (B) and risk map (C) of PPR in 2017 /// *Clusters (A), Hotspots (B) et carte des risques (C) de la PPR en 2017*

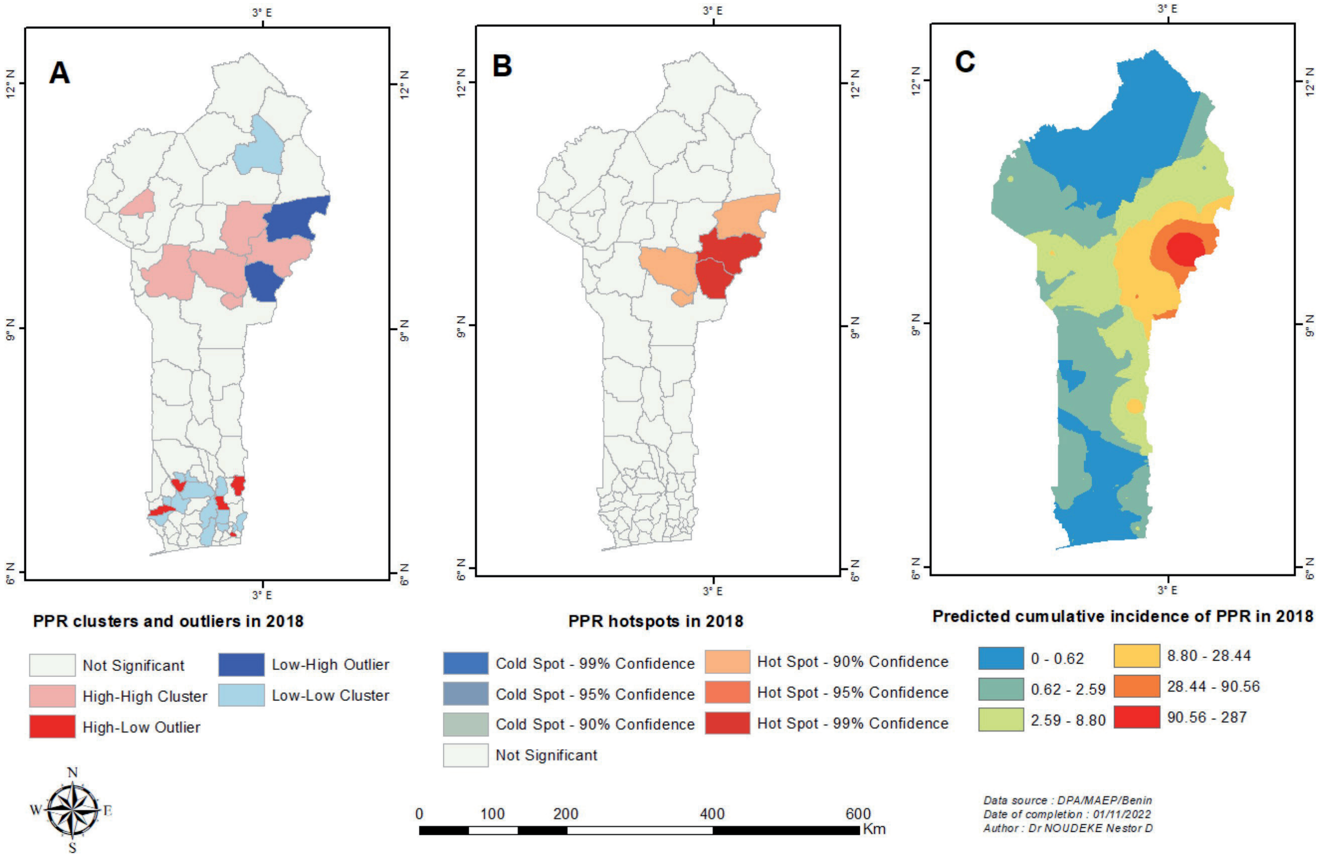

Figure 14: Clusters (A), hotspots (B) and risk map (C) of PPR in 2018 /// *Clusters (A), Hotspots (B) et carte des risques (C) de la PPR en 2018*

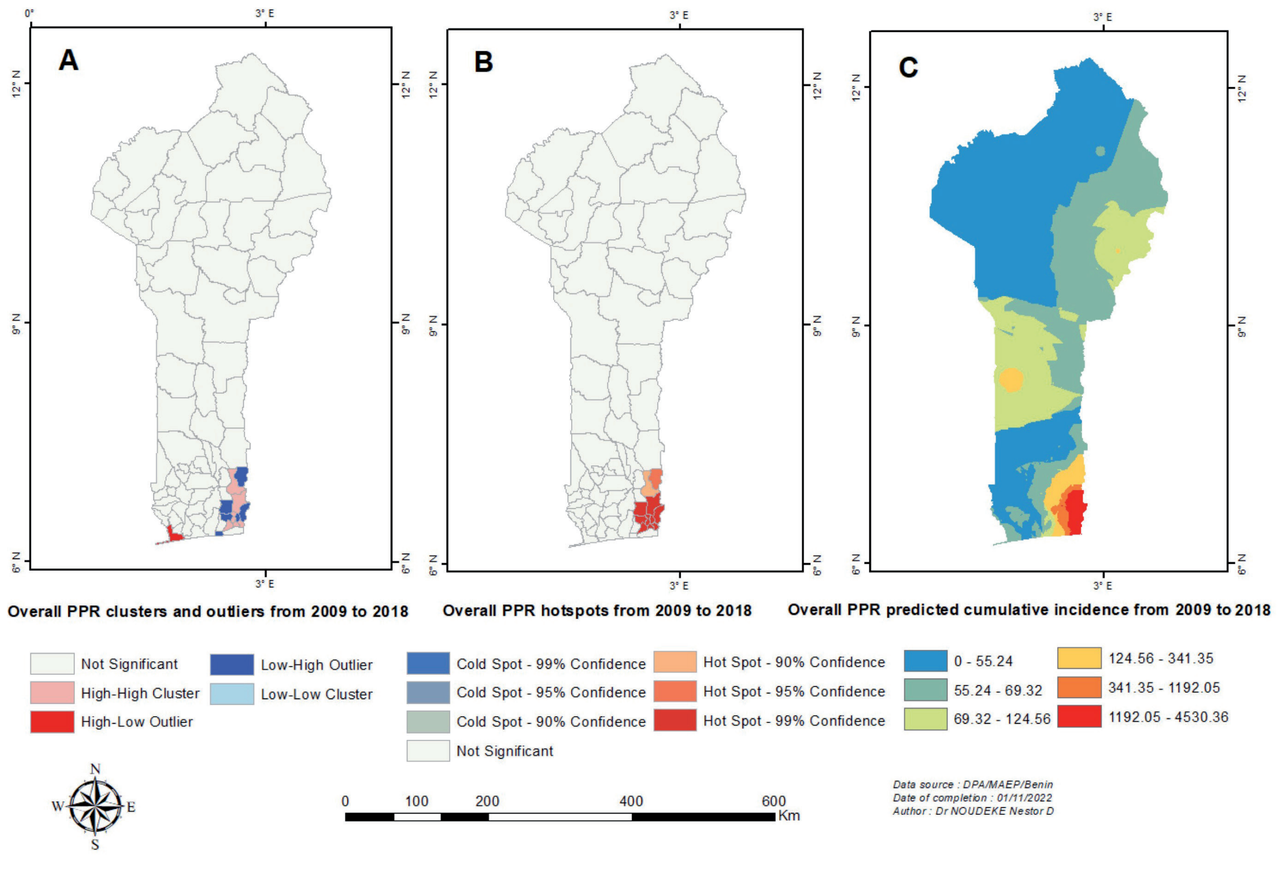

Figure 15: Clusters (A), hotspots (B) and risk map (C) of PPR according to the overall cumulative incidence in Benin between 2009 and 2018 /// *Clusters (A), hotspots (B) et carte de risque (C) de la PPR en fonction de l'incidence cumulée globale au Bénin entre 2009 et 2018*

Space-time analysis with SaTScan

Table III presents the results of the spatio-temporal analysis of PPR in Benin. The window size parameter was set at 50%, 40%, 30%, 20% and 10% of the centroids. Using a cylindrical window with a circular base, we were able to identify nine clusters at different locations, including 37 communes in eleven departments. Three clusters were detected in 2011, with the majority occurring in May (Table III). These clusters are illustrated in Figure 16. The group formed by Ifangni, Avrankou, Akpro-Missérété, Sakété, Adjarra,

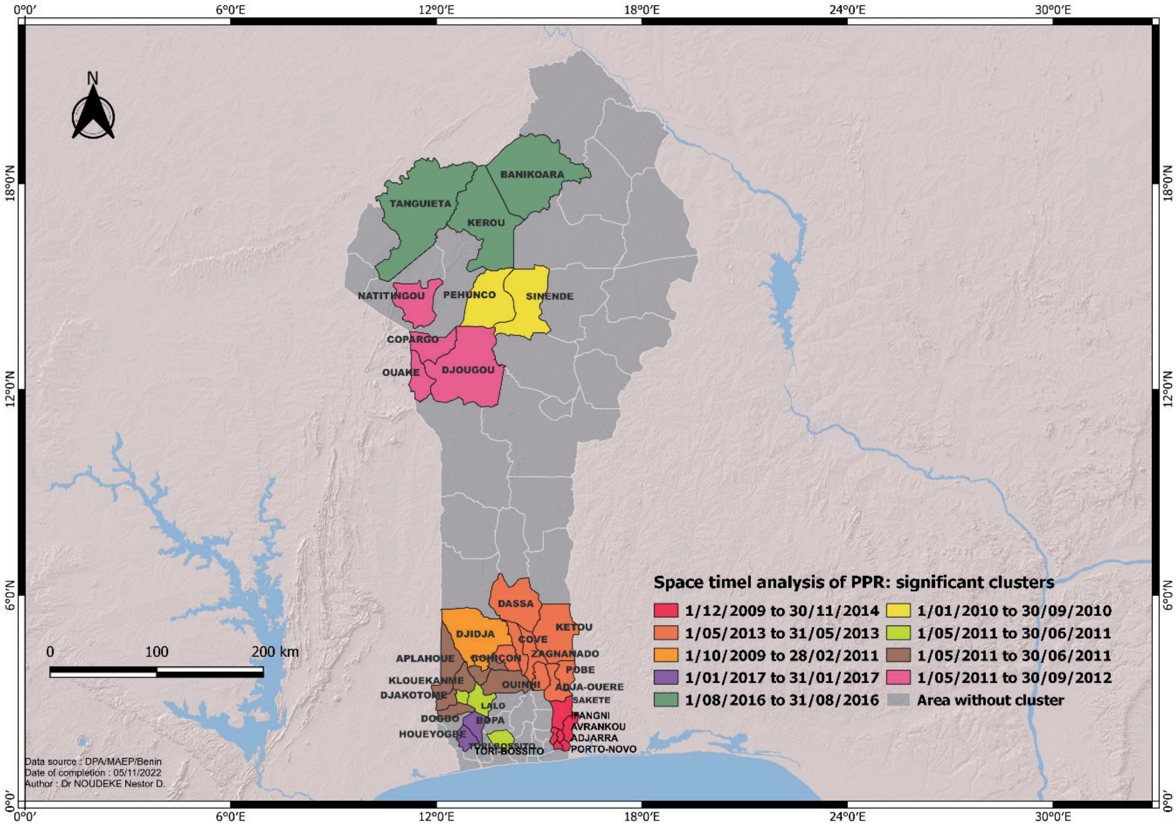

Figure 16: Significant clusters from space time analysis of peste des petits ruminants in Benin, 2009-2018 /// *Clusters significatifs issus de l'analyse spatio-temporelle de la peste des petits ruminants au Bénin, 2009-2018*

Table III: Significant clusters of PPR cases reported in the 77 communes in Benin between 2009 and 2018 /// *Regroupements significatifs de cas de Peste des petits ruminants signalés dans les 77 communes du Bénin entre 2009 et 2018*

Communes	Radius (km)	Periods	Log-Likelihood Ratio	Observed cases/ Expected cases	P value
Ifangni, Avrankou, Akpro-Missérété, Sakété, Adjarra, Porto-Novo	20.44	1/12/2009 to 30/11/2014	24138.01	9.2	< 0.001
Kétou, Za-Kpota, Covè, Pobè, Ouinhi, Dassa, Zagnanado, Adja-Ouèrè	53.16	01/05/2013 to 31/05/2013	2820.89	21.45	< 0.001
Lalo, Toviklin, Tori-Bossito	23.07	01/05/2011 to 30/06/2011	2105.94	19.18	< 0.001
Djidja, Abomey	29.63	1/10/2009 to 28/02/2011	2032.97	7.47	< 0.001
Bopa, Houeyogbe	16.02	01/01/2017 to 01/31/2017	585.32	13.41	< 0.001
Kerou, Tanguieta, Banikoara	59.81	01/08/2016 to 31/08/2016	174.76	4.34	< 0.001
Agbangnizoun, Abomey, Klouékanmè, Bohicon, Lalo, Zogbodomey, Toviklin, Zagnanado, Aplahoué, Tori-Bossito, Dogbo, Djakotomè	39.78	01/05/2011 to 30/06/2011	3129.41	10.86	< 0.001
Péhunco, Sinendé	31.89	01/01/2010 to 09/30/2010	564.64	4.13	< 0.001
Copargo, Djougou, Ouaké, Natitingou	40	01/05/2011 to 30/09/2012	416.04	2.41	< 0.001

and Porto-Novo communes was identified as the main cluster with a radius of 20.44 km. The cluster has the highest likelihood ratio (log-likelihood ratio LLR = 24138.01) and it lasted 5 years from December 1, 2009 to November 30, 2014. By varying the window size of the population at risk, we were able to identify eight other clusters. When we applied a cylinder with an elliptical base, the main cluster identified was composed of the following communes: Ifangni, Avrankou, Sakété, Akpro-Missérété, Adjarra, Adjohoun, Porto-Novo, Dangbo, Bonou, Adja-Ouèrè and Aguegues. These results confirm that the clusters identified during the analysis using the cylinder with a circular base were stable in time and space.

The different analyses clearly identified the main risk areas of PPR in Benin between 2009 and 2018. They include the following communes: Ifangni, Avrankou, Akpro-Missérété, Sakété, Adjarra, and Porto-Novo.

■ DISCUSSION

This study set out to identify the characteristics of PPR spread, PPR space-time clusters and risk areas with a view to developing predictive disease risk maps to improve our understanding of PPR in Benin.

Our analysis of retrospective epidemiological data from 2009 to 2018, reveals that 1,297 new outbreaks were recorded, with 88,668 cases of PPR and 23,002 deaths reported in small ruminants in Benin over the 10-year study period. The temporal trend of PPR outbreaks highlights the epizootic and re-emerging nature of the disease. It shows that the years 2010 to 2012 recorded among the highest number of new outbreaks, with the highest number of infected animals and deaths. The years 2017 and 2018 also recorded a high number of new outbreaks, but fewer deaths compared to 2010, 2011 and 2012. This can be explained by the fact that PPR is an enzootic and re-emerging disease in Benin (Brito *et al*., 2017).

Furthermore, our analysis of the monthly trend in terms of numbers of PPR outbreaks, cases and deaths, reveals that the disease is most severe in March, April and May. This corresponds to the main rainy season in southern Benin. The rainy season is a stressor for small ruminants, which could explain the higher occurrence of PPR at this time of year (Rahman *et al*., 2021). Ma *et al*. (2017) reported that weather conditions influence the transmission of PPR. Their findings suggest that a drop in temperature, hours of sunshine and atmospheric pressure, which occurs during the rainy season, could increase the probability of a PPR episode. Hu *et al*. (2016) also reported that the cold season favors disease emergence. It can influence animal behavior (animals gather together more frequently). It may reduce their immune system's activity due to stress mechanisms that affect the hypothalamic-pituitary-adrenal (HPA) axis and the adrenomedullary hormonal system. The cold season may also increase the resistance of microbes in an external environment.

The findings from our analysis of the spatial distribution of PPR outbreaks, affected animals and related deaths reveal that the disease is constantly re-emerging, despite the use of a live attenuated vaccine, which is safe and effective (Parida *et al*., 2015; Mariner *et al*., 2016). Indeed, results show that the departments of Ouémé and Plateau in the south and Borgou in the north, which are all on the border with Nigeria, were the most affected over the 10-year period. There are numerous reports documenting the endemic nature of PPRV in Nigeria (El-Yuguda *et al*., 2009; Emikpe & Akpavie, 2010; Woma *et al*., 2016). It is important to note that cross-border transhumance between Benin and Nigeria (OIM, 2021) generates multiple animal movements. Thus, Nigeria could play a key role in the epidemiological control of PPR.

Spatial analysis with cluster detection further highlights the role of Nigeria in the transmission and re-emergence of PPR in Benin. All the communes along the Nigerian border in the departments of Ouémé, Plateau and Borgou are either in High-High or Low-Low clusters or constitute PPR hotspots. (Clarke *et al*., 2018) suggested that subclinically infected sheep from one country may increase the risk of PPR transmission.

In 2016, Woma provided evidence of cases of PPR in the Nigerian states of Kwara and Ogun, bordering the department of Borgou in the north and the departments of Ouémé and Plateau in the south. Further evidence of the presence and persistence of PPR in the Nigerian states bordering different departments in Benin was also provided by (Esonu *et al*., 2022). For example, Kebbi state in Nigeria shares a border with the department of Borgou in Benin; Kwara state is on the border of the department of Collines; Oyo state borders the department of Plateau; Ogun state shares a border with Plateau and Ouémé. In these Nigerian states, the PPR lineages III and IV recurred regularly in 2009, 2010, 2011, 2012, 2013 and 2017, particularly in areas where there are regular movements due to the trade of small ruminants between the two countries. The peak period for trade occurs during the Tabaski and Ramadan festivals, especially at border livestock markets (Mantip *et al*., 2022). In addition, Mantip reported the existence of markets for terminal consumption and distribution in large cities in Benin, such as Cotonou, Bohicon, Porto-Novo, Parakou, etc. These markets are supplied by large livestock markets, such as the livestock market in Zé (Atlantique department), which in turn is largely supplied by the central eastern circuit connecting the breeding areas in southern Niger (IRAM, 2009) and Burkina-Faso. Other key markets include the livestock markets of Tchaourou and Parakou (Borgou) and those of Savé and Ouessé (Collines), bordering Oyo state (Nigeria); the markets of Pèrèrè, Nikki and Kalalé bordering Kwara state and the markets of Kétou, Pobé, Ifangni and Sakété (Plateau), which border Ogun state in Nigeria. Ogoun and Sakété play a relay role between the primary markets and regional markets in the south and external markets of Nigeria (CTA, 2004) Some authors (Zahur *et al*., 2008; Munir *et al*., 2015; Rahman *et al*., 2021) have also reported that animal movement is the primary factor in the spread of transboundary animal diseases. Any initiatives to control PPR in Benin would be more effective if the proximity to Nigeria was taken into account and if both countries implemented joint disease control programs.

Our findings reveal that the risk maps of cumulative PPR incidence, hotspots and clusters were similar for each year studied. Risk predictions for the cumulative incidence of PPR were higher in the southeast and northeast of Benin for each year and for the entire 10-year period. In contrast, overall risk predictions were lower in the southwestern, central, and northwestern regions of Benin for each year and across the 10-year period. Western Benin, on the border with Togo, is largely supplied by the markets in eastern and southern Togo. The markets provide animals for festivals, as well as for the traditional livestock sector (FAO, 2023).

The spatio-temporal analysis of PPR in Benin made it possible to identify nine clusters in different places. Most clusters occurred in May, during the main rainy season. The analyses revealed that the communes of Ifangni, Avrankou, Akpro-Missérété, Sakété, Adjarra, and Porto-Novo were the main areas at risk of PPR in Benin, between 2009 and 2018. As these communes are border communes, the cross-border movement of animals could explain these results.

Limitations

This study on the Peste of small ruminants (PPR) in Benin was based on passive surveillance data, which has several limitations. For example, the detection of outbreaks of PPR depends on the declaration of cases by breeders or local authorities. Some outbreaks may not be reported, especially in remote areas or regions where breeders lack awareness of the disease. This may cause bias and could underestimate the true extent of the disease. In addition, the spatio-temporal analysis identifies clusters, but does not take into account specific environmental factors (for example, climatic conditions, ruminant movement practices, local sanitary conditions), which could influence the spread of PPR. Taking account of these factors could provide crucial information for a better understanding of disease transmission mechanisms.

The models used (Moran's I, Getis-Ord, SaTScan) also have limitations. They are sensitive to the effects of window size and do not always take into account the variability of complex spatial structures. They can be influenced by the density of the data, as well as local anomalies, which do not necessarily reflect a general trend. Lastly, these models are based on specific assumptions concerning the shape of the clusters and the distribution of events, which may limit their applicability to certain types of data.

■ CONCLUSION

Our spatio-temporal analysis reveals that PPR has spread widely in Benin. Our findings could help improve disease risk management in future. Indeed, the use of PPR risk assessment and forecasting could enhance the implementation of control measures and help prevent future PPR epidemics by identifying spatio-temporal clusters. This approach could be applied to future PPR vaccination campaigns as part of disease eradication programs in Benin.

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Conflicts of interest

The authors declare no conflict of interest. The funders had no role in the design of the study, in the collection, analyses or interpretation of the data, in the writing of the manuscript or in the decision to publish the results.

Author contributions

GG and NN participated in the study design and planning; VA and OZ collected the data; GG drafted the first version of the manuscript; SF and AT participated in the study planning; NN performed the statistical analyses; IY, HA and SF revised the manuscript.

Ethics approval

Approval from an ethics committee regarding the use of animals was not necessary for this study because data were collected from previously collected sources from the Livestock Directorate of the Ministry of Agriculture, Livestock and Fisheries of Benin.

Access to research data

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration of Generative AI in the writing process

The authors did not use any artificial intelligence-assisted technologies in the writing process.

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Resumé

Guedegbe G., Noudeke N., Tonouhewa A., Allanonto V., Zannou O., Youssao I., Adakal H., Farougou S. Analyse spatio-temporelle de la peste des petits ruminants au Bénin, 2009-2018

Contexte : La peste des petits ruminants (PPR), maladie virale contagieuse qui touche les ovins et les caprins, est endémique au Bénin depuis des décennies. ***Objectif*** : Ce travail tente de décrire sa distribution spatio-temporelle au Bénin. ***Méthodes*** : Cette étude a utilisé dix années de données de surveillance passive (2009 à 2018) recueillies auprès de la Direction des productions animales du Bénin, englobant les 77 communes du pays. L'incidence cumulée de la PPR pour 10 000 animaux à risque par commune a été analysée pour effectuer des analyses de grappes et de points chauds et générer des cartes prédictives pour chaque année et pour l'ensemble de la période de dix ans. ***Résultats*** : Les résultats ont révélé plusieurs grappes spatio-temporelles (élevée, faible, élevée-faible, faible-élevée) ainsi que des points chauds. Au cours de cette période, 1 297 nouveaux foyers ont été signalés, 88 668 animaux ont été touchés et 23 002 sont morts. Les années 2010, 2011 et 2012 ont connu les taux d'incidence et de mortalité les plus élevés dus à la PPR. Les départements de l'Ouémé, du Plateau et du Borgou ont été les plus sévèrement touchés. Les mois de mars, avril et mai ont enregistré le plus grand nombre de nouveaux foyers, le plus grand nombre d'animaux affectés et le plus grand nombre de décès dus à la PPR. Les communes qui ont connu le plus grand nombre de foyers étaient situées dans les départements du Mono et du Couffo. En outre, d'importants groupes de cas de PPR ont été identifiés dans 26 communes de 9 départements au cours de la période de dix ans, avec quelques variations en fonction de l'année. ***Conclusions*** : Les résultats de cette analyse spatio-temporelle peuvent aider à prévoir les risques de PPR dans des régions spécifiques et guider la mise en œuvre de mesures de prévention et de contrôle ciblées.

Mots-clés : Petits ruminants, peste des petits ruminants, analyse du risque, surveillance épidémiologique, maladie à déclaration obligatoire, Bénin

Resumen

Guedegbe G., Noudeke N., Tonouhewa A., Allanonto V., Zannou O., Youssao I., Adakal H., Farougou S. Análisis espaciotemporal de la peste de pequeños rumiantes en Benín, 2009–2018

Contexto: La peste de los pequeños rumiantes (PPR), enfermedad viral contagiosa que afecta a ovinos y caprinos, es endémica de Benín desde hace decenios. ***Objetivo***: Este trabajo intenta describir su distribución espaciotemporal en Benín. ***Métodos***: El estudio utilizó datos de diez años de vigilancia pasiva (2009 a 2018) recogidos por la Dirección de Producciones Animales de Benín, y engloba las 77 comunas del país. Se analizó la incidencia acumulada de la PPR para 10 000 animales de riesgo por comuna para efectuar análisis de conjuntos y de puntos críticos y generar mapas predictivos para cada año y para el conjunto del período de diez años. ***Resultados***: Los resultados revelaron diferentes conjuntos espaciotemporales (elevado, débil, elevado-débil y débil-elevado), así como puntos críticos. Durante este período, se señalaron 1 297 nuevos focos, 88 668 animales fueron afectados y 23 002 murieron. Los años 2010, 2011 y 2012 se registraron las tasas de incidencia y de mortalidad más elevadas a causa de la PPR. Los departamentos del Ouémé, del Plateau y del Borgou fueron los más severamente afectados. Los meses de marzo, abril y mayo se registraron el mayor número de nuevos focos, el mayor número de animales afectados y el mayor número de muertes debidas a la PPR. Las comunas donde hubo más focos estaban situadas en los departamentos del Mono y del Kouffo. Además, se identificaron importantes grupos de casos en 26 comunas de 9 departamentos durante el período de diez años, con algunas variaciones en función del año. ***Conclusiones***: Los resultados de este análisis espaciotemporal pueden ayudar a prevenir los riesgos de PPR en regiones específicas y guiar en la aplicación de medidas de prevención y de control focalizadas.

Palabras clave: Pequeño ruminate, Peste de los pequeños ruminates, análisis de riesgos, vigilancia de enfermedades, enfermedad de declaración obligatoria, Benin