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Classification of ponds from high-spatial resolution remote sensing: Application to Rift Valley Fever epidemics in Senegal

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Abstract

During the rainy season the abundance of mosquitoes over the Ferlo region (Senegal) is linked to dynamic, vegetation cover and turbidity of temporary and relatively small ponds. The latter create a variable environment where mosquitoes can thrive and thus contribute to diffusion and transmission of diseases such as the Rift Valley Fever (RVF, with *Aedes vexans arabiensis* and *Culex poicilipes* mosquitoes) in the Ferlo. The small size and complex distribution of ponds require the use of high-spatial resolution satellite images for adequate detection. Here the use of SPOT-5 images (10 m-resolution) allows for detailed assessment of spatio-temporal evolution of ponds, through two new indices: i.e., the Normalized Difference Pond Index (NDPI), and the Normalized Difference Turbidity Index (NDTI). Small ponds less than 0.5 ha dominate whatever the time period. For example they represent nearly 65% of the total ponds during the peak of the rainy season, up to 90% at the end of the same season. Moreover, another product is proposed: the Zone Potentially Occupied by Mosquitoes (ZPOM). During the apex of the summer monsoon, it is found that RVF mosquitoes occupy 25% of the Ferlo region, while only 0.9% of the same area is covered by ponds. Overlapping areas occupied by grazing cattle and mosquitoes, enhance RVF virus transmission. The remotely sensed operational indices and products presented here are meant to better understand the mechanisms at stake and to contribute to the development of early warning systems in a changing climate and environment.

Keywords: Remote sensing, Rift Valley Fever; Ponds; *Aedes*; *Culex*; Senegal

1. Introduction

Over East Africa, climate ensemble forecasting technique may provide early warning of malaria risks in prone regions (Thomson et al., 2006). In general, higher than average seasonal rainfall should lead to increased cases of malaria. Linkages between rainfall and Rift Valley Fever (RVF) epidemics have also been highlighted by Linthicum et al. (1999) using the Normalized Difference Vegetation Index (NDVI) as a proxy for rainfall (Anyamba & Tucker, 2005; Tucker & Nicholson, 1999). Anyamba et al. (2001) have also studied relationships between RVF occurrence, interannual variability of the warm phase of El Niño-Southern Oscillation (ENSO), and excess rainfall over Kenya.

In West Africa and over Senegal and southern Mauritania, RVF epidemics (Diallo et al., 2005), do not seem to follow the same relationships as over East Africa. The spatio-temporal distribution of discrete rainfall events (such as squall lines) during the rainy/summer monsoon season (contrary to the seasonal amount of total rainfall over East Africa) appears to be the confounding parameter for mosquitoes' production (see Ndione et al., 2003). This is particularly true for the *Aedes vexans* mosquitoes whose eggs are often laid along the edges of the ponds. When the time lags between two rainfall events is large (~10 to 15 days), the number of eggs present along the dried-up ponds' edges becomes quite important. Intense rainfall events (i.e., more than 20 mm, as produced by squall lines),

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become thus triggering and powerful mechanisms for enhanced hatching (see also Mondet et al., 2005a,b). Recently, modeling results by Porphyre et al. (2005) linking ponds' dynamics, discrete rainfall events, and mosquitoes' abundance involved with RVF, have been successfully implemented.

Moreover, the mosquitoes' abundance and species seem to be a function of vegetation cover and turbidity within ponds (Bâ et al., 2005; Chevalier et al., 2004, 2005; Mondet et al., 2005b). Shallow ponds are declared turbid when they may become muddy on occasions due to rainfall events and use by local cattle. These muddy conditions can be short-lived, but at times a pond will become so well-mixed that it will fail to clear and stay turbid. Turbidity is caused by particles (typically clay with suspended organic/non-organic elements, including algae). In our case, turbidity is also a function of intensive domestic use from nearby villages. Overall turbidity is a measure of suspended sediments. According to Mondet et al., *Aedes vexans* lay eggs on ponds' edges with or without vegetation. Moreover the adult *Aedes* may use vegetation within ponds as resting heavens (Chevalier et al., 2005). The latter conditions favor reproductive amplification and diffusion of the RVF. This is particularly true at the end of the rainy season (Bâ et al., 2005). Concerning turbidity, *Culex poicilipes* and *A. vexans*, both prefer an environment with clear and free waters, for laying eggs (Beaty & Marquardt, 1996; Bicout, 2001).

From the above, a new approach using high-spatial resolution images from space, for ponds' detection and classification is being proposed. The area under investigation is the Ferlo region (Senegal) centered over the populated village of Barkedji (15°16′46″N, 14°52′5″W, Fig. 1). It belongs to the Sahelian savannah ecological zone, where recent studies on the RVF have been conducted, (i.e., Chevalier et al., 2004; Mondet et al., 2005b; Ndione et al., 2003; Traoré-Lamizana et al., 2001, among others). The main and original result was that the spatio-temporal distribution of rainfall, ponds' dynamics with their vegetation cover and turbidity, are all closely linked with the production of mosquitoes associated with RVF.

Here the climate is typically Sahelian with a summer monsoon (the rainy season) from July to mid-October. During that period the region is also under the influence of maritime influence from the deflected trade-winds and water-vapor advection from the eastern Atlantic Ocean (Jarlan et al., 2005; Moron, 1994). Overall, the mean annual rainfall there is mainly provided by squall lines, and ranges from 300 mm to 500 mm (Nicholson, 1979). During the summer monsoon, a large quantity of small and temporary ponds are thus formed leading to an environment favoring mosquitoes' breeding and hatching, including *A. vexans arabiensis* and *C. poicilipes* associated with the RVF (Bâ et al., 2005; Fontenille et al., 1998). Contemporaneously, human and/or grazing livestock from the relatively lush area are exposed to several vector borne diseases such as RVF, Malaria, West Nile, and Japanese Encephalitis, among others. Thus seasonal ponds are seen as key places where cattle and vectors do meet, and as such become potent sources for epidemics. In the Ferlo region, ponds are widely distributed, some isolated, and others organized in clusters of all sizes. Different types of ponds exist with different level of vegetation cover inside and different degrees of turbidity. Vegetation cover includes embedded trees such as *Acacia sp.*, *Mytragena inermis*, *Diospyros mespiliformis* and *Balanites aegyptiaca*, annual herbaceous plants such as *Oryza barthii* (wild rice), *Cassia obsutifolia*, *Eragrostis tremula* and *Schoenefeldia gracilis,* and floating vegetation such as *Cenatotheca sesamoïdes* (water-lilies). In this study, seven ponds have been selected for their specific characteristics. Their selection depended also upon the availability of contingent in-situ multidisciplinary datasets: entomology, virology, hydrology, meteorology, land cover, among others. The seven ponds are: Barkedji, Furdu, Kangaledji, Loumbel Lana, Ngao, Niaka and Yaralope. Physical characteristics of these ponds are presented in Table 1, using ground survey by Ndione from CSE (this study) and Chevalier et al. (2004, 2005).

In this paper the blend of in-situ data and local observation with images and datasets obtained from remote sensing permit to produce detailed mapping of variable environmental

Fig. 1. Map of Senegal in West Africa from Atlas of Africa (Jaguar Edit.). The small red square outlines the studied area, covered with ponds, and within the Ferlo region.