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Use of Geographic Information Systems (GIS) in veterinary epidemiology: a case study

Diploma thesis

University of Veterinary Medicine Vienna

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Ethical Declaration:

I hereby declare that I have independently written the submitted work and have used no sources or aids other than those specified. All text passages taken from external sources have been clearly marked.

I have carried out the key work myself and have listed all those who contributed to the work with their input.

The work submitted has not been submitted or published elsewhere.

Neulengbach, the 20.02.2024 Marlene Maier

Abstract

This diploma thesis evaluates the utility of Geographic Information Systems (GIS) in veterinary epidemiology. After introducing the history and usages of GIS in veterinary science, this work specifically exemplifies the use of GIS to examine the spatial distribution of West Nile virus (WNV) in humans and equines in Austria, from 2011 to 2020, and climatic conditions associated with the disease occurrence. Findings reveal that current risk areas for WNV infections in Austria are primarily concentrated in the eastern regions of Austria, characterised by certain average climatic conditions facilitating the virus's spread. Additionally, projected climate scenarios suggest an expansion of these suitable conditions, potentially facilitating the spread of WNV to new areas in the future. The thesis advocates for the integration of GIS education into veterinary curricula to bolster computer-based competencies among students. This approach aims to better prepare future veterinarians for a digitally driven professional environment. It is suggested that enhancing GIS training can facilitate a deeper engagement with epidemiological research and improve the overall skill set of veterinary students, making them better equipped for all possible future carrier paths. This diploma thesis not only contributes to the understanding of WNV epidemiology in Austria but also highlights the critical role of GIS in disease surveillance and management.

Zusammenfassung

Diese Diplomarbeit bewertet den Nutzen von Geographischen Informationssystemen (GIS) in der veterinärmedizinischen Epidemiologie. Nach einer Einführung in die Geschichte und Anwendungsbereiche von GIS in der Veterinärwissenschaft, exemplifiziert diese Arbeit spezifisch den Einsatz von GIS zur Untersuchung der räumlichen Verteilung des West-Nil-Virus (WNV) bei Menschen und Equiden in Österreich, von 2011 bis 2020, sowie der mit dem Krankheitsauftreten assoziierten klimatischen Bedingungen. Die Ergebnisse zeigen, dass die aktuellen Risikogebiete für WNV-Infektionen in Österreich hauptsächlich in den östlichen Regionen Österreichs konzentriert sind, die durch bestimmte durchschnittliche klimatische Bedingungen gekennzeichnet sind, welche die Ausbreitung des Virus begünstigen. Darüber hinaus deuten projizierte Klimaszenarien auf eine Ausweitung dieser geeigneten Bedingungen hin, was potenziell die Ausbreitung des WNV in neue Gebiete in der Zukunft erleichtern könnte. Die Arbeit spricht sich für die Integration von GIS-Ausbildung in die veterinärmedizinischen Lehrpläne aus, um die computerbasierten Kompetenzen unter den Studierenden zu stärken. Dieser Ansatz zielt darauf ab, zukünftige Tierärzte besser auf ein digital getriebenes berufliches Umfeld vorzubereiten. Es wird vorgeschlagen, dass die Verbesserung der GIS-Ausbildung eine tiefere Auseinandersetzung mit epidemiologischer Forschung erleichtern und die Gesamtfähigkeiten von Veterinärmedizinstudierenden verbessern kann, wodurch sie besser für alle möglichen zukünftigen Karrierewege ausgestattet werden. Diese Diplomarbeit trägt nicht nur zum Verständnis der WNV-Epidemiologie in Österreich bei, sondern hebt auch die kritische Rolle von GIS in der Krankheitsüberwachung und -management hervor.

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List of abbreviation

Abbreviation	Definition
°C	Celsius degree
ADIS	Animal Disease Information System
AFP	Acute flaccid paralysis
AGES	Austrian Agency for Health and Food Safety
BCC-CSM1-1	Beijing Climate Center Climate System Model version 1.1
csv	Comma-separated values
CWD	Chronic wasting disease
ECDC	European Centre of Disease Prevention and Control
EFSA	European Food Safety Authority
EMPRES	Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases
ESRI	Environmental Systems Research Institute
FMD	Foot and mouth disease
GIS	Geographic Information Systems
GRASS	Geographic Resources Analysis Support System
HPAI	Highly pathogenic avian influenza
MCDA	Multi-criteria decision analysis
mm	Millimetre
QGIS	Quantum Geographic Information System
SAGA GIS	System for Automated Geoscientific Analyses
SD	Standard deviation
WAHIS	World Animal Health Information System
WNE	West Nile encephalitis
WNF	West Nile fever
WNND	West Nile neuroinvasive disease
WNV	West Nile virus
WOAH	World Organisation for Animal Health

1 Introduction

1.1 Brief history of Geographic Information Systems

A major cholera outbreak affected the district of Soho, London, in August 1854. Doctor John Snow (1813−1858), by meticulously mapping the locations of the cholera-related deaths and interviewing the households which recorded infections on their daily behaviours, noted that the majority of individuals affected by cholera had their nearest access to water from the Broad Street pump. He identified a clear geographical pattern, with a cluster around Broad Street, that led him to pinpoint the source of infection to one single water pump. Therefore, Snow was able to trace the source of the outbreak and successfully persuade public health authorities to take action, even in the absence of microbiological evidence (1,2). Snow's work on cholera played a pivotal role in epidemiology as it is considered as the first epidemiological analysis of a disease but also as the first spatial analysis of disease data.

In modern epidemiology, paper maps become less common due to the widespread use of digital technologies. Geographic Information systems (GIS) arose in the mid to late 20th century. Per definition, GIS is a computer program, which allows the user to capture, store, manipulate, analyse, display and report geographically referenced data (3,4). The period from the1960s to the 1980s was a pioneering era for GIS. During this time, advancements in computer technology, data storage, and data processing capabilities laid the foundation for the development and widespread adoption of GIS as a valuable tool in various fields, including epidemiology (5).

The 1980s marked a significant turning point for GIS as it transitioned from academic and research domains to the commercial market. Companies like the Environmental Systems Research Institute (ESRI) were founded during this period and became prominent vendors of GIS software. They played a crucial role in making GIS technology more accessible and usable from workstations and minicomputers (3).

With computer technology further advancing, the Internet getting accessible in the late 1990's and early 2000's, and the advent of user-friendly GIS software, GIS became increasingly accessible to a wider audience, including epidemiologists. There were an increasing number of GIS software options, providing mapping capabilities to users without the requirement of specialised software or advanced technical knowledge. This has made it significantly easier for everyone to visualise, analyse, and interpret data (6). The integration of remote sensing technology within GIS has also led to the development of specialised applications in fields like agriculture, urban planning, natural resource management, and disaster response. As the benefits of GIS became apparent, its adoption expanded beyond academic and research circles. GIS found its way into classrooms, businesses, and governments worldwide (3,5).

In the 2010s many open source GIS software products (i. e., software for which the original source code is made freely available and may be redistributed and modified) became available, which further facilitated the use of GIS for the broader public, e. g. Quantum Geographic Information System (QGIS) (7), Geographic Resources Analysis Support System (GRASS GIS) (8) and System for Automated Geoscientific Analyses (SAGA GIS) (9).

In this thesis, QGIS (7) will be used.

1.2 Use of GIS in veterinary epidemiology

Geographic Information Systems have played a crucial role in veterinary epidemiology, with diverse applications. For instance, GIS may enable the reporting of specific diseases by incorporating geolocation data and information about the disease and affected populations, providing valuable insights into disease patterns over space and time. For example, GIS can help analysing the spread of one (or several) infectious disease(s) within a region and identify high-risk areas, such as the case of bovine tuberculosis in England where a possible correlation between infected badgers and the occurrence of the disease in cattle was found (10). Therefore, a GIS can greatly enhance disease monitoring and support informed decision making, e. g., for targeted interventions and preventive measures, like the GIS-based Internet mapping surveillance tool for wildlife rabies in the United States (6,11).

A historical example is provided by the study by Yilma and Malone (12). They used GIS in 1998 to create a forecast and a risk assessment of fasciolosis in Ethiopia. They used agroecological zones along with their associated environmental characteristics (that influence the distribution and abundance of the disease and its snail intermediate hosts) to generate an annual and a monthly regional forecast of the risk associated with *Fasciola hepatica* and *Fasciola gigantica*. They demonstrated that the four climatic Ethiopian regions presented distinct risk and transmission patterns for *F. hepatica*. Furthermore, they were able to distinguish a seasonal pattern in the transmission of the parasite; they predicted a positive association between rainfall and the prevalence of cercariae-shedding, suggesting that increased rainfall may contribute to higher transmission rates.

Hässig et al. (13), in 2019, conducted a spatial analysis of the incidence of cattle diseases recorded in 2013 within the geographic area covered by the ambulatory clinic of the animal hospital in Zurich, Switzerland. All farms were geolocated and a map was created, displaying the topography of the region, water bodies, forests, main roads, altitude, and sun exposure. The occurrence of 14 diseases was analysed and the results indicated that most of the diseases were linked to animal density. Moreover, additional statistical analysis showed that parasitic diseases and traumatic reticuloperitonitis were more often associated with proximity to nearby forests whereas claw diseases were positively associated with the presence of nearby roads.

In order to improve disease control measures and develop a risk-based surveillance program for foot and mouth disease (FMD) in Thailand, Sangrat et al.(14) used a GIS-based multi-criteria decision analysis (MCDA). Potential spatial risk factors for FMD were identified (including livestock and human densities, distances to previous outbreak points, distance to livestock markets, slaughterhouses, and major road density) and incorporated into a GIS, leading to the successful development of a suitability map for FMD in Thailand.

Another practical application of GIS involves searching for disease clusters (or hot spots) and further analysing them for specific risk factors using different spatial statistics, as shown by the Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases (EMPRES) for highly pathogenic avian influenca (HPAI) H5N1 (15). This approach allows for identifying disease clusters and the factors that contribute to increased disease incidence in certain areas, enabling more targeted allocation of efforts and resources (4,6).

GIS has also proved a useful tool in more exotic fields of veterinary science, such as research on marine mammal diseases. Indeed, GIS can be used to monitor complex relationships between animal's environments and emerging diseases. Studying diseases of marine mammals presents significant challenges due to the inherent difficulties in obtaining samples and the limited understanding of stock and population boundaries (16,17). For example, GIS can be used to visualise and analyse dynamic disease events in marine mammals, such as morbillivirus infections in seals, by overlaying data on sea surface temperature data and harmful algal bloom events onto disease maps to identify potential associations between ecological and environmental factors influencing disease occurrence in marine mammals (17,18).

In the field of conservation medicine, GIS plays a crucial role in understanding the relationships between dynamics of wildlife populations and disease spread. It has helped identifying disease hot spots, assess habitat suitability, and analyse the spatial patterns of disease occurrence, as shown in the study conducted by Conner and Miller (2004) (19), which evaluated the spatial epidemiology of chronic wasting disease (CWD) in mule deer in north-central Colorado, USA. The authors demonstrated that CWD prevalence in mule deer varied from 5-18 %, with low winter exchange between populations and higher potential for exchange during summer (19).

Overall, GIS has demonstrated its versatility and usefulness across various domains of veterinary science. By leveraging GIS capabilities and integrating ecological, climatic, and epidemiological data, researchers and health officers can make informed decisions across various fields. This includes disease monitoring, prevention, and mitigation strategies as well as conservation strategies and wildlife health management. Moreover, GIS possesses the capability to render data in a more comprehensible manner by means of cartographic representation, as opposed to comparative tabular formats. This makes GIS a valuable tool for effective communication with stakeholders and the public.

1.3 GIS in veterinary education

While GIS is widely recognised as a valuable tool in veterinary epidemiology and other related fields, its integration into veterinary *curricula* can vary significantly as it is not seen as a core competence for veterinary education (20,21). For example, at Vetmeduni Vienna, classes in GIS are limited to the field of Conservation Medicine, with only a limited number of students having excess to GIS courses (https://online.vu-wien.ac.at/VUWonline/ee/ui/ca2/app/desktop/#/login).

Veterinary education typically focuses on clinical skills, diagnostics, and treatments, with less emphasis on data analysis and analytical tools. Unless students happen to come across GIS coincidentally, such as through elective courses or specialised programs, the majority of veterinary medicine students may not be exposed to GIS during their education. However, especially in the context of Conservation Medicine, teachers are getting more aware on the need for education in GIS (21). At Tufts University, a professor established a one semester long GIS course for the students of the master Conservation Medicine (22) and the University of Vienna offers a GIS course for biology students, focusing on nature conservation (23). Additionally, several GIS courses focusing on animal diseases are available online, generally organised by non-academic institutions (24–26). Competences in GIS may also be acquired through ongoing professional education, addressing specific career-stage needs. Such courses typically involve a fee (27–29).

1.4 Objectives of this work

The objective of this thesis is to provide a straightforward and accessible example of GIS application in veterinary epidemiology and showcase the value and benefits of GIS in veterinary education.

The thesis focuses on presenting a pedagogical case study on the epidemiology of West Nile virus (WNV) in Austria. This research was conducted as part of the "Wissenschaft in der Veterinaermedizin" lecture series, under the topic of "Use of Spatial Data in Animal Infectious Disease Epidemiology". For the practical exercise, I chose to work on WNV as it caught my interest as an emerging disease in Austria (2008 (30)) and because of its potential capacity for further spread due to climate change. The assignment included defining a research question and identifying relevant and available epidemiological and spatial data to answer it using GIS. Output of the exercise was a mini scientific paper.

2 Case study: distribution of human and equine cases of West Nile virus in Austria and link with bioclimatic variables

2.1 Background

West Nile virus is an arbovirus belonging to the genus Flavivirus that was first described in Uganda in 1937 in a human patient (31–33). The virus' transmission cycle runs between birds and ornithophilic mosquitos, primarily belonging to the genus *Culex* (34–37). However, the virus can infect a variety of other animal species, particularly mammals, including humans (38–40). Equids and human beings are incidental and dead-end hosts. Eighty percent of human infections are asymptomatic. The main clinical form presents influenza-like symptoms, however, human WNV disease also encompasses West Nile fever (WNF), West Nile encephalitis (WNE), or West Nile acute flaccid paralysis (AFP) (41). West Nile neuroinvasive disease (WNND) typically combines both encephalitis and paralysis. It occurs in one percent of WNV-infected human patients and can be fatal (38–40). West Nile virus can also induce disease in some bird species and horses (35,42). Not all WNV syndromes that are defined in humans are recognised in horses (43).

Monitoring of WNV in humans, equids, and birds is mandatory in the EU/EEA countries (44). Specifically, animal health authorities must report equine encephalomyelitis cases through the European Commission's Animal Disease Information System (ADIS) (45). Since 2017, the European Centre for Disease Prevention and Control (ECDC) has included equid related WNND infections in their weekly maps of human WNV infections in the EU (46). Additionally, WNF in animals is a disease listed in the World Organisation for Animal Health Terrestrial Animal Health Code and must be reported to the WOAH via the World Animal Health Information System (WAHIS) system (47) .

Since the first observation of WNV, infections have been documented across Africa and the middle East during the 1950s and 1960s (31–33). The first report of WNV in Europe dates back to 1958 when neutralising antibodies were detected in human sera in Albania (31,48). An outbreak of WNV occurred in France in 1962−1963, leading to WNND in horses (31,32). Other major outbreaks of WNV were observed in Romania and Russia from 1996 to 2000, where WNND was diagnosed for the first time in humans in Europe, causing 17 deaths in Romania and 40 deaths in Russia (31,32). From 2000 until today WNV was reported in several countries in southern-, central- and eastern Europe including Austria (31,32,42,49). In Austria, the disease was first described in birds of prey in 2008 (30). The virus was evidenced in human sera dated from 2009 and infection was first evidenced in horses in 2016 (42,50). Since 2008, surveillance programmes have been carried out in wild birds and, since 2011, also in horses. Moreover, a monitoring of some human vector-borne diseases, including WNV, in different mosquito species is conducted by the Austrian Agency for Health and Food Safety (AGES) (51).

Over the past decade, the epidemiology of WNV in humans, equids, and birds has changed in Europe, with an increasing incidence of WNF and WNND, even in more northern regions (52–55). Studies about WNV in Europe have shown that temperature and precipitation influence the distribution and abundance of the mosquito vectors and therefore, are key drivers of WNV transmission. Temperature anomalies, such as heat weaves might lead to WNV becoming endemic in new regions (32,56–59).

The objective of this research is to provide an overview of the climatic conditions in which WNV occurs in Austria. This analysis will consider specific bioclimatic variables, allowing us to identify potential future risk areas based on a selected future climatic scenario.

2.2 Materials and methods

2.2.1 Data sources and specific vocabulary

2.2.1.1. Case data

Data on the reported annual number of WNV cases in humans in Austria between 2011 and 2020 was retrieved from the annual reports published by the ECDC, which provides annual incidence data aggregated at level 3 of the nomenclature of territorial units for statistics (NUTS 3) (60–65) (the NUTS is a hierarchical system divided into three levels. NUTS 1: major socio-economic regions, NUTS 2: basic regions for the application of regional policies, NUTS 3: small regions for specific diagnoses that divide the territory of the European Union into hierarchical levels).

Data on the reported annual number of WNV cases in horses in Austria from 2011 to 2016 was retrieved from the public interface of the WOAH database (66), by filtering the database for the country "Austria", disease "West Nile virus", and animal species "Equids". The data was gathered using the previous iteration of the (OIE-)WAHIS platform (subsequently, the WAHIS interface underwent significant renovations). Based on the report data, each equine case was manually allocated to an Austrian NUTS 3 region. Data on WNV cases in equids from 2017 to 2020 was retrieved from the ECDC website, which provides both human and equine case data in the same format.

The annual number of reported WNV cases in humans and horses per NUTS 3 region was entered into a Microsoft Excel sheet, which was subsequently saved as a comma-separated values (.csv) file, compatible with QGIS (7). A csv file is a delimited text file that uses a comma to separate values. It stores tabular data (numbers and text) in plain text and may contain geographic information (e. g. geocoordinates). The case data does not include any geographic coordinates but the table includes locational information in the form of NUTS 3 names.

2.2.1.2. Administrative boundaries data

The shapefile containing regional boundaries at the NUTS 3 level for Europe was acquired from the Eurostat database (67).

The shapefile of the administrative borders of the Austrian country (AUTadm0) was retrieved from the Database of Global Administrative Areas (GADM) (68). A shapefile is a geospatial vector data format for storing geometric location and associated attribute information (69).

2.2.1.3. Historical and future bioclimatic data

Bioclimatic variables were retrieved from WorldClim database (70), which provides raster data in GeoTiff format. Raster data is a grid-based representation of spatial features, where each cell in the grid contains a numerical value representing attributes like elevation, temperature, or land cover (71).

Four historical bioclimatic variables were selected, based on i) a review of relevant literature regarding influencing factors for WNV distribution and ii) their ease of interpretation, ensuring that the results could be readily understood: annual mean temperature (BIO1), maximum temperature of the warmest month (BIO5), minimum temperature of the coldest month (BIO6), and annual precipitation (BIO12). They represent annual trends as well as extreme phenomenon's, over the period 1970–2000.

Furthermore, I used the same four variables projected under the future Beijing Climate Center Climate System Model (BCC-CSM1-1) and the Representative Concentration Pathway (RCP) scenario. The RPC 4.5 (72), which is described by the Intergovernmental Panel on Climate Change (IPCC) as a moderate scenario in which emissions peak around 2040 and then decline (73). The BCC-CSM1-1 model shows how these four variables will develop on average in 2041–2060. The variables were used in the 30 seconds resolution (70).

2.2.2 Processing of the data in QGIS

Each data mentioned above will be treated as a “layer” in QGIS. A map layer in a GIS contains geographic data in the form of groups of point, line, or area (polygon) features, representing a particular class or type of real-world entities such as, in our study, case data, NUTS 3 regions, Austrian border, and bioclimatic data.

The .csv file of the number of WNV cases in humans and horses in Austria, 2011−2020 as well as the polygons of the NUTS 3 European geospatial units were imported into QGIS v.3.4.15 (7) as a *“Delimited Text Layer”* and as a “*Vector Layer”*, respectively (Figure 1).

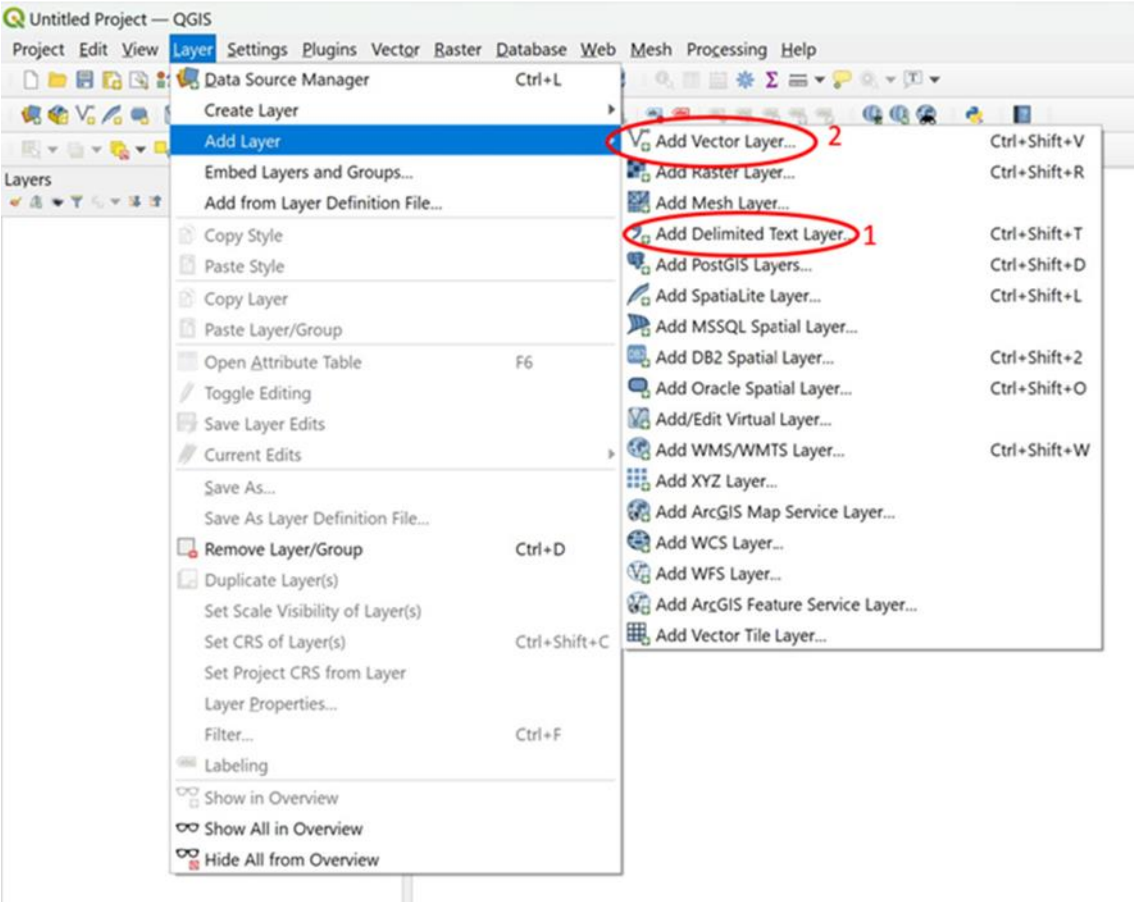

Figure 1. Functions used in QGIS to add 1. a Delimited Text Layer, 2. a Vector Layer.

The "*Query Builder"* tool in QGIS was used to filter for NUTS 3 regions of Austria (Figure 2), so that only Austrian NUTS 3 regions appear on the map. The .csv data points was joined to the NUTS 3 spatial layer using the function *"Joins"* and the target field NUTS 3 (Figure 3). The WNV cases could then be visualised on a map, aggregated at NUTS 3 level. The function "*Symbology"* and, within this function, the elements *"Categorise"* and *"Classify",* were then used to customise the visualisation of the WNV cases for each species per NUTS 3 geographical unit (i. e., humans *versus* equids), thereby displaying the total number of human or equid cases per NUTS 3 unit during 2011–2020 as a choropleth map (Figure 4).

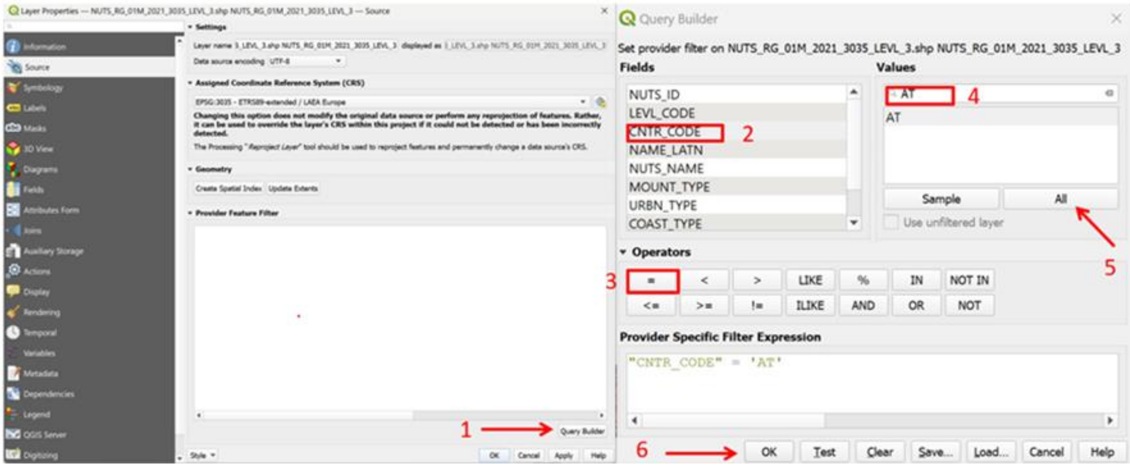

Figure 2. Query Builder and expression to display Austrian NUTS 3 regions only. 1. open Query Builder, 2. add expression "CNTR_CODE", 3. add equal sign, 4. search for AT (Austria) in the Values section, 5. add AT to the expression.

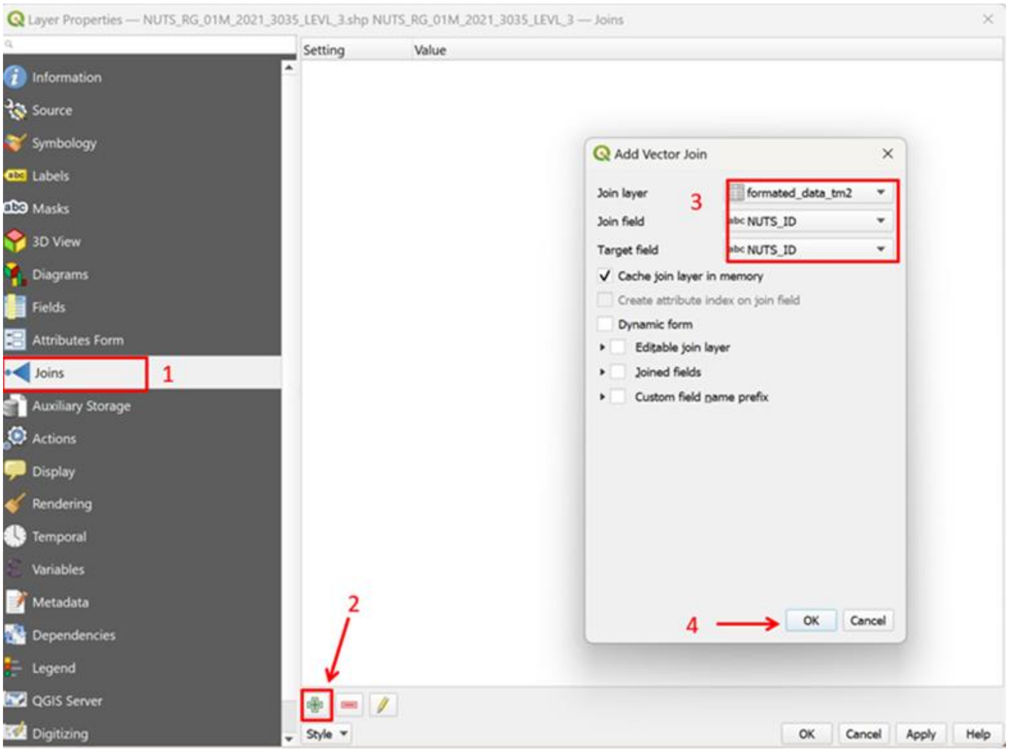

Figure 3. Menu to join .csv and Vector Layer. 1. Function "Join" to join case data and NUTS 3 Vector Layer, 2. click the green symbol "plus" to open "Add Vector Join" field, 3. set field to expressions displayed in the figure, step 4: click OK.

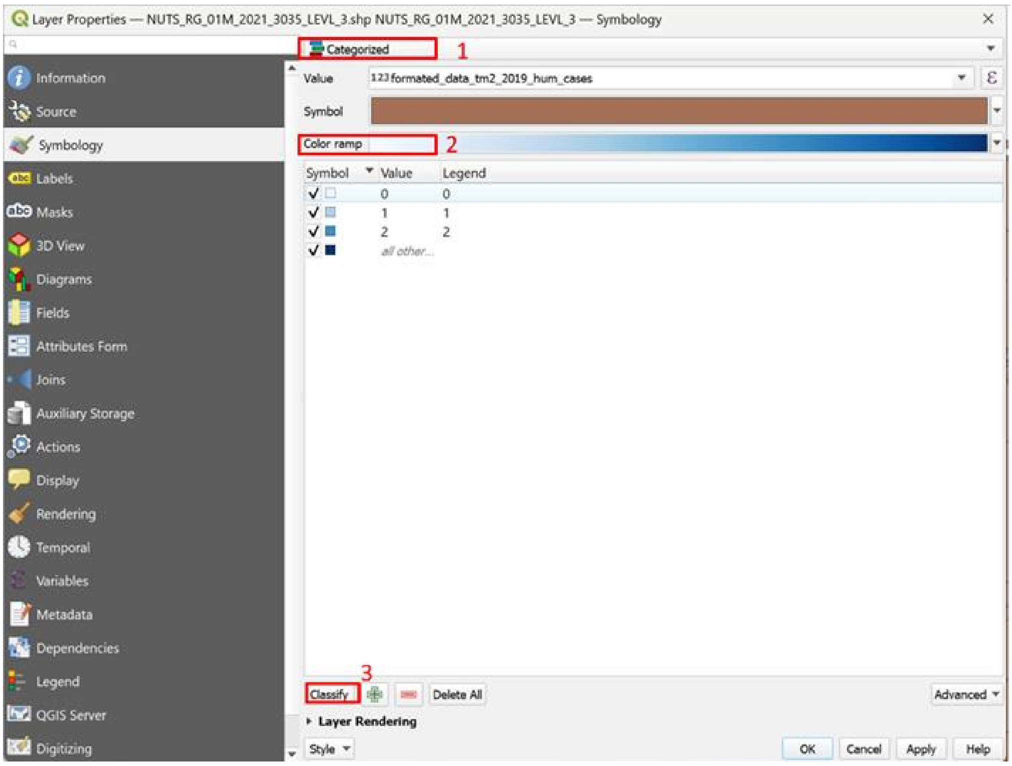

Figure 4. Menu "Symbology " for visualising cases in specific regions. 1. choose "Categorized", 2. choose the "color ramp" option, 3. click on "Classify".

The WorldClim raster layers were imported into QGIS (*Layer* → *Add Layer* → *Add Raster Layer*). The raster layer displayed worldwide data. It was therefore "clipped" to the Austrian border area using the corresponding shapefile (AUTadm0) (68) by using the function *"Clip Raster by Mask Layer"* from the menu *"Raster"* (Figure 5).

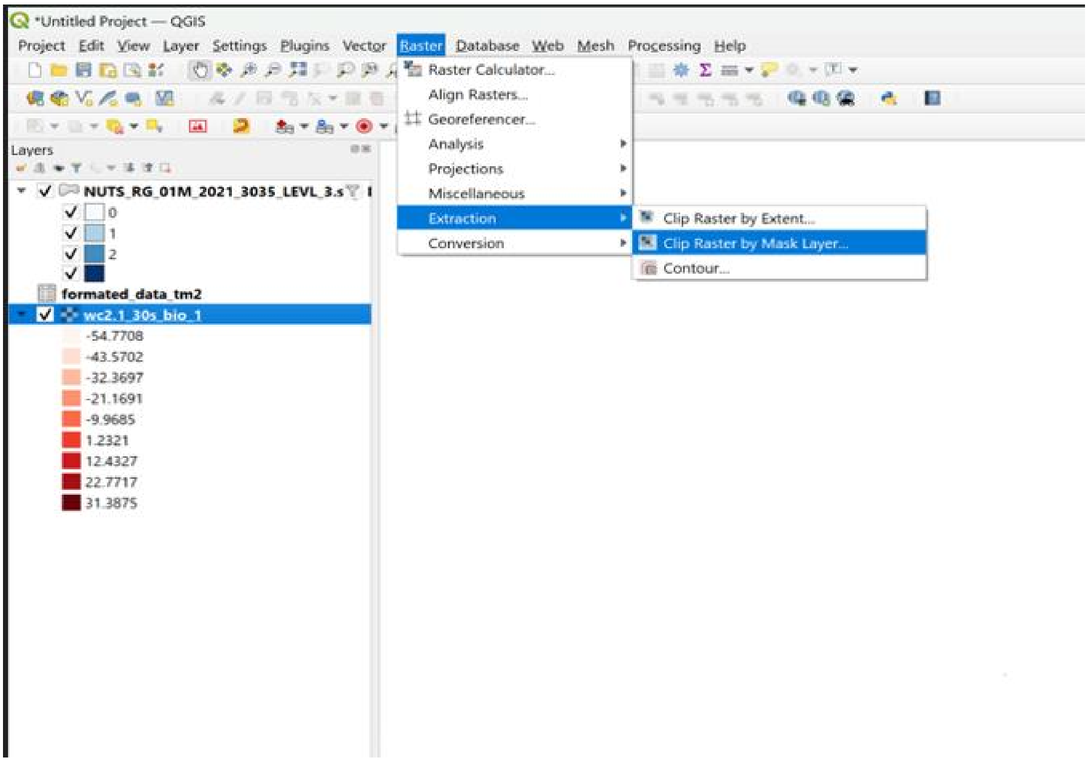

Figure 5. Function "Clip Raster by Mask Layer" to display a map of Austria as a Raster Layer.

To visualise and calculate *"Raster Layer statistics"* over the area where WNV occurs in horses and humans in Austria, I created a WNV-affected area, combining all NUTS 3 units in Austria where at least one case in human or equid was reported during the study period. To achieve this step, first, I used the "*Query Builder"* to select the NUTS 3 unit of interest (i. e., presenting at least one human and/or equid WNV). Then, I applied the function *"Dissolve"* (from the menu *"Vector"*) to the selected NUTS 3 units to obtain a "mask" that can be used to crop the bioclimatic raster layers (Figure 6). The same procedure was performed to obtain a mask of the WNV non-affected areas. I subsequently clipped the masks of the WNV-affected and WNV-non-affected areas to each historical

Bioclim raster using the function *"Clip Raster by Mask Layer"*. Furthermore, I used the function *"Raster Layer Statistics"* in the QGIS Toolbox (from the menu *"Processing"*) to compute the summary statistics (mean, standard deviation, minimum, and maximum) for each historical bioclimatic variable over the WNV affected and non-affected area (Figure 7). Colour scale for visualisation of the projected bioclimatic data was optimised to support the discussion on which Austrian areas might be favourable to WNV transmission in the future.

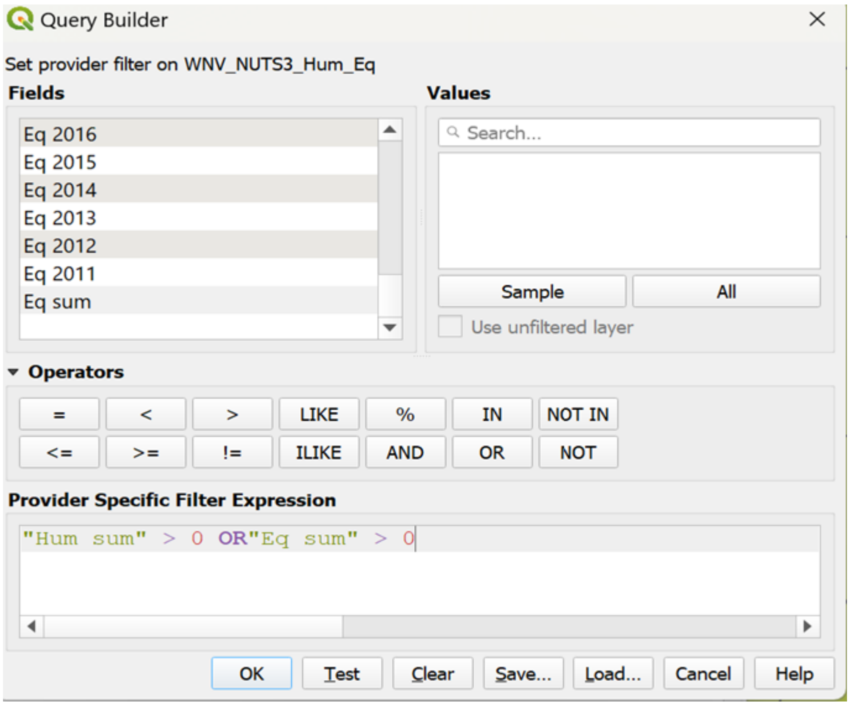

Figure 6. Query Builder Expression to display NUTS 3 regions with at least one WNV case.

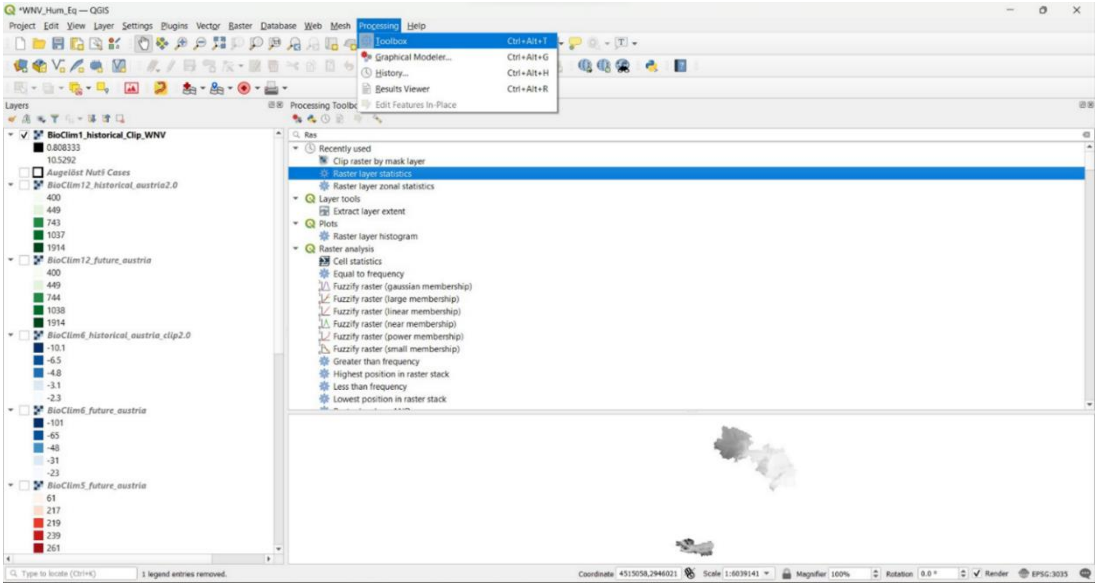

Figure 7. Function "Raster Layer statistics" in the section “Processing” and “Toolbox”.

2.3 Results

2.3.1 Incidence and geographic distribution of WNV in Austria

Over the study period 2011–2020, there were 38 cases of WNV infections reported in humans and 13 cases of WNND reported in horses in Austria.

In 2011, 2012, and 2013, there were no reported human WNV infections. During the study period, the first human cases were reported in 2014 (note that first human cases in Austria was reported in 2009 (50), which is not covered by this study). Subsequently, in the following years, the annual incidence of cases in humans remained relatively low, fluctuating between zero and five cases per year. The median annual number of human cases over the study period was two. However, in 2018, there was a notable surge, with a peak of 20 cases (Figure 8A). The majority of human infections (i. e. 35/38, 92.1 %) were concentrated in Vienna and its northern and southern surrounding NUTS 3 regions, known as Wien Umland/-Nordteil, Wien Umland/-Südteil. In addition, two more cases were reported in northern Burgenland (Nordburgenland) in 2018, which marks the year with the highest number of human cases. Furthermore, a single case was documented in the Waldviertel region, which is the northernmost region of Lower Austria (Figure 9).

The first reported WNV cases in equids in Austria occurred in 2016. The incidence of equids infections remained consistently low throughout the study period, ranging from two to four cases annually, with a median of one case per year. There were no significant peaks in infection observed (Figure 8B). Twelve out of the 13 cases (92.3 %) in equids were reported in Vienna and the northern and southern surrounding regions of Vienna. Additionally, one case occurred in 2019 in Klagenfurt-Villach, a region in Carinthia, southern Austria (Figure 10).

Overall, occurrences of WNV infections in both humans and horses were limited to six specific regions within Austria, all situated in the eastern and southern parts of the country.

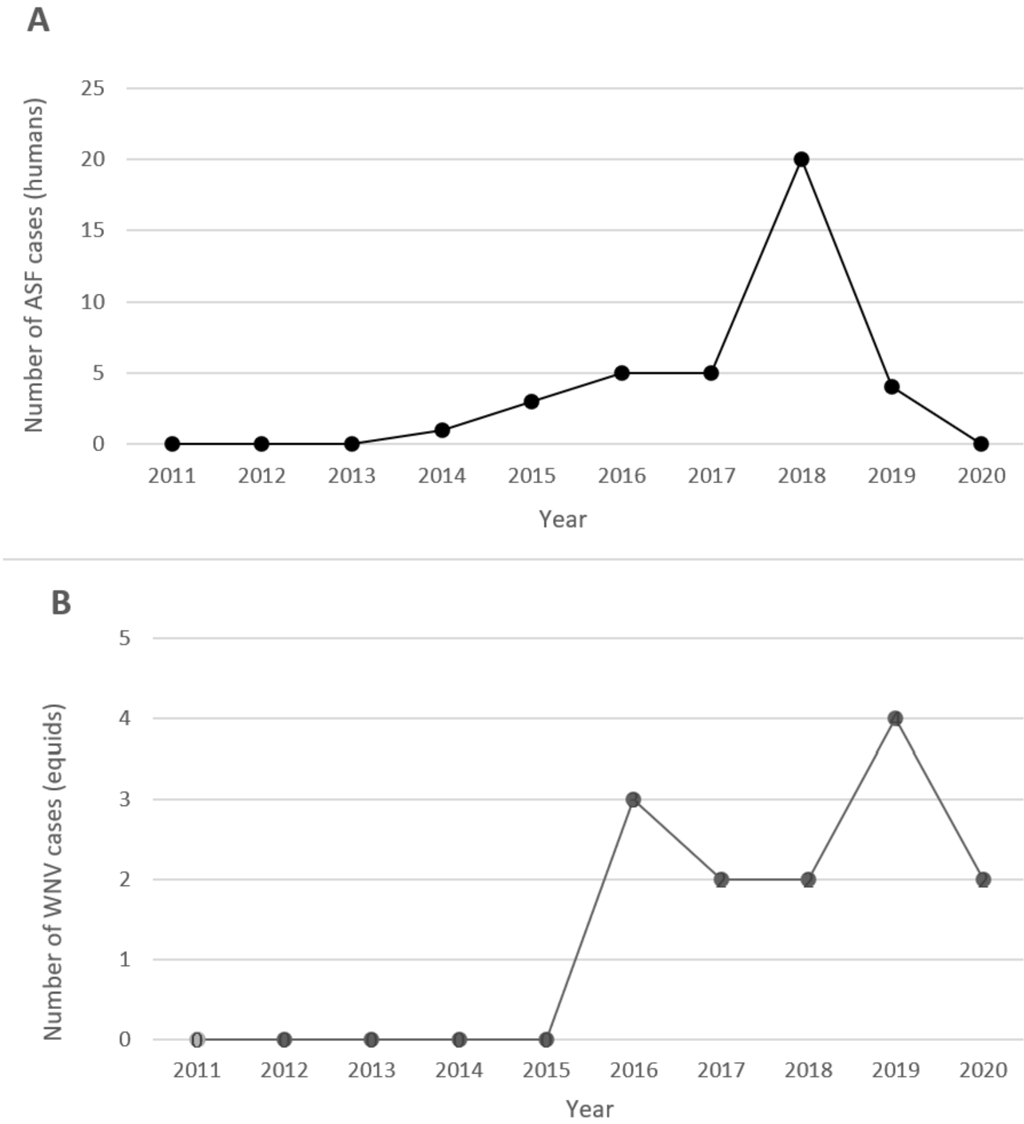

Figure 8. Yearly number of WNV cases reported in Austria, 2011–2020. A. in humans; B. in equids. Data: ECDC, WOAH.

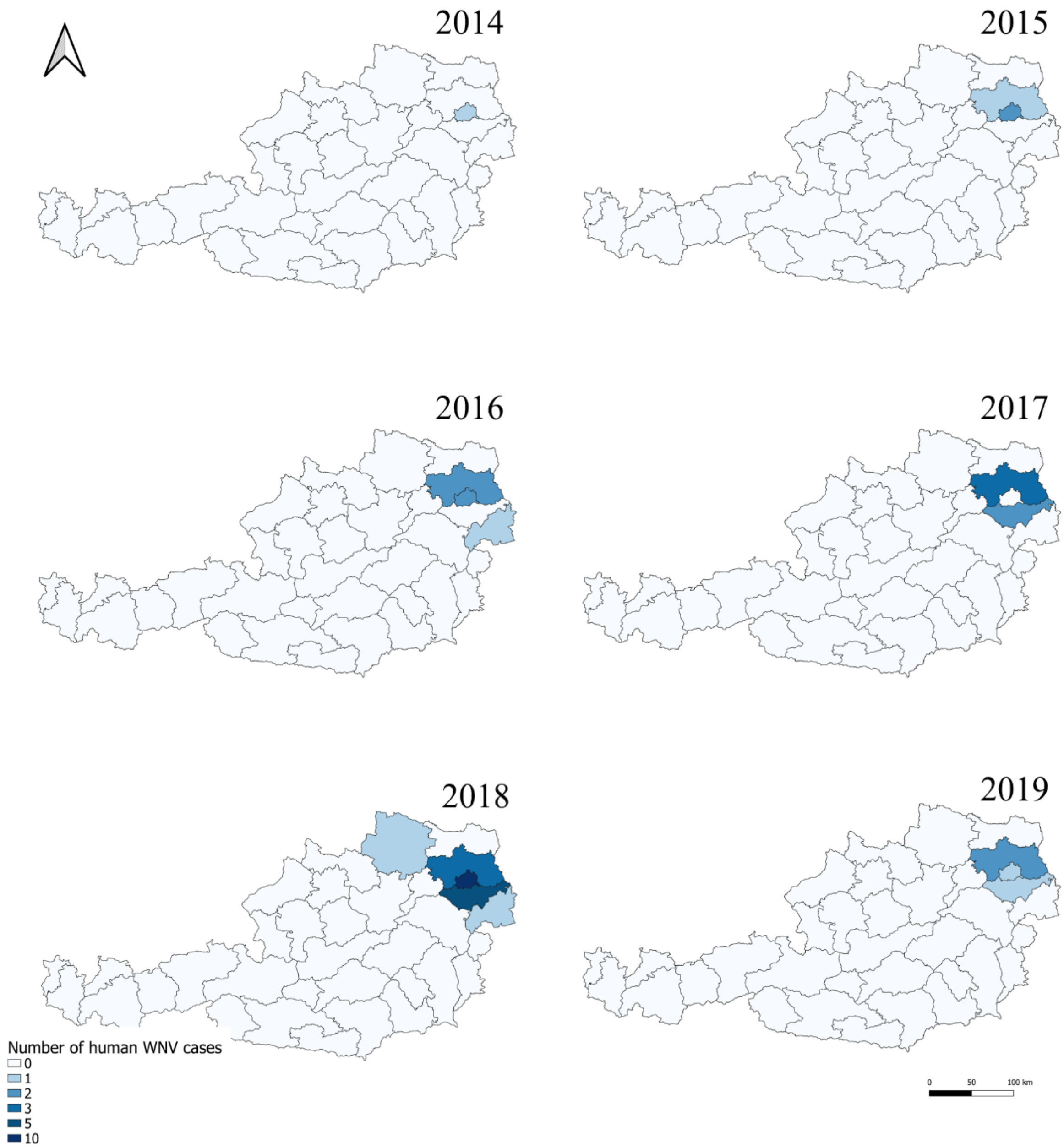

Figure 9. Annual incidence of human WNV cases per NUTS 3 area, Austria, 2011‒2020. Only years with number of cases > 0 are shown.

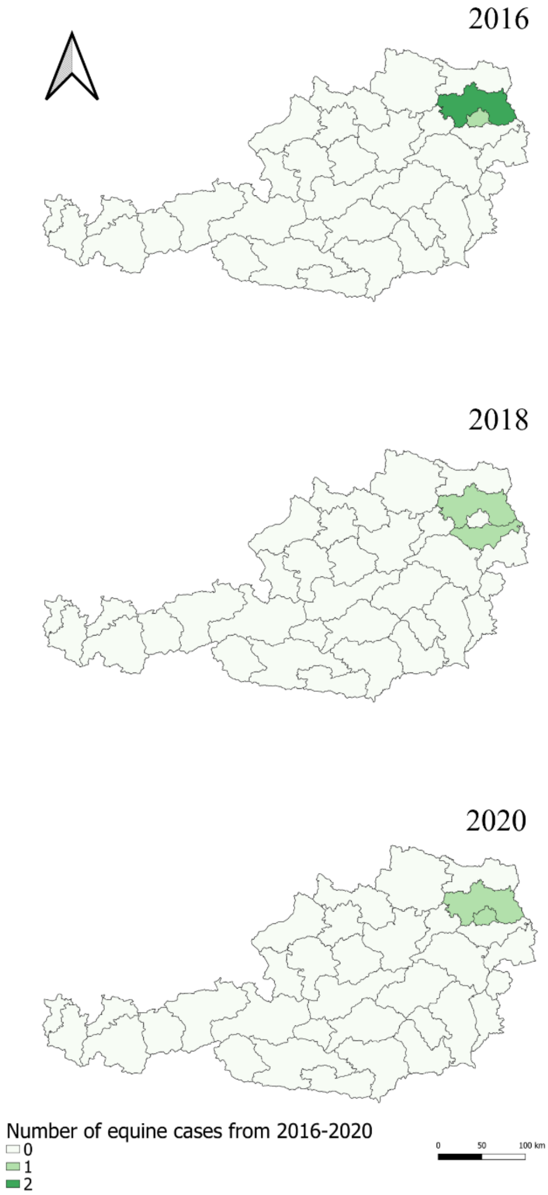

Figure 10. Annual incidence of equid WNVD cases per NUTS 3 area, Austria, 2011–2020. Only years with number of cases > 0 are shown.

2.3.2 West Nile virus and climate

Figure 11 illustrates the spatial extent of the WNV-affected and non-affected areas from 2011 to 2020, as computed in QGIS. The WNV-affected area was smaller (13050.11 km^2) than the non-WNV-affected area (70832.21 km^2). The affected area was composed of two regions, with a larger segment located in Lower Austria, Vienna, and the Burgenland while the smaller portion was located in Carinthia, where one case in was reported in a horse during the study period.

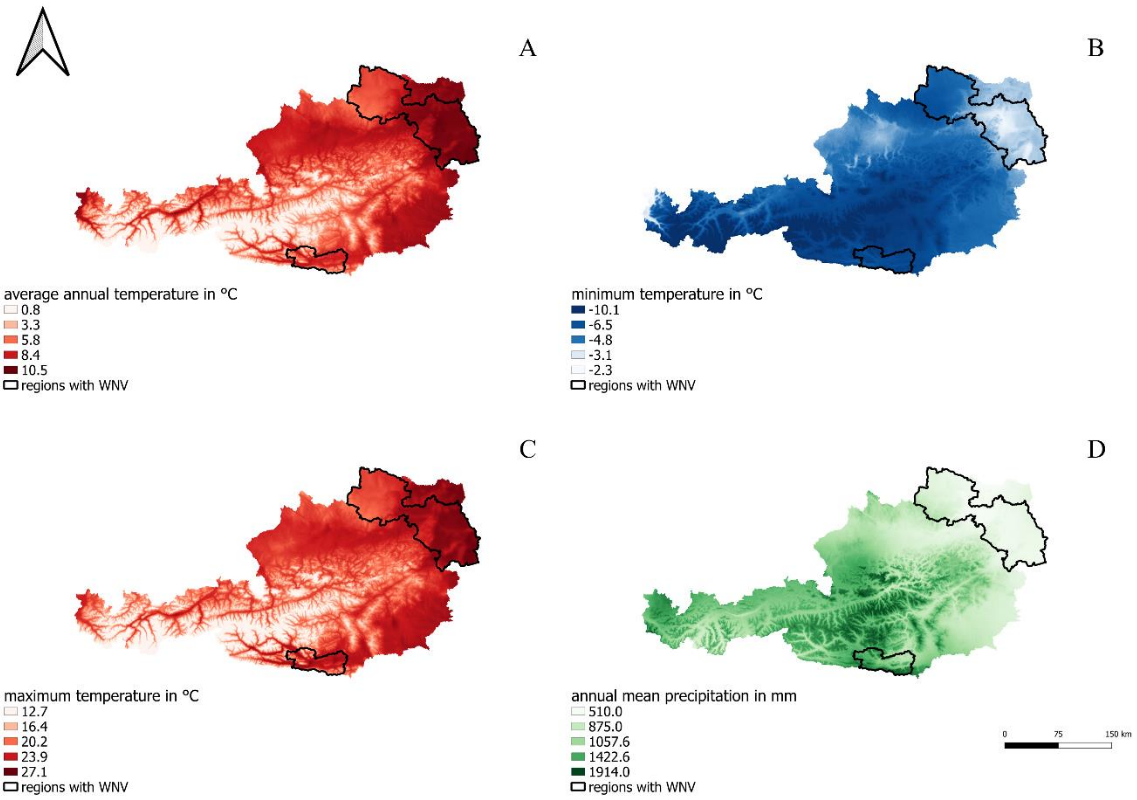

Figure 11. Historical bioclimatic data in Austria, 1970-2000 (data source: WorldClim (70)). A. Average annual temperature (BIO1); B. Maximum temperature of the warmest month (BIO5); C. Minimum temperature of the coldest month (BIO6); D. Annual mean precipitation (BIO12). The black contour shows the WNV affected area, 2011–2020.

Summary statistics computed in QGIS for each bioclimatic variable within the WNV-affected and non-affected areas are presented in Table 1 and Table 2, respectively. Within the WNV-affected area, a mean temperature (BIO1) of 8.3 °C was calculated, which is warmer than observed in the WNV-non affected area. Furthermore, the average maximum temperature of the hottest month (BIO5) was 23.9°C in the WNV-affected area, which is four Celsius degrees warmer than the average BIO5 in the non-affected area. The minimum temperature of the coldest month (BIO6) in the WNV-affected area was, in average, higher than in the non-affected area. Finally, the average annual precipitation (BIO12) was lower in the WNV-affected area compared to the non-affected one although minimum and maximum values did not show important difference.

Table 1. Summary statistics for the four historical bioclimatic variables in the WNV-affected area. BIO1: average annual temperature; BIO5: maximum temperature of the warmest month; BIO6: minimum temperature of the coldest month; BIO 12: annual mean precipitation.

Variable	Mean	SD[1]	Minimum	Maximum	Unit
BIO1	8.3	1.7	0.8	10.5	°C
BIO5	23.9	2.2	12.7	27.1	°C
BIO6	-4.8	1.7	-10.1	-2.3	°C
BIO12	743.5	294.2	510.0	1914.0	mm

[1] SD: Standard deviation.

Table 2. Summary statistics for the four historical bioclimatic variables in the area not affected by WNV. BIO1: average annual temperature; BIO5: maximum temperature of the warmest month; BIO6: minimum temperature of the coldest month; BIO 12: annual mean precipitation.

Variable	Mean	SD[1]	Minimum	Maximum	Unit
BIO1	5.8	3.2	-7.8	10.4	°C
BIO5	19.9	4.4	1.0	26.9	°C
BIO6	-6.7	2.3	-16.8	-0.4	°C
BIO12	1128.2	294.2	500.0	1974.0	mm

[1] SD: Standard deviation.

2.3.3 Future risk areas

Visualisation of the projected bioclimatic variables BIO1, BIO5, BOI6, and BIO12 under the BCC-CSM1-1 climate model and the scenario rcp 4.5 indicated that temperature will increase in several regions of Austria that are currently free of WNV. In contrast, in these regions, on average, the minimum temperature of the coldest month is expected to decrease, while the maximum temperature is projected to rise. Precipitation did not show a specific trend in this climate model compare to the historical data (Figure 12).

Table 3 Summary statistics for the four future bioclimatic variables in the area not affected by WNV. BIO1: average annual temperature; BIO5: maximum temperature of the warmest month; BIO6: minimum temperature of the coldest month; BIO 12: annual mean precipitation.

Variable	Mean	SD[1]	Minimum	Maximum	Unit
BIO1	7.4	3.2	-5.5	12.4	°C
BIO5	23.9	4.5	6.1	29.9	°C
BIO6	-6.1	2.2	-15.0	-1.6	°C
BIO12	1048.3	232.1	557.0	1972.0	mm

[1] SD: Standard deviation.

In this scenario, more areas in Upper Austria, southern Styria, and Carinthia may display climatic conditions supporting sustained WNV transmission. Indeed, projected climatic conditions for these areas (Table 3) closely resemble those of the current WNV-affected regions (Table 1) with regards to the mean temperature (BIO1), the average maximum temperature of the hottest month (BIO5) and the minimum temperature of the coldest month (BIO6) (Figure 12).

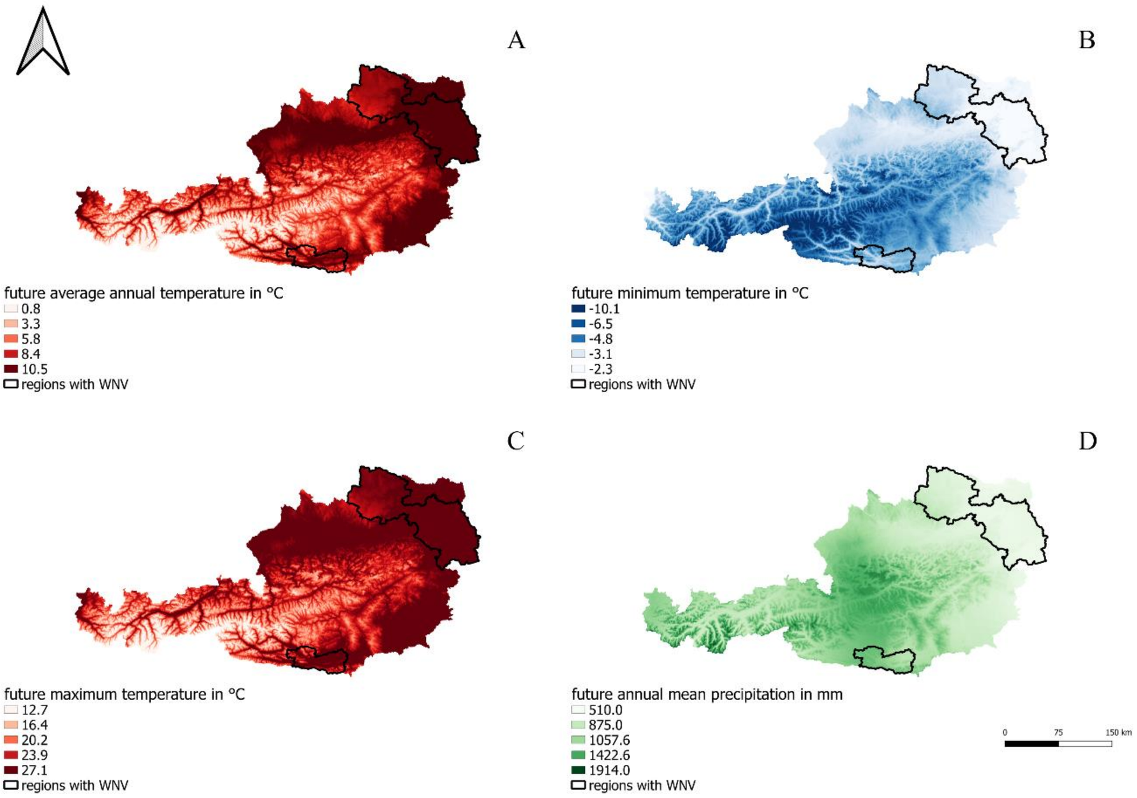

Figure 12. Projected bioclimatic data for Austria, 2041-2060 (data source: WorldClim). A. Annual mean temperature (BIO1). B. Maximum temperature of the warmest month (BIO5). C. Minimum temperature of the coldest month (BIO6). D. Annual mean precipitation (BIO12). For an easier comparison, colour scale is similar as Figure 12. The black contour shows the WNV affected area 2011–2020.

2.4 Discussion

Leveraging spatial data, including case data for both humans and animals, along with climatic data, within a GIS, this study describes the dynamics of WNV in Austria since 2011. It shows the relatively slow spread of the disease from the initially affected region and characterises climatic conditions associated to the disease occurrence. The findings of this research demonstrate that WNV infections in humans and horses are limited to six specific NUTS 3 regions within Austria, which share specific climatic conditions: Wien, Wien Umland/-Nordteil, Wien Umland/-Südteil, Nordburgenland, Waldviertel, Klagenfurt-Villach. However, findings also indicate the potential for WNV to expand further as a result of climate change.

Mapping of WNV cases in Austria, 2011–2020, evidenced hotspots of WNV infections in humans and horses in eastern Austria, which supports previously reported findings (34,74). The clustering of WNV cases in this particular region may be attributed to the proximity of the Equine University Clinic of the University of Veterinary Medicine Vienna, which increases the likelihood for rapid and accurate diagnoses for horses compared to areas lacking such facilities. However, this explanation does not address the higher incidence of human cases in this region.

The single case of an equid in Carinthia could potentially be linked to an import from Italy. Italy has a higher incidence of WNV cases compared to Austria (75), and given the proximity to the Italian border, it is plausible that this particular case may not be autochthonous (76). Similarly, one human case was reported from the northernmost part of Lower Austria (Waldviertel). This region exhibits distinct climate conditions compared to the other areas affected by WNV. It is therefore likely that the patient was not infected in this region.

The spatial analysis enabled characterising the climatic conditions associated with WNV occurrence in both humans and equids in Austria. Warm exhibit higher WNV incidence, that may be attributable to favourable conditions for the arthropod vector (37,57–59). Notably, the biotype *Culex pipiens*, recognised as the primary WNV vector in Europe (77,78), presents an increase in transmission rates from 0 % to 33 % within a temperature range of 18 °C to 28 °C (37,78,79). Therefore, average temperatures of 28 °C and presence of the arthropod vector are favourable for WNV to establish. However, a study in Germany, comparing the susceptibility of German *Cx. pipiens* for WNV to Serbian *Cx. pipiens,* showed that the vector was also able to transmit WNV at 18 °C (80). Similarly, between August and September 2020 nine human cases of WNF and WNND were reported in Leipzig, a city in central-eastern Germany with an average temperature of 18 °C in July (corresponding to the warmest month) (81,82). There is no difference in the vector competence to WNV of *Cx. pipiens* mosquitoes from the northern and southern part of Europe, highlighting therefore temperature as the key factor influencing mosquito distribution, and suggesting that the virus may become endemic in northern Europe in the future (79,78).

In 2020 a bird and two pools of *Culex* mosquitos tested positive for WNV in the Netherlands following a heatwave with an average temperature just below 20 °C, marking the emergence of WNV in the country (83). Such extreme weather event might account for the peak in human WNV infection in Austria in 2018. This year was presented as the one of hottest years since the beginning of the records, not only in Austria but across all Europe (32) where 2083 human cases of WNV were reported during the 2018 transmission season (84), representing a 7.2-fold increase in confirmed human cases compared to 2017 (32).

West Nile virus outbreaks in humans show a significant positive correlation with temperature, following a geographic latitude gradient (85), linkage between WNV incidence and precipitation proves to be more complex (56). Heavy rainfall can have dual effects on mosquito larval development: it can promote it by generating more standing water or inhibit it by diluting nutrients or flushing larval habitats (86–88). Conversely, drought conditions can also facilitate mosquito and virus proliferation by altering aquatic food webs and increasing bird-mosquito interactions (89).

Although the spatial distribution of WNV infections in humans and horses is currently limited in Austria, a comparison of climatic conditions in currently affected areas with projected conditions for 2041–2060 suggests a high probability for WNV to spread to new areas due to climate change. These results align with findings by Semenza et al. (2016), who predicted, using A1B scenario projection, an expansion of WNV in Austria by 2025 and further spread by 2050 (90).

This study presents some limitations. First, the modest sample size (49 cases in both human and horses) did not allow advanced statistical analyses (e. g. modelling of the ecological niche of the virus). Second, as for any infectious disease, the number of cases in humans and animals is probably underestimated due to the presence of asymptomatic cases and underreporting (91).

Geographic Information Systems have become as an essential tool in the investigation and prediction of the spread WNV disease, notably, playing a pivotal role in monitoring and analysing WNV spread across multiple countries. In West Azerbaijan, Iran GIS was used to map and analyse the distribution of WNV arthropod vectors along with environmental factor influencing it, in order to identify high-risk areas for transmission (92). In Greece a monitoring system for mapping WNV was implemented, utilizing wild bird serological surveillance data and environmental factors. The study found that low altitudes and proximity to water significantly predicted WNV outbreaks (93). Finally, a real-time web-based surveillance program was developed in Canada using GIS components to improve monitoring of dead birds (94).

Additional research is needed to further deepen our understanding of the complex and intricated factors that could contribute to creating favourable conditions for transmission during the favourable season and survival of the infected vector during less favourable periods. Consequently, other ecological and environmental factors may be considered, e. g. land use, demography, presence of open water bodies, migratory bird routes, urbanisation, and altitude (34,58,92,95–100). These factors may play a crucial role in the transmission circle of WNV in Austria.

With this study, I demonstrate how a straightforward application of GIS can be used to enhance our understanding of the spatial distribution and ecological risk factors of a zoonotic disease, WNV, in Austria. Notably, my study applies a One Health approach to address WNV epidemiology, in which GIS proves to be a highly valuable tool for visualising and analysing diverse data types and generating insightful outputs that can be harnessed for public health applications. Understanding spatial variations and the complex factors influencing the risk of WNV transmission enable the development of One Health surveillance for early warning (101). Another critical public health strategy for WNV prevention involves educating both the general public and specific groups at risk, such as older residents and furthermore horse owners in affected areas, about measures to control mosquito populations locally (102).

In conclusion, this research demonstrates that the risk of WNV infection in both humans and horses is unevenly distributed in Austria, suggesting potential implications for ongoing and future risk based One Health surveillance programmes, especially when considering emerging risk areas.

3 Perspective and conclusion

3.1 Learning experience through the pedagogical case study

With a basic skillset in the use of GIS, veterinary students, like me, can create a simple case study. Despite presenting some challenges, QGIS is a powerful tool to improve skills, as users benefit from a rich online documentation, technical guidelines, and community. It has also helped me to gain insight into some basic research work. Through this case study, I not only learned how to manipulate vector- and raster-data in GIS, but also learned how to find relevant publicly available data and developed a better understanding of scientific processes.

While creating the case study, I encountered several challenges. My first hurdle was locating the appropriate data sets, a task that proved frustrating due to my limited experience in data sourcing. Next, I had to familiarise myself with QGIS, a program I had not used before. Although adapting to the new software was time consuming, it eventually became more intuitive. Similar to acquiring clinical skills, mastering a new program requires patience and the ability to handle frustration, but the final result—especially with GIS offering a visual map—is rewarding.

Furthermore, engaging with GIS, provided me new insight into scientific methodologies. I developed a skill that was previously unfamiliar to me and delved deeper into epidemiology, an aspect of veterinary science with which I would have had little contact otherwise. It is important to point out that the case study presented in this thesis holds more pedagogical value than scientific significance. While it provides some insight into the situation of WNV in Austria, the limited number of cases and the absence of more advanced statical analysis represent clear limitations. Nevertheless, the study effectively visualises the cases and shows the connection between the climatic conditions and the virus. Therefore, it can serve as an educational resource for other students, offering an example of how GIS can be utilised in epidemiology and contributing to their understanding of WNV.

3.2 The value of making your own map

From ancient etchings on cave walls to intricate digital overlays on computer screens, the art of mapmaking has continuously evolved to become a cornerstone of navigation and spatial analysis. Maps are an essential part of our view on the world and a great necessity for further enhancing our ability to understand the dynamics of our environment. Learning to read a map is a vital part of children's school education however, making a map is not taught in primary education but still brings important skills to a student. GIS education is not just about learning to use software; it's about cultivating a deeper understanding of issues and fostering the ability to communicate and act on findings. It promotes spatial thinking, enhancing how students understand and interact with the world. Critical thinking is sharpened around data and methods, while project-based learning with GIS enables students to address real-world problems. GIS provides career-relevant skills and comprehensive content knowledge, empowering students to become proactive change agents in their communities and future workplaces (103).

3.3 Factors that hinder or support the adoption of GIS among pre-graduate veterinarians

Because there is limited education in GIS for veterinary students, they face challenges in adopting GIS. Although many online tools, tutorials, and classes to teach GIS skills exist, some may come at a cost students are unwilling to pay (26). However, there are multiple free online GIS courses that offer basic training in GIS (104–107). Therefore, there is a need for more basic information about GIS to ensure that students are aware of the existence of such courses and can access them.

Another obstacle that I personally experienced is the lack of general education in software skills among pre-graduate veterinarians. At Vetmeduni Vienna, aside from a single mandatory class teaching Excel for basic statistical analysis, no dedicated courses are offered for developing skills in computer technology. This gap in training often leaves veterinary students with reduced confidence in their technological abilities, creating a psychological barrier that hinders the adoption of tools like GIS.

On the other hand, veterinary students are educated in a diverse range of fields, cultivating a broad skillset in areas such as physics, chemistry, physiology, surgery, and more. This multifaceted education extends well beyond clinical skills and demands significant time, effort, and adaptability to various requirements. Consequently, it would be reasonable to assert that veterinary students are well-equipped to learn basic GIS skills. Incorporating this knowledge would not only enrich their existing competencies but would also bolster their qualifications as future veterinary researchers. In veterinary universities, there is a considerable emphasize on students' clinical skills, a reasonable approach as many students want to work as a veterinary practitioner after graduation. However, there are also several students who may pursue a research career or work in the field of public health and food safety, e. g. working in national health agencies like AGES. Therefore, offering a greater variety of courses, including a GIS course, would be beneficial.

In conclusion, there is a need for additional education for veterinary students at the Vetmeduni Vienna beyond clinical skills. My own experience as a veterinary student revealed a limited understanding not only of GIS but also of scientific research in general. While some teachers are educating students on scientific data sources and GIS, the availability of such education depends on the courses chosen by the students. To improve the curriculum, more non mandatory courses may be offered, focusing on scientific research methods while existing ones could be better advertised. This approach would allow students uninterested in scientific research to avoid unnecessary pressure, while those interested can easily access additional training within their university.

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