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A GEOSPATIAL RETROSPECTIVE STUDY OF AFRICAN SWINE FEVER SPREAD IN SERBIA (2019–2025) IN DOMESTIC PIG AND WILD BOAR POPULATION

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Abstract

African Swine Fever (ASF) has been posing a significant threat to pig production and wildlife management in the Republic of Serbia since its first detection in 2019. The goal of this study is to provide a comprehensive overview of the spatial and temporal spread of ASF in both domestic and wild pig populations in Serbia from the initial outbreak in the summer of 2019 through May 2025. Additionally, the study aimed to map the risk of ASF in the domestic pig sector to identify the areas where enhanced biosecurity measures could improve future disease control efforts.

The analysis is based on official data obtained from the Serbian Veterinary Directorate, specifically from issued decisions related to all affected settlements and hunting grounds where ASF was confirmed. The data on the number of disease outbreaks used in the study are official records submitted to the European Commission through the Animal Diseases Information System for the 2019– 2025 period.

Between 2019 and 2025, the spread of ASF in Serbia followed a distinct trajectory, moving from the southeastern regions toward the northwest, ultimately reaching the West Bačka District in Vojvodina in 2025. The disease demonstrates distinct seasonal dynamics: in domestic pigs, the majority of outbreaks occur during summer months, with an additional peak observed

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in November and December, while in wild boars the number of cases increases during the winter period. ASF is showing signs of becoming endemic in Serbia.

The implemented control strategies have largely been reactive rather than preventive, demonstrating limited effectiveness in altering the overall trajectory of the epidemic. The principal risk factors contributing to the spread of ASF in Serbia are linked to the continued circulation of the virus between domestic pig and wild boar populations, predominantly driven by human activities associated with both animal groups.

Keywords: African swine fever, Serbia, Geographical information systems, Analysis, Epidemiology, Spatial distribution, Retrospective studies**.**

GEOPROSTORNA RETROSPEKTIVNA STUDIJA ŠIRENJA AFRIČKE KUGE SVINJA U SRBIJI (2019–2025) KOD DOMAĆIH I DIVLJIH SVINJA

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Kratak sadržaj

Afrička kuga svinja predstavlja značajnu pretnju za proizvodnju svinja i lovstvo u Republici Srbiji. Cilj ovog istraživanja je da pruži sveobuhvatan pregled prostornog i vremenskog širenja afričke kuge svinja u populacijama domaćih i divljih svinja u Srbiji, počev od inicijalne pojave bolesti 2019. godine pa do maja 2025. godine. Pored toga, cilj studije bio je mapiranje rizika od pojave afričke kuge svinja u proizvodnom sektoru domaćih svinja, kako bi se identifikovale oblasti u kojima bi unapređene mere biosigurnosti mogle doprineti efikasnijoj kontroli bolesti u budućnosti.

Analiza se zasniva na zvaničnim podacima Uprave za veterinu Republike Srbije, a posebno na rešenjima izdatim za sva zaražena naseljena mesta i lovišta u kojima je potvrđena afrička kuga svinja. Podaci o broju izbijanja bolesti koji su korišćeni u ovom istraživanju predstavljaju zvanične podatke dostavljene Evropskoj komisiji putem informacionog sistema za o bolestima životinja za period od 2019. do 2025. godine.

Tokom navedenog perioda, širenje afričke kuge svinja u Srbiji pratilo je specifičnu putanju – od jugoistočnih delova zemlje ka severozapadu, da bi u 2025. godini zahvatila i Zapadnobački okrug u Vojvodini. Bolest pokazuje izraženu sezonsku dinamiku: kod domaćih svinja, najveći broj žarišta registruje se tokom letnjih meseci kao i pojavi velikog broja slučajeva u novembru i decembru, dok se kod divljih svinja broj slučajeva povećava u zimskom periodu.

Rezultati ukazuju da afrička kuga svinja poprima karakteristike endemske infekcije u populaciji domaćih i divljih svinja u Srbiji. Dosadašnje strategije kontrole bolesti u najvećoj meri su bile reaktivne, a ne preventivne, sa ograničenom efikasnosti u promeni ukupnog toka enzootije. Ključni faktori rizika za širenje afričke kuge svinja u Srbiji povezani su sa kontinuiranom cirkulacijom virusa između populacija domaćih i divljih svinja, pri čemu ljudske aktivnosti povezane sa obe populacijske grupe životinja predstavljaju dominantni mehanizam širenja.

Ključne reči: Afrička kuga svinja, Srbija, Geografsko informacioni sistemi, Analiza, Epidemiologija, Prostorna distribucija, Retrospektivne studije.

INTRODUCTION

African swine fever (ASF) is a significant infectious hemorrhagic disease affecting domestic and wild pigs, with a case fatality rate that can reach up to 100%. It is caused by the African swine fever virus (ASFV), the sole member of the *Asfarviridae* family, which affects only members of the Suidae family (domestic pigs and wild boars) (Calò et al., 2023; Guinat et al., 2016; Lazov et al., 2025). Although initially identified only on the African continent, several instances of the virus spreading outside of Africa have been reported (Chenais et al., 2019; Lazov et al., 2025). A genotype II virus entered Georgia in 2007 and subsequently spread across Europe, into Asia, and more recently into the Americas, affecting a total of 62 countries globally since 1 January 2022 (WOAH, 2024). Nowadays, the disease is present worldwide and represents a global challenge for the pig production sector (Sánchez-Cordón et al., 2018; Whitaker et al., 2024).

In Europe, ASF is primarily maintained within wild boar populations, with frequent spillover events into domestic pig herds (Calò et al., 2023; Gervasi et al., 2020; Martinez Aviles et al., 2023) through direct contact with infected animals and via various indirect routes, including contaminated fomites and feed, which enable long-distance spread often driven by human activity (Boklund et al., 2020; Chenais et al., 2019; Guinat et al., 2016; Lazov et al., 2025; Whitaker et al., 2024). Since its introduction into the European Union in 2014, the virus has become endemic in wild boar populations in several member states, posing a continuous threat to domestic pig farming (Stahl et al., 2025). Since there is currently no effective vaccine available, control efforts depend on prevention, early detection, and the enforcement of strict biosecurity protocols (Calò et al., 2023; Plut et al., 2023). To date, biosecurity remains the most important tool in preventing ASF spread and combating the disease (Plut et al., 2023; Prodanov-Radulovic et al., 2022). While ASF does not pose a zoonotic threat, its economic and socio-political consequences are profound. Trade restrictions and depopulation measures associated with outbreaks cause significant disruptions on both local and international markets (Calò et al., 2023; Whitaker et al., 2024).

One of the most important differences between pig production in Western Balkan countries and EU member states lies in the structure of the pig production sector (Plut et al., 2023). The Serbian pig sector is largely made up of backyard farms, where pig rearing provides both a source of meat and plays a role in preserving the traditional rural lifestyle (Prodanov-Radulovic et al., 2022). Notably, over 60% of pig holdings in Serbia are backyards and small-scale operations with fewer than ten pigs and minimal or no biosecurity measures (Plut et al., 2023; Prodanov-Radulovic et al., 2022). According to the Statistical Office of the Republic of Serbia, pig farming accounted for the largest share of livestock production, comprising approximately 52% in 2023 (Stat. Office-Serbia, 2024). Pig production sector plays a vital role in Serbia's agricultural economy, with pork being the second most consumed animal protein after poultry (Kureljušić et al., 2024; Prodanov-Radulovic et al., 2022). Intensive commercial pig farms are mainly situated in the northern part of the country, particularly in the Vojvodina Province, where pigs are raised indoors under strict biosecurity measures (Prodanov-Radulovic et al., 2022). However, surrounding these commercial operations are numerous smallholdings and backyards that operate under traditional, semi-extensive, or extensive systems (Kureljušić et al., 2025). These farms are especially susceptible to disease outbreaks due to the absence of effective biosecurity measures. Since its emergence in 2019, ASF has severely affected small-scale and backyard farms, which remain a significant source of risk for virus spillover into large commercial operations (Nešković et al., 2021; Plut et al., 2023; Polaček et al., 2021). Furthermore, various anthropogenic factors - such as activities of farm workers, veterinarians, household pig keepers in villages and hunters - can act as bridges for ASFV transmission.

The transboundary nature of ASFV transmission had become evident even before its first detection in Serbia. Neighbouring countries - Romania (2017) and Bulgaria (2018) - reported ASF outbreaks near the Serbian border shortly after the initial cases were confirmed within their territories (Gao et al., 2023; Gervasi et al., 2020; Nielsen et al., 2019). Serbian border in this region is not fenced, enabling the natural migration of wild boars across national boundaries. Moreover, disease control strategies implemented in neighbouring countries, which included intensified hunting of wild boars, likely contributed to the transboundary spread of the virus (BFSA 2018).

However, the first confirmed ASF outbreaks in Serbia were not reported in border areas but rather in central municipalities - Mladenovac and Smederevska Palanka - in July 2019 (Milićević et al., 2019). In response, emergency control measures were promptly implemented. These included stamping out, preventive depopulation, disinfection, bans on restocking and swill feeding, movement restrictions, and the suspension of live animal markets (2019). By September 2019, an isolated outbreak was recorded in the northern province of Vojvodina, near the Romanian border.

Since 2020, ASF has been detected annually in both domestic pigs and wild boars across Serbia (Nešković et al., 2021; Polaček et al., 2021; Prodanov-Radulovic et al., 2023).

From 2022 onward, the disease has also been detected in several neighbouring countries. ASF was confirmed in North Macedonia (2022); in Croatia, Bosnia and Herzegovina, and Kosovo (2023); and in Albania and Montenegro (2024) - with the latter reporting cases only in wild boars. As of 5 July 2025, during the current year, ASF remains present in both domestic pigs and wild boar populations in Serbia, Croatia, and Bosnia and Herzegovina, in North Macedonia (ADIS, 2019, 2020, 2021, 2022, 2023, 2024, 2025).

Since 2020, both active and passive surveillance programs have been implemented in the domestic pig sector in Serbia. Based on our direct involvement in the organization, coordination, and laboratory diagnostics, as well as feedback from field veterinarians, we assume that the effectiveness of active surveillance has been limited. This limitation appears to result from weak local response, insufficient cooperation at the field level, and various logistical challenges. Consequently, the majority of positive ASF cases have been detected through passive surveillance. A specific feature of the program is its adaptation to backyard holdings, which also includes the requirement for ante-mortem health checks and laboratory testing to be conducted at least 24 hours prior to home slaughter.

The program requires the submission of samples in suspected ASF cases, regardless of farm size and production type. In other words, every pig holding must participate in the program of active and passive surveillance, while the number and type of samples collected vary depending on herd size and production type (farrow-to-wean, farrow-to-finish, or fattening only).

In the existing production sector, with a large number of different farm types concentrated in a relatively small area, spatial tools such as GIS-based mapping and cluster detection techniques are valuable for visualising disease hotspots, while temporal analyses help identify seasonal or cyclical patterns. When combined with descriptive epidemiology, these tools can reveal key risk factors, support targeted intervention planning, and inform the development of tailored biosecurity programs for small-scale systems.

The aim of this study was to investigate the spatiotemporal patterns of ASF spread in Serbia from the first confirmed case in 2019 through the end of May 2025 and to make ASF epidemiological patterns more visible and accessible for interpretation. Additionally, the study aimed to map the risk of ASFV in the domestic pig sector in order to identify areas where enhanced biosecurity measures could improve future disease control efforts.

MATERIAL AND METHODS

In this study, official data from the Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia – Veterinary Directorate (2023–2025) were utilised, available at the following link: https://www.vet.minpolj.gov.rs/zarazne-bolesti-zivotinja/africka-kuga-svinja-aktuelne-informacije.

Publicly accessible data consists of official decisions (resolutions) issued for all settlements and hunting grounds where ASF was confirmed. For the 2019–2022 period, additional detailed data were obtained directly from the Veterinary Directorate upon formal request. These data included all official resolutions issued for each settlement and hunting ground where ASF was diagnosed in the form of MS Excel spreadsheets.

In order to determine the total number of confirmed outbreaks during the 2019- 2025 period, publicly available official data submitted by the Republic of Serbia to the Animal Diseases Information System (ADIS) of the European Commission were used (ADIS, 2019, 2020, 2021, 2022, 2023, 2024, 2025). These data are accessible on the following link: https://webgate.ec.europa.eu/tracesnt/adis/public/notification

Geospatial visualisation and analysis were conducted using QGIS software, version 3.4. Administrative boundary polygons within the Republic of

Serbia were obtained from OpenStreetMap datasets provided by NextGIS in GeoPackage format. Hunting ground boundaries were obtained from the official website of the Forest Directorate of the Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia, available on the links below:

https://upravazasume.gov.rs/wp-content/uploads/2025/01/Granica_lovista_RS.zip, in ESRI shapefile format.

In order to visualize the occurrence of ASF over the 2019–2025 period, the Dynamic Temporal Control option in QGIS was used, based on the official data on the issuance of veterinary authority decisions. The selected time frame for displaying cases included July 2019 - May 2025 period, with the event duration set to one month. Additionally, the accumulation over time option was enabled.

For exporting individual frames, the Temporal Controller was configured with a display step of one month. The exported frames were subsequently combined into GIF and MP4 formats using free online tools available at https://ezgif.com.

Data processing for visualisation, as well as analyses were carried out using Microsoft Excel 365.

RESULTS

In 2019, during the July–August period, a total of 18 outbreaks of ASF were reported in domestic pigs in the city municipality of Mladenovac, Belgrade (villages of Rabrovac and Velika Krsna), Podunavski district municipality of Smederevska Palanka (village of Kusadak) and Žitiste municipality (Srpski Itebej). No cases were detected in wild boar populations during this year (Figure 1).

Figure 1. ASF occurrence in 2019 in Serbia

In 2020, ASF was confirmed in 16 domestic pig outbreaks across the municipalities of Bela Palanka, Negotin, and Pirot, and in 69 outbreaks in wild boars across the Borski, Zaječarski, and Pirotski districts (Figure 2).

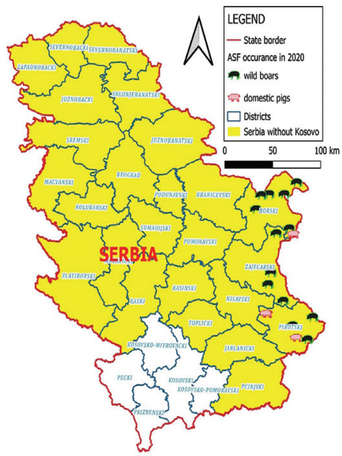


Figure 2. ASF occurrence in 2020 in Serbia

In 2021, a total of 32 outbreaks in domestic pigs were reported across several districts, including South Banat, Braničevski, Zaječarski, Nišavski, Pirotski, and Pomoravski (Paraćin municipality), as well as in the Rasinski district (Kruševac and Aleksandrovac municipalities) and the Borski district. A total of 43 wild boar outbreaks were registered in the South Banatski, Braničevski, Zaječarski, Nišavski, and Pirotski districts (Figure 3).

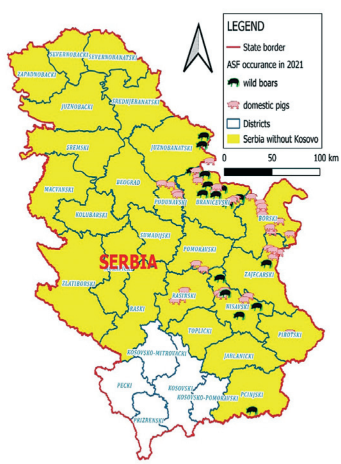


Figure 3. ASF occurrence in 2021 in Serbia

In 2022, 107 ASF outbreaks were reported in domestic pigs across the South Banatski, Braničevski, Pomoravski (Despotovac municipality), Zaječarski, Nišavski, Pirotski, and Pčinjski districts , and 146 outbreaks in wild boars across the South Banatski, Braničevski, Jablanički, Zaječarski, Nišavski, Pčinjski, and Zlatiborski districts (Figure 4).

Figure 4. ASF occurrence in 2022 in Serbia

The year 2023 marked the highest number of outbreaks, with 992 cases in domestic pigs occurring across the South Banatski, Sremski, City Municipality of Belgrade, Mačvanski, Braničevski, Podunavlski, Zaječarski, and Pčinjski districts. Additionally, 213 outbreaks in wild boars were recorded in the South Bački, South Banatski, Sremski, Mačvanski, City Municipality of Belgrade, Braničevski, Pomoravski, Jablanički, and Pčinjski districts (Figure 5).

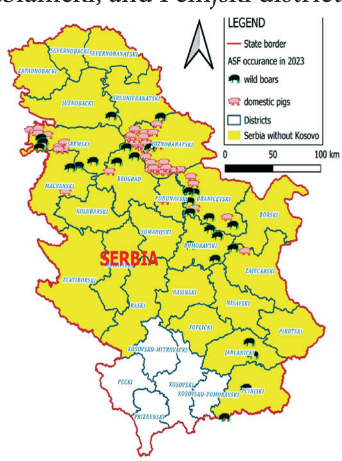


Figure 5. ASF occurrence in 2023 in Serbia

In 2024, 310 outbreaks in domestic pigs were reported in the Srednje Banatski district (Zrenjanin municipality), City Municipality of Belgrade, Sremski, Kolubarski (Ub municipality), Nišavski, Zaječarski, and Pčinjski districts, while 101 outbreaks in wild boars were detected in South Bački, Sremski, City Municipality of Belgrade, Pomoravski, Borski, Zaječarski, and Zlatiborski districts (Figure 6).

Figure 6. ASF occurrence in 2024 in Serbia

As of May 26, 2025, 18 outbreaks in domestic pigs were confirmed in the City Municipality of Belgrade (Obrenovac, Sopot), Kolubarski (Ub municipality) and Nišavski (Aleksinac municipality), and 28 outbreaks in wild boars occurred in the City Municipality of Belgrade (Obrenovac, Sopot, Kosmaj), South Bački, Western Bački (Kamarište), and the Podunavski district (Figure 7).

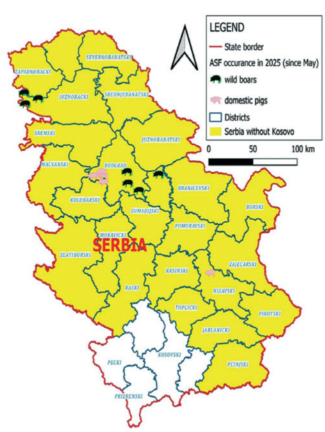


Figure 7. ASF occurrence in 2025 (since May) in Serbia

The occurrence of all ASF cases in Serbia during the observed period (2019–May 2025) is presented in Figure 8.

Figure 8. ASF occurrences 2019-2025 in Serbia

The total area of hunting grounds in which ASF has been confirmed in wild boars amounts to 23,776 km², representing 30.64% of the territory of the Republic of Serbia (excluding the territory of Kosovo) (Figure 9).

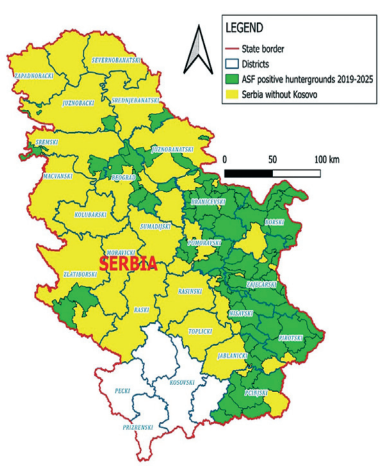


Figure 9. Affected hunter grounds with ASF 2019-2025 in Serbia

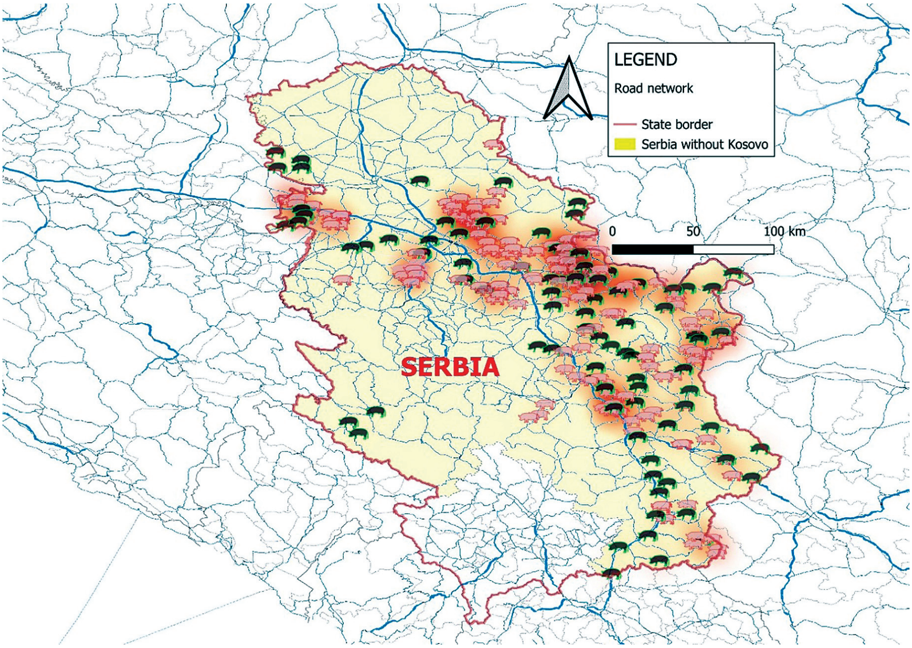
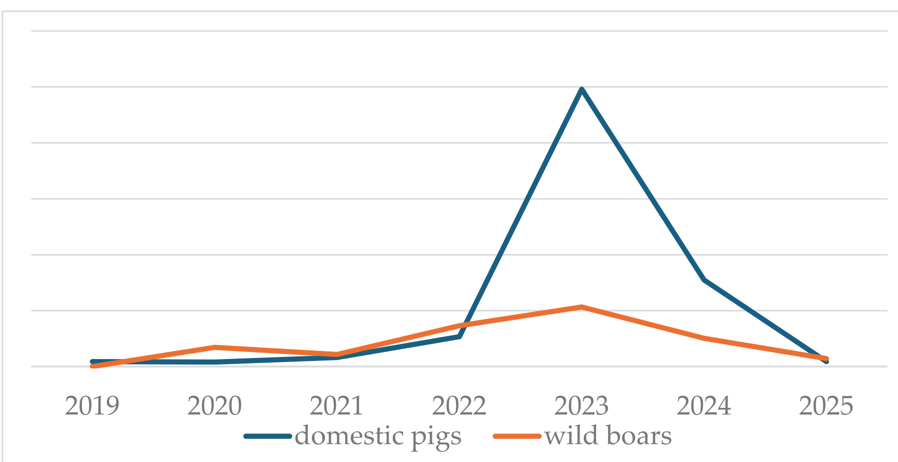


Figure 10. Highway network influence on ASF spread in Serbia

Figure 11. Number of ASF outbreaks in domestic pigs and wild boars by years (ADIS 2019-2025) in Serbia



From the detection of the first confirmed ASF case in 2019 through May 26, 2025, the highest number of reported cases occurred in 2023, predominantly affecting domestic pigs (Figure 11). Outbreaks in domestic pigs were most frequently detected during the summer months, whereas in wild boars, ASF was more commonly detected in winter (November -December) (Figure 12).

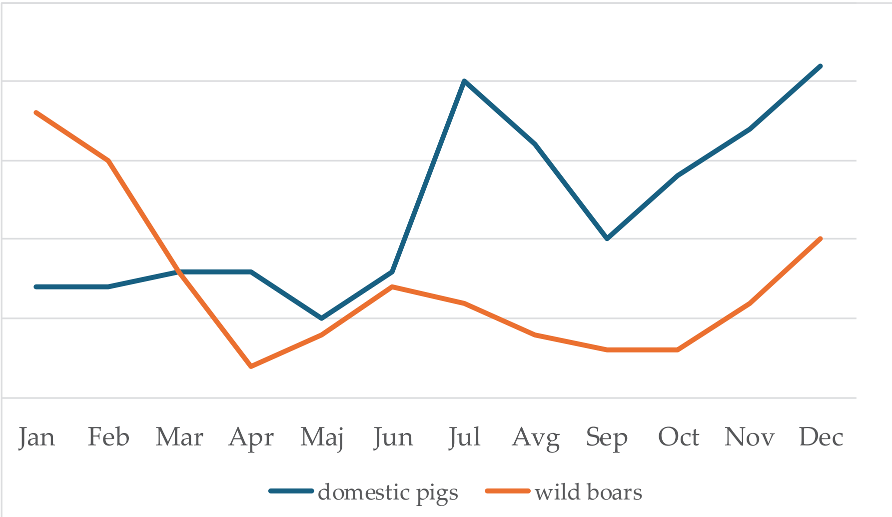


Figure 12. Seasonal dynamics of African Swine Fever (ASF) occurrence in domestic and wild pigs in Serbia, 2019–2025.

DISCUSSION

Today, six years after the first case was detected, ASF continues to spread throughout Serbia's entire pig production sector as well as the wild boar population. As observed in other parts of Europe (Calò et al., 2023; Rusinà et al., 2023), ASFV presents a significant threat to smallholder farms, which are especially susceptible to outbreaks due to limited biosecurity measures, proximity to wild boar populations, and farmer attitudes and behaviours related to disease risk and biosecurity practices. Human activities have already been identified as the main drivers of disease transmission (Nešković et al., 2021; Polaček et al., 2021; Prodanov-Radulovic et al., 2023). From the perspective of the Serbian economy, these small-scale farms do not contribute significantly to annual pork production (Polaček et al., 2021; Prodanov-Radulovic et al., 2022). However, as in other parts of Europe, these outdoor farming systems carry substantial socio-economic and cultural importance (Boklund et al., 2020). The loss of smallholder farming systems in rural Europe would represent an economic loss for farmers and local economies, as well as a loss of cultural and natural heritage (Stahl et al., 2025; Whitaker et al., 2024).

Studies on biosecurity in backyard and smallholder farms in Serbia have demonstrated a low level of biosecurity and a high risk of ASF spread from wild boar to domestic pigs in villages (Kureljušić et al., 2025; Kureljušić et al., 2024). It is well known that inadequate biosecurity on smallholder farms contributes to ASF outbreaks in domestic pigs (Stahl et al., 2025; Penrith et al., 2023; Whitaker et al., 2024). The proximity of wild boars to farms is also associated with increased ASF risk (Boklund et al., 2020; Prodanov-Radulovic et al., 2022). Wild boars can transmit the disease directly to domestic pigs, and domestic pigs can also transmit it to wild boar. Moreover, humans in contact with wild boars may inadvertently introduce the virus to farms (Nešković et al., 2021; Rusinà et al., 2023). Indeed, in different parts of the world human behaviour and socio-cultural factors are increasingly recognized as crucial in the spread and control of ASF (Chenais et al., 2019; Penrith et al., 2023; Whitaker et al., 2024). Understanding farmer decision-making and the socio-ecological context of small-scale farming is essential for developing national regulations that incorporate biosecurity measures (Biebaut et al., 2025; Whitaker et al., 2024).

During the 2018–2019 period, it was anticipated that ASF would first appear in the bordering regions between Serbia and Romania or Bulgaria, due to the high number of reported ASF cases in those countries, including areas close to Serbian borders (Boklund et al., 2020). However, the first ASF case in Serbia was detected in central Serbia, far away from the Romanian or Bulgarian border (Milićević et al., 2019).

Retrospective epidemiological investigations - including interviews with residents of affected holdings - indicated that official detection of ASF cases in 2019 did not reflect the actual time of virus introduction into Serbia. Timeline reconstruction suggested earlier virus entry in May, likely in the border municipality of Veliko Gradište, which lies on the Danube River, bordering Romania. The virus likely circulated undetected for several months and may have spread in multiple directions. Large rivers, like the Danube, do not serve as effective barriers to ASF spread; rather, they may facilitate it, especially through the movement of infected wild boar carcasses. The risk increases with improper disposal of domestic pig carcasses in the river. Water may even aid in viral persistence by shielding it from sunlight, UV radiation, and desiccation, while maintaining low temperatures (Carrau et al., 2023; Prodanov-Radulovic et al., 2023). Similarly, during the ASF outbreak in the Vršačke Planine hunting grounds of South Banat, a stream separating two areas was identified as the most likely route for ASFV transmission (Prodanov-Radulovic et al., 2023).

In 2020, ASF emerged in the Hrastovača hunting ground (Požarevac municipality) on the southern Danube bank. Shortly thereafter, the virus was detected on the northern bank in Deliblatska peščara (South Banat), suggesting that improper carcass disposal into the river may have facilitated ASFV transport via water to adjacent areas (Prodanov-Radulovic et al., 2023).

Human activity is now widely recognised as the primary contributor to ASF spread, followed by wild boar transmission (Glisic et al., 2023; Glišić et al., 2025; Polaček et al., 2021; Prodanov-Radulovic et al., 2022). This may explain why the initial ASF outbreak occurred in central Serbia, in domestic pigs, rather than near the borders or in wild boar populations. Hungary had constructed a double fence along its southern border with Serbia for migrant control, reducing the likelihood of ASF spreading through wild boar in that direction.

In contrast, Serbia's highway network appears to function as a physical barrier - or at least as a decelerating factor - in the spread of ASF, particularly among wild boars (Figure 10). Contrary to the findings of Glišić et al. (2025), our results suggest that fenced highways and railway corridors may effectively impede ASFV transmission by wild boars. The previous study likely assessed road proximity without differentiating between fenced and unfenced highways.

Serbia's major longitudinal highway, stretching from Horgoš (Hungary) to Preševo (North Macedonia), effectively divides the country along an east–west axis. The predominant direction of ASF spread follows a southeast-to-northwest pattern, with significantly fewer ASF cases reported west of this highway (Figure 10).

Though highways can present ASF risks due to discarded food waste, double-fencing and heavy traffic reduce wild boar movement. Unfenced roads near rest stops, scenic spots, and recreational areas may present a higher risk, particularly in locations where food is prepared or consumed. Improper waste management, especially when infected food waste is transported to unfenced landfills may further increase this risk.

Intensive hunting in Serbia's border regions with Bulgaria may have pushed wild boars across the border, contributing to the initial detection of ASF in wild boar in Bulgaria in 2020. This movement correlates with the emergence of new ASF cases in eastern Serbia during 2021 and 2022. In Pomoravlje District, no link was found between ASF spread in wild boars and domestic pigs; transmission was attributed to transport (Glisic et al., 2023). In 2021, Serbia confirmed its first ASF outbreak on a large commercial farm near the Bulgarian border, resulting in the culling of 18,000 pigs (Nešković et al., 2021).

In 2023, the number of ASF cases peaked, with domestic pig outbreaks exceeding wild boar cases. The virus advanced northwest, reaching Vojvodina, Serbia's most pig-dense region. That summer, ASF was detected on several large industrial farms in the Srem district (Stara Pazova, 21,000 pigs) and in

South Banat (Pančevo~14,000 pigs, Crepaja~10,000, and Straža, Vršac~7,000 heads). On all affected farms, the entire pig population was stamped out. Additionally, in same year, numerous smallholder farms were affected by ASFV nationwide.

In 2023–2024, outbreaks continued in Vojvodina's Srem, South Banat, and Central Banat districts. In 2025, the spread extended toward West Bačka, previously unaffected.

Unlike most of Europe, Serbia reported more ASF cases in domestic pigs than wild boars during the 2022–2024 period (Stahl et al., 2024; Stahl et al., 2025). The seasonal analysis showed that outbreaks in domestic pigs peaked in summer, while wild boar cases peaked in winter. Winter peaks likely relate to hunting season visibility, longer carcass persistence, reduced vegetation, and increased hunter activity. During summer, decreased hunting activity and quicker carcass decomposition hinder ASF detection, which is consistent with findings by Glišić et al. (2025). Seasonal wild boar activity may influence summer/autumn farm outbreaks. Wild boars reproduce in winter and farrow in spring, though milder winters have lessened this seasonality (Pascual-Rico et al., 2022). Human and wild boar activity increases during summer harvests, boosting spillover risk (Penrith et al., 2023). In Romania, 2022 ASF outbreaks on small farms peaked in summer and winter, while in other EU states, summer remained peak season (Stahl et al., 2024; Stahl et al., 2025). Similar seasonal patterns are observed globally, with summer/autumn peaks in Europe and Asia.

In many villages or municipalities, hunting grounds are managed by fee-based local hunting associations. In Serbia, only two large state-owned forestry enterprises, two hunting grounds are managed by the army, and national park areas may implement structured measures. (Prodanov-Radulovic et al., 2023). Since 2021, fenced hunting areas and grounds have experienced a complete loss of wild boars. Single perimeter fencing proved to be inadequate. These hunting grounds are all located in Vojvodina (Vršačke Planine, Dragićev Hat, Karađorđevo, Ristovača, Plavna, Kamarište, Karakuša, Morović, Bosutske šume, and Kučine). Between 2019–2025, ASF was confirmed in over 30% of hunting grounds in Serbia (Figure 10), a likely underestimate since urban zones are excluded.

As in some other European countries, it was established that the highest number of domestic pig cases occurred in summer, coinciding with peak insect activity (Olesen et al., 2020; Olesen et al., 2018a; Olesen et al., 2022; Olesen et al., 2018b). For example, in most villages in Vojvodina Province, smallholder farms are often located several tens of meters away from each other and mechanical transmission by insects such as houseflies is plausible (Vasic et al., 2024). However, the role of hematophagous insects outside Africa in summer is unclear and remains to be fully understood (Guinat et al., 2016).

It should be emphasised that studies on ASFV environmental persistence rely mainly on molecular detection of viral DNA, which does not confirm viral viability or infectivity (Bergmann et al., 2021; Carrau et al., 2023; Olesen et al., 2022; Vasic et al., 2024). Field experience in Serbia suggests that ASFV has limited environmental transmission under real-world conditions. Despite its high transmission potential, the virus spreads slowly. On some industrial farms, outbreaks took weeks to exceed the expected mortality rates. For instance, on one large farm in Zaječar, the High-Risk Period (HRP) ranged from 7–19 days (minimum) to 21–34 days (maximum), depending on the scenario (Nešković et al., 2021).

A significant increase in reported ASF cases in domestic pigs is also observed in the final months of the year (November and December). This may be attributed to the traditional home slaughter of pigs, which typically takes place during this time of year. Uncontrolled disposal of offal can certainly heighten the risk of ASF spreading. These activities typically involve relatives, neighbours or friends, groups of people who assist one another in the slaughter and processing of meat products, often using shared equipment and tools. Human population movement also increases during this time due to the celebration of Orthodox family patron saints' day (Slava), as well as Christmas and New Year holidays. During these family and religious holidays, pork products are frequently consumed or given as gifts, and kitchen waste, potentially ASF-contaminated, may end up in swill, even though swill feeding is legally prohibited in Serbia.

Certainly, municipalities that host both industrial and small-scale farms require heightened surveillance and rigorous enforcement of biosecurity measures. These two farm circuits are interconnected through shared transports, slaughterhouses and finally by personnel. The outlined potential transmission cycle allows infection to flow from wild boars to backyard pigs, and subsequently to industrial farms. Even small-scale or backyard ASF outbreaks can significantly impact the entire pig sector.

Overall, the measures implemented in Serbia between 2019 and 2025 appear to have been reactive rather than preventive. Although effective in the local control of infected premises, these measures had limited impact on controlling the spread of ASF on the national level and even less in preventing its transboundary dissemination. Future policies need to focus more on proactive strategies, early detection, and enhanced coordination with hunting associations, especially regarding carcass search and removal in affected ecosystems.

Above all, when it comes to the domestic pig production sector, it is necessary to legally define biosecurity measures in the future for each type of farm unit (e.g., backyards, small-scale family farms, intensive holdings). Moreover, it raises the important question of whether, and under what conditions, extensive production units should be allowed to participate in commercial or trade activities.

For a more comprehensive understanding of the dynamics of ASF spread in Serbia during the period 2019–2025, access to precise geolocations of each individual case, together with detailed data on the course and outcome of the disease, would have been highly valuable. In this study, however, the processed data were derived from the official records of the competent authorities, which identify only the settlement where an outbreak occurred. These records often encompass multiple cases within the same locality and lack information on the disease outcome, representing the main limitation of this study. Nevertheless, this limitation does not diminish the relevance of the findings or the validity of the conclusions drawn. Furthermore, the official data submitted by the Republic of Serbia to the ADIS system consist of aggregated annual figures on the number of outbreaks in domestic and wild boar populations. For future analyses, the consolidation of all available information at the level of individual cases, including the outcome of infection, would provide more accurate results and significantly improve the detection of spatiotemporal patterns in the spread of ASF in Serbia.

CONCLUSION

Since the summer of 2019, ASF has been reported annually in Serbia, affecting both the domestic and wild boar populations. It is important to emphasise that the virus predominantly circulates within the population of domestic pigs on rural backyards and small-scale family farms. However, at the beginning of 2021, virus transmission into industrial pig production was reported (Nešković et al., 2021), along with cases in fenced hunting grounds involved in wild boar breeding for commercial hunting purposes (Prodanov-Radulovic et al., 2022). Approximately 70,000 pigs have been culled on five industrial-type farms, four of which are located in the Vojvodina Province. In fenced hunting grounds, all located in the territory of Vojvodina, ASFV has completely devastated the wild boar population. Moreover, based on the established disease outbreak occurrence trends, it can be assumed that the disease has now become endemically present in the country. It can be concluded that its spread has followed a consistent southeast-to-northwest trajectory. In 2025, ASF reached its northernmost point in the country and expanded into the West Bačka District in the domestic pigs and wild boar population. The accuracy of the predictions made in this study is confirmed by the emergence of new ASF cases reported during the preparation of this conclusion in July 2025. Specifically, this month, the Veterinary Directorate reported ASF outbreaks in the Western Bačka District, in the villages of Bogojevo and Sonta. Additionally, the presence of ASF was confirmed in the wild boar population within the enclosed hunting ground Apatinski rit.

Given the current structure of the pig production sector, studying the livestock–wildlife interface and their interactions is highly complex and involves multiple factors to consider. Considering the heterogeneous epidemiological contexts and their potential impact on ASF seasonality, further research could help clarify the relative contributions of wild boar-to-farm/backyard and farm-to-farm transmission routes of ASFV, thereby informing targeted prevention and control strategies.

In Serbia, ASF appears to be spreading with partial autonomy from policy interventions. Control measures seem to have been largely reactive rather than preventive. The persistence of the virus in domestic and wild pig populations is most commonly sustained through various human activities, which may serve as the dominant link for virus transmission between these two populations.

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Author's Contribution:

VP conceived the study, developed the conceptual framework, and prepared the thematic maps. JPR contributed to the writing of the manuscript. MŽB and DL were involved in proofreading and final revisions. JP and MS participated in data preparation and analyses. DP translated the manuscript into English.

Competing interest

The authors declare no conflict of interest.

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Supplementary Data

The supplementary material (GIF file) associated with this article is available online at the following permanent link: **https://niv.ns.ac.rs/e-avm/index.php/e-avm/article/view/493/317**

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