Preliminary analysis of biotic and abiotic factors influencing the occurrence of West Nile virus infection in Tunisia

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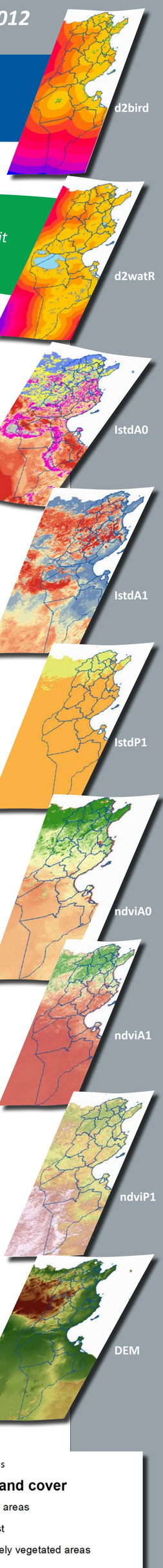


INTRODUCTION

West Nile virus (WNV) is a mosquito-transmitted *Flavivirus* belonging to the Japanese encephalitis antigenic complex of the Family *Flaviviridae*. WNV is transmitted primarily by the bite of infected mosquitoes that acquire the virus by feeding on viraemic birds. Birds represent the vertebrate amplifying hosts, responsible for the virus maintenance in the environment as well as migratory birds probably account for the virus dispersal (Calistri *et al.*, 2010). Humans, horses and other mammals are regarded as incidental or dead-end hosts.
In the last decades an increasing number of cases of West Nile infection in horses and humans have been notified in the Mediterranean basin (Calistri *et al.*, 2010). Remote sensing techniques have been widely used to study mosquito-borne diseases and their epidemiology, not only for assessing the geographical distribution, but also to predict the risk of introduction or occurrence at different spatial scales (de La Rocque *et al.*, 2007).
In autumn 1997 an epidemic outbreak of human meningoencephalitis due to WNV was observed in eastern coastal districts of Tunisia. A total of 173 cases were recorded with 8 deaths (Hachfi *et al.*, 2010). Between August and October 2003 a second cluster of infection was observed. Diagnosis of WNV infection was confirmed serologically in 36 of the 64 patients. No deaths were recorded in humans during this outbreak (Hachfi *et al.*, 2010). Following these two major epidemics, further studies were performed to detect the infection in other regions, in humans (Bahri *et al.*, 2011) and in equines (Ben Hassine *et al.*, 2011). Remotely sensed climatic and environmental variables together with migratory bird settlements and water bodies distribution have been analysed to investigate potential risk factor associated to the WND spread in Tunisia.

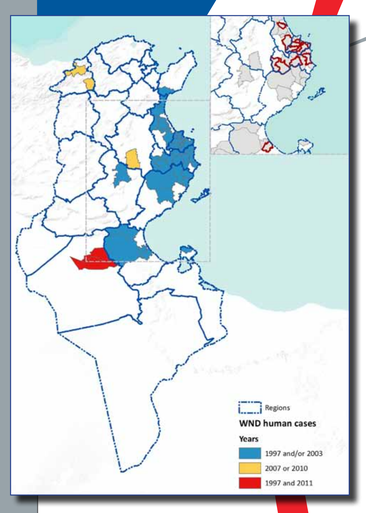


Figure 1.
WND human cases reported in Tunisia (left) and 'case' area highlighted in red (upper right)

MATERIALS AND METHODS

The number and geographical distribution of WNV human cases reported in Tunisia from 1997 to 2011 have been considered.
The provinces with more than 5 reported cases (to assure the consistency to human reported cases) and a surface less than 500 km^2 (to have the smallest area around the cases thus avoiding confounding effects due to larger areas) have been identified as pilot study area having the suitable conditions for WNV occurrence ('case' area).
The following climatic and environmental variables were considered:

- "d2bird"- Euclidean distance from migratory bird settlements (Orders *Charadriiformes* and *Passeriformes* from "Rapport de recensment des oiseaux d'eau en Tunisie – janvier 2008", Feltrup-Azafzaf *et al.*, 2009);
- "d2watR"- Euclidean distance from water bodies (perennial/non-perennial), marshes or other humid areas (20 Ramsar Sites of Tunisia, http://ramsar.wetlands.org);
- "lstdA0"- Daytime Land Surface Temperature: amplitude 0 of Fourier transformation is a measure of how much the phenomena vary, i.e. it is an overall average of the daytime temperature;
- "lstdA1"- Daytime Land Surface Temperature: amplitude 1 is a measure of the annual amount of variability of the temperature;
- "lstdP1"- Daytime Land Surface Temperature: phase 1 measures the timing of the annual seasonality in temperature pattern;
- "ndviA0"- Normalized Difference Vegetation Index: amplitude 0 of Fourier transformation, i.e. overall average of vegetation growth;
- "ndviA1"- Normalized Difference Vegetation Index: amplitude 1 is a measure of the annual amount of variability of vegetation growth;
- "ndviP1"- Normalized Difference Vegetation Index: phase 1 measures the timing of the annual seasonality in vegetation growth;
- "DEM"- Digital elevation model, Global 30-Arc-Second Elevation Data Set for the World.

Temporal Fourier analysis (Eastman et al., 2009) on MODIS NDVI (250m spatial resolution and 16 days of temporal resolution) and daytime LST (1km spatial resolution and 8 days of temporal resolution) was run to derive amplitudes and phases of vegetation and temperature.
The 6-years (2005-2010) data has been first submitted to a pre-processing phase of Missing Data Interpolation to remove pixel without data due to clouds or snow through IDRISI© Taiga software.
Mean, minimum and maximum values for each variable have been extracted for each province.
Minimum-maximum range recorded in the 'case' area has been used to characterize all the other provinces, assigning the value 1 when its values fell within that range. For each province the sum of all assigned values for all the variables has been calculated and mapped (Figure 3).
To better characterise the type of vegetation, the Global CORINE land cover map, derived from classification of satellite MERIS time series, has been considered, with a 300-m spatial resolution. The ESRI® Spatial analyst tool has been used to derive all the summary statistics.

RESULTS

Figure 1 shows the 47 provinces experiencing WNV human cases, 14 of which meet the criteria to be included in the 'case' area. Table 1 reports the summary statistics for each variable in the 'case' area.
The difference in the percentage of provinces having assigned values of 1 for each variable in two groups (provinces with WNV human infection not included in the 'case' area, n=33, and the provinces where WNV has never been reported, n=216) has been tested through a χ^2 test (Figure 2).
When the type of vegetation is considered, in the 'case' area the majority of the territory (56.4%) is classified as *sparsely vegetated*, followed by *mosaic cropland / natural vegetation* (16%), *bare areas* (15%) and *urban areas* (9%). When comparing the percentage of these class areas in the two groups (provinces with WNV human infection not included in the 'case' area and the provinces where WNV has never been reported), a statistical significant difference (Mann-Whitney test $p < 0.05$) was observed for *sparsely vegetation*, *bare areas* and *mosaic cropland / natural vegetation* (Figure 4).
In particular, *sparsely vegetation* and *bare areas* seems more associated to areas with an history of WNV human cases, whereas *mosaic cropland / natural vegetation* are more associated to provinces where WNV has never been reported (Figure 5).

Table 1. Characteristics of the study area (n=14 provinces)

VARIABLE	Measure unit	MEAN	STD	Minimum	Maximum
d2bird	meters	20967.68	10612.25	8242.19	46430.20
d2wateR	meters	8737.05	5550.77	0.00	22028.50
lstdA0	°C	30.04	1.31	25.88	31.01
lstdA1	°C	14.46	1.38	11.60	17.20
lstdP1	days	266.24	2.08	259.69	268.38
ndviA0		0.24	0.04	0.17	0.31
ndviA1		0.06	0.02	0.03	0.08
ndviP1	days	71.86	7.46	60.25	84.80
DEM	meters	53.71	34.13	6.00	103.00

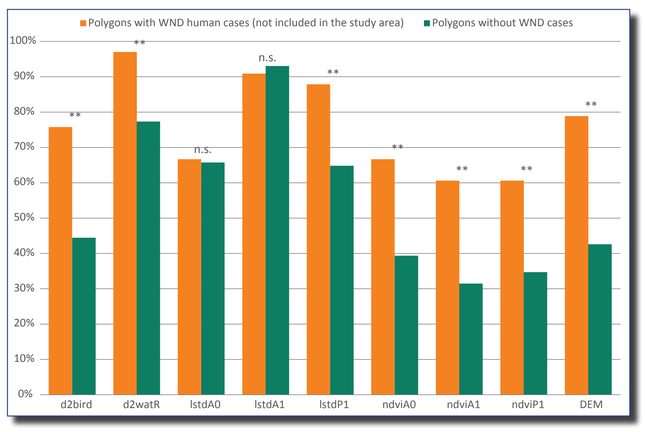


Figure 2.
Percentage of provinces having the mean value in the range of the 'case' area (values in table 1) for the 9 variables. In orange the provinces with WNV human infection outside the study area (n=33), in green the provinces where WNV has never been reported (n=216).
*** significant chi-square comparison ($p < 0.05$)*

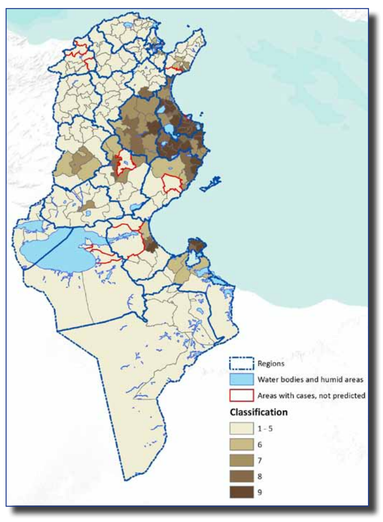


Figure 3.
Classification of Tunisia polygons according to environmental and climatic variables

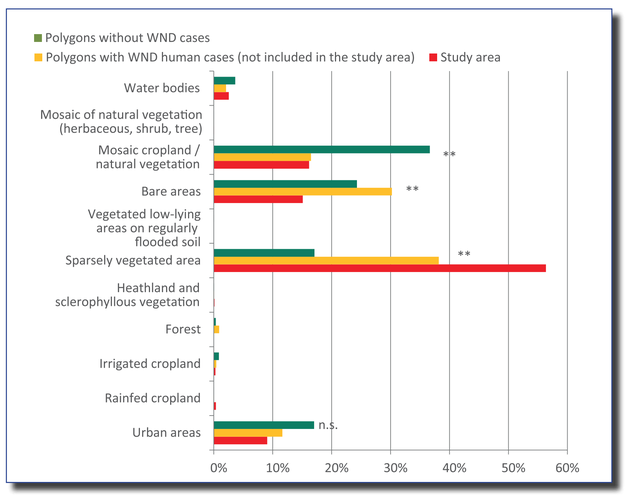


Figure 4.
Percentage of CORINE land cover classes in the study area (in red), the remaining provinces WNV human cases (in orange) and provinces where WNV has never been reported (in green).
*** significant Mann-Whitney test ($p < 0.05$)*

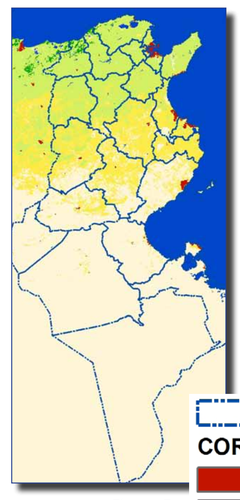
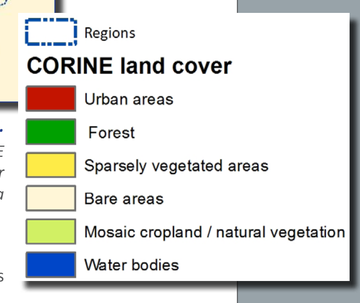


Figure 5.
CORINE land cover map for Tunisia



DISCUSSION

This first attempt to identify and classify the climatic and environmental variables associated with the occurrence of WNV human cases in Tunisia, indicates that a set of biotic and abiotic factors should be taken into consideration. Although further analyses should be performed to better evaluate the contribution of each variable, this preliminary analysis (Figure 2) identify the closeness to marshes ecosystem, where migratory bird populations are located, as an important risk factor for WNV infection.
On the contrary, the average temperature seems to be not significant in Tunisian epidemiological situation. This is reasonable in northern Africa, where temperatures can be suitable for mosquito survival and replication for the major part of the year. In relation to NDVI values, more complex considerations should be made. Although NDVI high values are used as predictors for WNV infection in USA (Ward, 2009), the type of vegetation involved may be different, characterizing environments extremely dissimilar for mosquito population suitability. The preliminary analysis of the type of vegetation between provinces with an history of WNV human cases and the others seems to indicate the presence of sparsely and bare vegetation areas mainly in the areas with WNV occurrence, whereas croplands are more present in non infected areas.
This is important for better interpreting the NDVI and the potential contribution of rainfall and other natural phenomena in the distribution of the disease.

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