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Zoning approach to guide FMD in Tunisia

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Summary

The World Organization for Animal Health advocates the zoning approach for the surveillance and monitoring of foot and mouth disease (FMD), a highly contagious animal disease.

Our purpose is to implement the zoning approach in Tunisia by identifying existing natural and artificial obstacles to the movement of standing animals. A geographic Information System (GIS)-based MultiCriteria Evaluation approach was developed. Eight national and international experts were asked to identify the obstacles and prioritize them in order of importance, characterized by a percentage weight between 0 and 100. These obstacles were mapped and combined, taking into account their relative importance, to create a friction map that makes it possible to visualize areas where animal movements are restricted. Uncertainty analysis was performed to assess the robustness of the model.

The results showed that the selected obstacles were, in order of importance: maritime borders with a weight of 33.5%, rivers (13.8%), slopes equal to or greater than 10% (13.8%), wetlands (13.3%), forests (7.7%), land borders (7.7%), railway networks (5%) and main roads (4.9%). The Cap Bon zone is the only favorable zoning area for the control of FMD in Tunisia. A regional type approach resulting from this work could indeed be a major asset in identifying zonal regions in North Africa.

Keywords: zoning approach, foot and mouth disease, spatial model, multi-criteria evaluation approach, animal movements, North Africa.

Introduction

Foot and mouth disease (FMD) is a highly contagious viral disease caused by an Aphtovirus belonging to the family *Picornaviridae*. The disease that affects cloven-hoofed ungulates including small ruminants, cattle, pigs, and buffaloes. The economic impact of FMD is colossal. It generates direct and indirect losses in the countries concerned **(Knight-Jones & Rushton, 2013)**.

The absence of FMD outbreaks in Tunisia, Algeria, and Morocco between 1999 and 2014 encouraged the three countries to prepare an official control program to prove the absence of FMD, which was recognized and approved by the World Organization for Animal Health (OIE) in May 2012. This initiative was an important step toward recognition of the region's status of "Officially free of foot-and-mouth disease". In April 2014, Tunisia notified the OIE of its first detected case of the offending serotype "O" since 1999 **(Bouguedour & Ripani, 2016; Ripani et al., 2017)**. The disease spread rapidly within Tunisia. In response to this incursion, an emergency vaccination campaign was set up to limit the spread of the disease. In 2017, FMD hit Tunisia once again and the serotype "A", which had been absent for over 30 years, was identified **(Ripani et al., 2017; Sana et al., 2018)**. The outbreaks of FMD observed in 2014 and in 2017 in several regions mainly occurred in central and northern Tunisia (Figure 1) **(Sana et al., 2018)**. The introduction of FMD in Tunisia was due to animal movements across the border and within the country, particularly in regions that host a large number of animals **(Bouguedour & Ripani, 2016; Sana et al., 2018)**.

The OIE introduced the zoning approach in 1993 in the Terrestrial Animal Health Code to encourage countries to control and eradicate a disease on a regional scale and then to extend it throughout the country **(OIE, 2019b)**. The concept was first established for FMD and then extended to other diseases including the Peste des Petits Ruminants (PPR). The aim of this approach is to define animal sub-populations characterized by distinct health status within its territory and to prove its ability to maintain the free status of the sub-population concerned **(OIE, 2019b; Thiermann, 2008)**. Zoning or regionalization is mainly based on natural geographical features (rivers, mountains, etc.), infrastructure (roads, railways) or administrative zones where the health status of animal sub-population differs from the population in the rest of the country **(OIE, 2019b; Stone, 2017)**.

Zoning has not yet been tested or implemented in North Africa, but is already used in several member countries of OIE to control FMD. Eighteen member countries have one or more FMD-free zones, including 11 countries without vaccination and seven with vaccination **(OIE, 2019a)**. For example, in Zimbabwe, a country where the export of animals plays a significant role in the national economy, barbed wire fences have been installed to prevent the free movement of animals between zones with an adequate surveillance system, legislation and emergency response plan **(Derah & Mokopasetso, 2005)**. The implementation of this strategy is very costly and is not currently possible for Tunisia due to its socio-economic situation. On the other hand, the identification of natural and/or artificial barriers to animal movement could enable the establishment of zoning for FMD control at a lower cost.

The zoning approach described in this paper is different and innovative. Indeed, the geographic Information System (GIS)-based MultiCriteria Evaluation approach developed by Carver focuses on the cartographic integration of artificial and natural obstacles and on the knowledge of national and international experts **(Carver, 1991)**. A spatial model was created to identify the areas that fit the OIE definition and to propose a different approach to fight against FMD in Tunisia.

Materials and methods

Tunisia, like other North African countries, is crossed by the Atlas mountain range on a south-west to north-east axis. Tunisia is bordered by the Mediterranean to the north and east, by Libya to the south-east and by Algeria to the west. Tunisian topography is irregular, the northern and western region is mountainous, the eastern region is flat and the southern part is desert (Figure 1).

The GIS-based MultiCriteria Evaluation approach was developed in five steps:

1. Identification and mapping of natural or artificial obstacles to the movement of standing animals
2. Weighting obstacles
3. Combination in a friction map
4. Uncertainty analysis

Identification and mapping of natural or artificial obstacles

The first step was to identify the different types of obstacles that can be used to define an area within the country based on a literature review, the physical characteristics of the country and expert knowledge **(OIE, 2019b; Stone, 2017)**. Of the six experts we contacted, four responded to our request. The experts are veterinary inspectors, specialists in animal health, of "Greater Tunis", Cap Bon and the North of the country. A total of eight types of obstacles were identified (Figure 2).

Geographic data to map barriers were downloaded from online databases (Table 1). Using QGIS version 2.18.17 and R version 3.6.1 geo-processing and transformation were performed to extract elements of interest, i.e. natural and artificial obstacles **(QGIS Development Team, 2018; R Core Team, 2019)**. These pre-processing operations are detailed below:

<u>Main roads</u>

The hypothesis is that national roads and highways prevent the passage of animals because of their traffic **(Rico et al., 2007; Stone, 2017)**. The map of the main roads was downloaded from MapCruzin. National roads and highways were selected.

<u>Railway networks</u>

According to the opinion of national experts, animals do not cross railway tracks that are raised above the ground. The track map was downloaded from OpenStreetMap. This map was used as a reference as it is consistent with the map on the website of the Tunisian national railway company **(SNCFT, 2018)**.

<u>Forests</u>

According to Article 35 of the Forestry Code, grazing in forests is prohibited in Tunisia. Forests are protected by forest rangers and livestock found in the forest are confiscated and herdsmen have to pay a fine **(Ministère de l'agriculture, 2017)**. Forests thus form a real obstacle to the movement of animals in Tunisia. A raster of urban areas was used to construct the forest map, and forests were selected accordingly **(Schneider et al., 2009, 2010)**.

<u>Wetlands</u>

According to the opinion of national experts, animals cannot cross permanent lakes and rivers due to the depth and width of the water surface, and they were thus considered as natural obstacles. Wetlands (lakes) and permanent rivers were extracted from the water network map and downloaded from the Data-Interpolating Variational Analysis-geographic information system (DIVA-GIS) platform **(Bhandari, 1993)**.

Slopes equal to or greater than 10%

According to the opinion of national experts, animals do not cross a slope of 10% or more, thus representing a natural obstacle. To identify the obstacles in question, a Digital Terrain Model (DTM) was downloaded from The Shuttle Radar Topography Mission (SRTM) **(Farr et al., 2007)**. It consists of four tiles that were merged into a single elevation map from which a slope map was calculated. Areas with a slope value of 10% or more were selected.

Maritime borders

Tunisia is bordered to the north and east by the Mediterranean Sea. This natural geographical limit was extracted from a map of the world's coasts from Natural Earth.

Land borders

Tunisia is bordered to the west by Algeria and to the south-east by Libya. These borders were extracted from a vector containing the contours of the two countries from Natural Earth.

All these geographical layers were then transformed into raster format with a spatial resolution of 1 km * 1 km using R software **(R Core Team, 2019)**. Rasters were created to fit the same spatial coverage as the borders of Tunisia (Figures 2 & 3). Each pixel of the raster has a value of 0 or 1. The value 0 was assigned to cells with no obstacle and the value 1 to cells containing one or more obstacles.

Weighting of these obstacles

For this purpose, the opinion of eight experts was used; four national experts (the same experts mentioned above) and four international experts. A pairwise comparison matrix was created on an Excel file (Table 2) **(Saaty, 1987)**. It was completed in person and individually by each expert during a workshop entitled «Qualitative analysis and risk-mapping for optimizing FMD and prioritizing disease surveillance in the Maghreb and West and Central Africa" (April 2018, Montpellier, France).

First, for each pair of obstacles, the experts were asked to say which obstacle represented the best barrier to movements by standing animal movements. Secondly, to quantify the degree of importance using a five-level scale (Table 3).

The consistency of the matrix was calculated and judged. For example, stating that A > B > C, and C > A is inconsistent. The coherence ratio (CR) quantifies the deviation of the perfect coherence adjusted by the average deviation expected for a random matrix of the same size. Thus, a CR = 0 implies perfect coherence and a CR = 1 implies an inconsistency equivalent to a random choice of matrix values **(Saaty, 1987)**. Saaty (1987) argued that a CR of 10% or less is acceptable, while a CR greater than 10% merits a review of pairwise comparisons **(Saaty, 1987)**. Among the eight experts, two had a CR > 10%. A matrix correction was performed by the face-to-face expert to obtain a CR value below 10%.

For each expert, the weight of each obstacle category was calculated from the matrix of the pairwise comparison. The value of the weights was expressed as a percentage and classified from 0 to 100. The final weight used for each category of obstacles is the average of the calculated weights attributed by the experts.

The CR and obstacle weights attributed by the experts were calculated using the Analytic Hierarchy Process online software **(Goepel, 2018)**.

Combination in a friction card

A friction map, reflecting the hindrance of livestock movements, was obtained by calculating the weighted sum of the rasters for each obstacle. On this map, areas of high friction, representing a bigger obstacle to animal movement, have high pixel values, while areas where animals can move more freely have low pixel values.

The friction map was discussed with national experts which enabled identification of areas suitable for the zoning approach and meeting the OIE definition. The zones selected had to contain natural and/or artificial obstacles, lend themselves to the implementation of FMD control and surveillance measures during animal movements and must be adapted to the terrain while taking into account the socio-economic and epidemiological context of FMD in Tunisia.

Uncertainty analysis

Uncertainty analysis was used to assess the robustness of the model by estimating the divergence of expert opinions by calculating coefficients of variation (CV=standard deviation/mean). To calculate these variations, friction maps were generated from the weights given to the different types of obstacles by each of the experts, resulting in eight different friction maps (one map per expert). The standard deviation map was then created by calculating the standard deviation of the pixel values of the eight friction maps for each pixel. The uncertainty map was obtained by dividing the standard deviation map by the mean friction map. The smaller the coefficient of variation, the more the expert opinions converge.

Results

The expert opinions were mostly consensual. They followed the same pattern, although there was a certain natural variability in the allocation of weights to each type of obstacle, which was greater for factors with intermediate weight than for those with low weight (Figure 4). The results of the calculations of the weights assigned for each type of obstacle as well as the CR of judgments are listed in **Table 4**. Three groups of factors can be distinguished in order of importance. First, maritime borders are clearly the biggest obstacle with weight values ranging from 30 to 40%. The second group consists of rivers, slopes greater than 10% and wetlands with weights ranging from 10 to 20%. The third group consists of forests, land borders, main roads and railway networks with weight values < 10%.

Friction values ranged between 0 and 60 (Figure 5). They are represented by a color gradient from white (no obstacles at all) to dark red (many obstacles).

Consulting national experts led to the definition of three zones based on their socio-economic, climatic and epidemiological context. The characteristics of zones A, B and C are the following (Figure 5):

<u>Zone A:</u>

Zone A is Cap Bon, a peninsula enclosed by the Mediterranean Sea on three sides and by a highway, a national road and a railway on the fourth side. Based on the knowledge of national experts, animals enter the zone by land via secondary roads served by the national road.

<u>Zone B:</u>

Zone B is the Kerkennah archipelago bounded by the Mediterranean Sea. Animals enter this zone by ferry from the port of Sfax.

<u>Zone C:</u>

Zone C corresponds to the island of Djerba, bounded by the Mediterranean Sea. Animal movements into this zone are by land and sea. Access by the land route is via the Roman road that connects the island to the mainland through the city of Zarzis. Access by sea is by ferry from the port of Joref to the port on the island of Djerba l'Adjim.

Zones B and C could be part of zoning approach. However, they have an arid, Saharan climate with low irregular rainfall **(Béchir et al., 2011; Ministère de l'agriculture des ressources hydrauliques et de la pêche, 2019)**. Livestock raising is not widely practiced and is a secondary agricultural activity (Table 5), and fodder resources are limited. Livestock herdsmen have to travel long distances to graze their animals, especially small ruminants, in common grazing areas. Thus, for socio-economic and climatic reasons, these two zones were not selected as a first attempt to develop a zoning plan **(Najeh, 2018)**. The two zones could become part of a zoning approach if there is a shift to a value-added livestock system such as organic farming or livestock raised for export.

Zone A "Cap Bon" is a favorable zone, with good climate conditions, characterized by regular rainfall, and fertile soil. A rainwater supply system extends from the northwestern part of the country to this zone to enable agricultural development, in addition to the large number livestock already present in this zone (Table 5) **(Najeh, 2018)**. The area is host to 9% of the national cattle herd and 3% of small ruminants **(Onagri, 2017)**. Moreover, the peninsula is connected to the rest of the country by a national road, a railway and a 40 km highway, and could consequently be controlled.

Uncertainty analysis

The lower the coefficient of variation, the more the experts' opinions converge. Except for one side of zone A, the coefficient of variation observed within the boundaries of the three zones was less than 0.2. This low value indicates a consensus among the expert opinions (Figure 6).

Discussion

The data used in this work belong to the public domain. More precise and detailed information concerning the different layers would help identify other potential zones in Tunisia. This information includes in particular:

- Main roads: separating highways from main roads and the width of the roads i.e. the number of lanes.

- Railways: acquiring information on the type of railway tracks and how high they are in relation to the ground.

- The depth and width of rivers and the surface area of wetlands.

In this work, the advice of 14 experts was sought for the weighing of obstacles, however, only eight experts responded. The experts were selected for their local knowledge on animal mobility and the epidemiologyical context of animal diseases, particularly FMD. The experts are veterinary practitioners from the Tunis region, Cap Bon and Northern Tunisia, national and international epidemiologists (veterinary experts in animal epidemiology and mobility). The use of a larger number and more varied fields of expertise would reduce the risk of subjectivity due to their respective professional experiences and opinions **(Dufour et al., 2011)**. Although the number of experts was relatively small compared to the usual number (10 to 18), their responses did not diverge widely (Figure 4) **(Okoli & Pawlowski, 2004)**.

In addition to the limited number of experts, only one round of questionnaires was conducted whereas four rounds would have been better. In that case, in each round, the experts would receive a summary of the anonymous results of the previous round to enable them to review their opinions to finally reach a consensus between the opinions **(Crawford & Wright, 2016)**. However, the uncertainty analysis showed that the coefficient of variation in the three zones: A, B and C was less than 0.2, showing that the consensus of expert opinions concerning these three zones was good. The average experts' responses was very close to the median, which has been used in several studies **(Santos et al., 2017; Stevens et al., 2009)**.

Implementation of zoning approach in Zone A:

To meet the OIE recommendations, accompanying measures will be needed to insure the establishment and maintenance of the disease free status in Zone A **(Derah & Mokopasetso, 2005; Ferrari, 2016; Letshwenyo, 2018; OIE, 2019b)**:

- Strict control of incoming animals including:

- Inspection of national livestock identification (ear tags), circulation permits and an efficient animal traceability system.
- Monitoring through checkpoints at strategic points, for example at intersections between main and secondary roads.
- Clinical examinations of animals at checkpoints, and only animals certified free of disease and properly vaccinated allowed to enter the zone.
- Active surveillance for clinical signs of FMD.
- The establishment of a quarantine system for animals prior to entry into the zone.

- An appropriate vaccination program for the circulating (and/or threatening) virus, should be periodically evaluated through serological surveys to insure vaccinated animals have good immune coverage.

- Early detection and rapid intervention when a case of FMD is suspected as well as a clear case definition, well-defined procedures and a specifically equipped laboratory are essential.

- Periodic and continuous training and awareness raising activities for all actors in the zone and in neighboring areas. Regular targeted information for each type of actor concerning the activities carried out in Tunisia and international news on the disease will thus enhance to the involvement of the actors in the program.

- Awareness-raising among field agents, breeders, livestock dealers and traders on the importance of zoning.

- Legislation drawn up to prohibit movement in the event of FMD and make it compulsory to slaughter FMD-infected animals to reduce the risk of the disease spreading within the zone.

- The rules and compensation rates should be defined by involving farmers and professionals in the process in order to maintain the health status in the area.

The above measures related to the risks of the spread of FMD could be enhanced by taking into account the many surveys of animal mobility conducted since 2016, particularly those carried out by the National Center of Zoosanitary Vigilance (CNVZ) **(Sana et al., 2018)**.

Conclusions

In this study, one zone of geographical and economic interest (number of livestock and forage resources) was identified to define and preserve a potential animal sub-population with a distinct health status with regard to FMD in Tunisia. Once the disease has been eradicated from the zone and the absence of viral circulation confirmed by serological surveys, the zoning approach presented here could be implemented accompanied by the listed described above. This would enable Tunisia to become the first North African country to implement this concept.

As the North African region forms a single epidemiological entity, the eradication of FMD and other transboundary or endemic diseases requires a regional approach. The zoning approach explored in this work could be applied throughout the region in accordance with the OIE Terrestrial Code to fight against FMD in North Africa.

Countries wishing to implement the zoning approach would be required to comply with the conditions described in the OIE Terrestrial Animal Health Code. Zones would have to be defined by the veterinary administration. The country concerned would have to demonstrate that it has a reliable system of control, epidemiological and clinical surveillance and adequate biosecurity measures in place.

The two most important criteria that prove a State has control over zoning are animal identification and traceability, this entails reliable animal identification and the use of a permit to move animals between zones.

To prevent the introduction of the pathogenic agent into a free zone, official checkpoints would be required and an animal originating from an infected zone would only be allowed to enter the free zone after the appropriate controls established by the Veterinary Administration certifying the absence of infection have been carried out.

Once the concept of zoning has been mastered, the country would apply to the OIE for evaluation of the zone(s) concerned including a detailed description in accordance with the questionnaire provided in Chapter 1.6 of the OIE Terrestrial Code **(OIE, 2019b)**.

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"Posthumous tribute-This article is dedicated to the memory of our colleague and friend Ms Caroline Coste who left us far too early."

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Conflict of interest

None declared.

Ethics Statement

Ethical statement is not applicable to this study as the data were gathered through questionnaire survey without any animal experimentation.

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Table 1: Obstacles identified for the zoning approach, origin, and type of data

Obstacles		Origin	File type
Main roads (highways and national roads)		MapCruzin	Vector (polyline)
Railway networks		OpenStreetMap	Vector (polyline)
Forests		**(Schneider et al., 2009, 2010)**	Raster
Water networks	Rivers	**(Bhandari, 1993)**	Vector (polyline)
	Wetlands	**(Bhandari, 1993)**	Vector (polygon)
Slopes ≥ 10%		**(Farr et al., 2007)**	Raster
Maritime borders		Natural Earth	Vector (polyline)
Land borders		Natural Earth	Vector (polyline)

Table 2: Pairwise comparison matrix

Obstacles	Main roads	Railway networks	Forests	Rivers	Wetlands	Slopes ≥ 10%	Maritime borders	Land borders
Main roads	1							
Railway networks		1						
Forests			1					
Rivers				1				
Wetlands					1			
Slopes ≥10%						1		
Maritime borders							1	
Land borders								1

Table 3: Fundamental scale

Relative weight of the obstacles on an absolute scale	Definition
1	Equally important
2	One obstacle moderately more important than another
3	One obstacle much more important than another
4	One obstacle very much more important than another
5	Maximum weighting of one obstacle over another
1/2	One obstacle less important than another
1/3	One obstacle moderately less important
1/4	One obstacle much less important
1/5	Minimum weighting of one obstacle with

respect to another

Table 4: Weighting attributed to obstacles by the eight experts expressed as a percent

Expert n°	Main roads	Railway networks	Forests	Rivers	Wetlands	Slopes ≥ 10%	Maritime borders	Land borders	Coherence ratio
1.	3.9	3.2	9.1	11.8	17.8	10.2	39.1	4.9	8%
2.	3.3	3.4	6.8	9.8	13.8	15.9	39.5	7.5	6.8%
3.	3.9	3.5	15.4	9.7	7.4	26.3	23	10.8	6.5%
4.	3.8	3.8	7.8	20	8.6	8.5	36.8	10.7	8.3%
5.	9.4	5.4	5.6	13.6	8.8	19.8	31	6.4	5.6%
6.	5.5	4.2	5.6	19.2	24	10.2	26	5.3	6%
7.	3.4	4.3	8	16.3	9.4	10.7	39	8.9	8.3%
8.	6.5	12.4	3.7	10.3	17	8.6	34	7.5	8.7%
Mean	4.9	5	7.7	13.8	13.3	13.8	33.5	7.7	-
Standard deviation	2.1	3	3.5	4.1	5.8	6.4	6.3	2.2	-

Table 5: Livestock distribution in the three zones compared with national livestock statistics (Onagri, 2017)

	Cattle	Sheep	Goats
Zone A	58,500	210,000	35,000
Zone B	33	4,124	318
Zone C	640	13,938	5,401
National	646,076	6,406,070	1,184,620

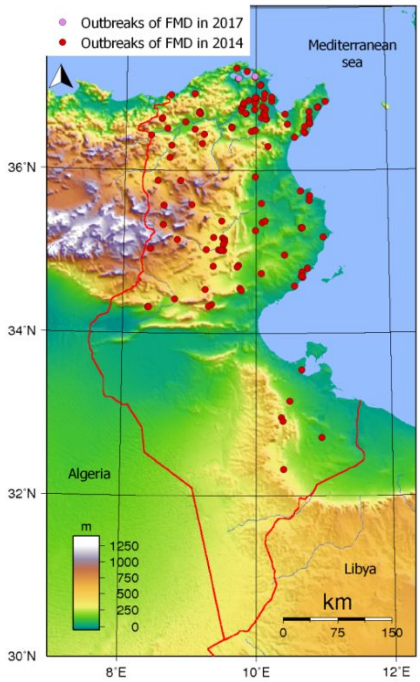

Figure 1 Tunisia topography and outbreaks of FMD in 2014 and 2017 (Source: www.cartograf.fr, outbreaks of FMD were retrieved from FAO's Global Animal Disease Information System (EMPRES-i))

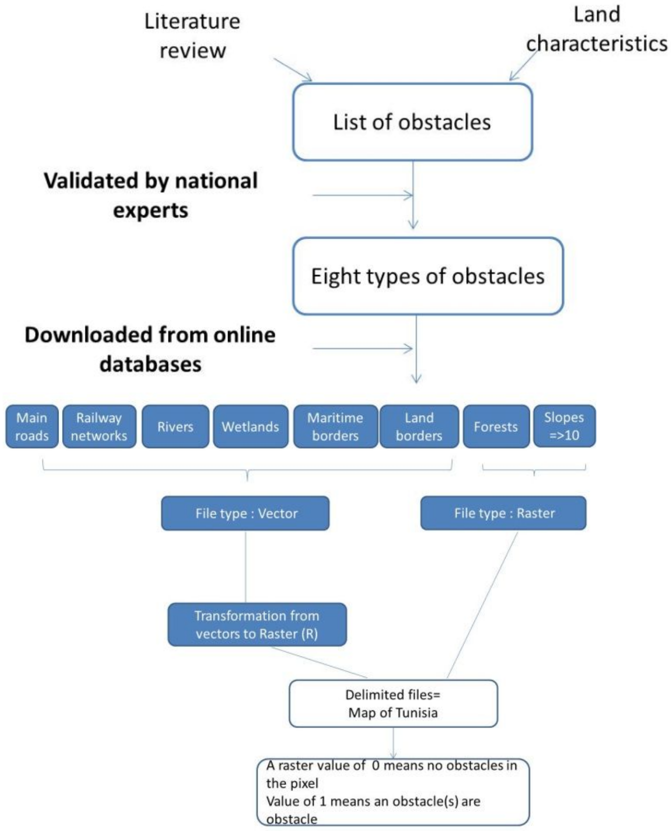

Figure 2: Obstacle mapping process applied to Tunisia

Figure 3: Rasters of identified obstacles

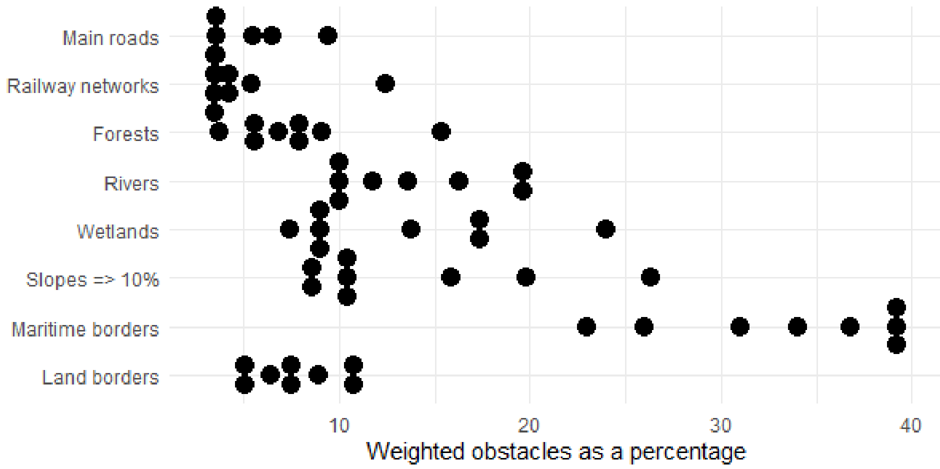

Figure 4: Opinion of Tunisian and international experts regarding obstacles

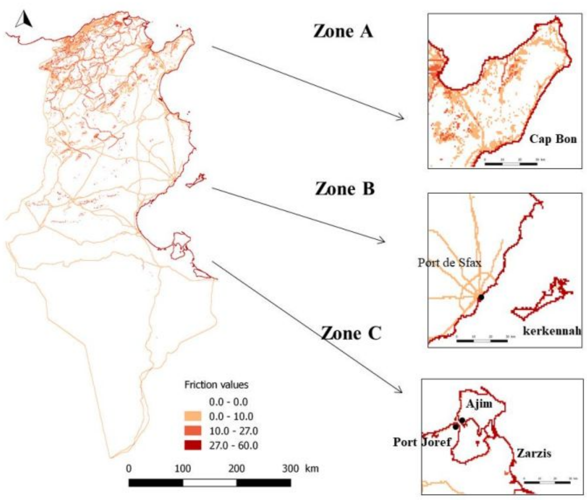

Figure 5: Friction map

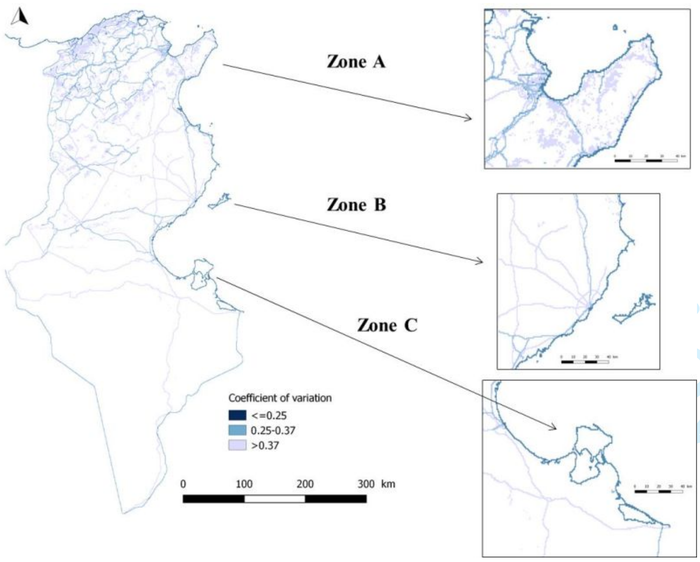

Figure 6: Uuncertainty map