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Salt distribution in the Senegal middle valley. Analysis of a saline structure on the future irrigation schemes from N'Galenka creek.

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Abstract

In the middle Senegal valley, the saline soil distribution is not related to the present faint topography. This lack of logic is one of the major constraints for establishment of new irrigated schemes. The salt distribution is here studied to better understand its variability, and to describe its structure and spatial arrangement. Saline areas are delineated by measuring the electromagnetic soil conductivity (ECm), a rapid technique with a portable instrument (EM38). The results indicate that the saline soils are distributed as stripes. A detailed examination revealed that this major stripe is actually composed of two parallel minor stripes, and the comparison with the aerial photograph shows that one lies in a former creek bed, and the other is fringing it on the southern bank. The stripe is intersected by an actual creek bed, indicating that the salt distribution is ancient, related to the former geomorphology, and does not result from a recent remobilisation of the marine salt deposits incorporated in the soil. The identification of this relationship between the present saline soil distribution and the former geomorphology allows us to survey the whole N'Galenka region (about 6000 ha) using the ECm measurements on selected transects.

Keywords: Salinity, Electromagnetic induction, Irrigation Schemes, Senegal.

Introduction

The Senegal river valley has been recently managed by the surrounding countries taking advantage of the construction of two major dams, “Diama” in the delta and “Manantali” upriver in Mali (OMVS, 1975). On the Senegalese side, the development of irrigation projects concerns about 240,000 ha. About 60,000 ha are today under full irrigation control. Most of the irrigation infrastructure was constructed by the donors as a response to the droughts of the 70s (Verheye, 1995). The ecological, economical and social changes induced by this new way of water management are studied in a common IRD/ISRA research program, which main objective is to define the conditions for the establishment of a sustainable irrigated agriculture in the Senegal valley.

A synthesis of the studies concerning the environmental side of the program is given by Boivin et al., (1995). The situation is mainly characterised by a lack of information prior to irrigation and absence of impact studies or keeps track of the environment.

The soil salinity is one of the major constraints for the development of irrigated agriculture. For example, in the Nianga irrigation scheme, which has been managed in 1974-1975, a large area has been deserted by the farmers due to excess of salinity. This is not due to a secondary salinisation but to the expression of the salt already present in the soil prior to the establishment of the rice culture. An inventory of the most suitable sites and particularly of the salt distribution, which is dangerously lacking, is a first prerequisite for a successful implementation of sustainable irrigated agriculture in these expensive infrastructures. Many irrigation schemes are today under construction along the creek N'Galenka, in the middle Senegal valley. This area has never been cultivated and the occurrence of saline soil can not be related to former land-use. Preliminary studies (Laval, 1996, Zanolin, 1997) have revealed that the salt distribution is not related with the present faint topography or geomorphological units. First, a saline area is here studied to better understand its variability, to describe its structure and spatial arrangement. Then the results are made profitable to attempt a regional survey of the saline soil distribution along the N'Galenka.

Site

The N'Galenka creek is located in the region of Podor (Northern Senegal) from 16°26 to 16°30 N and from 14°50 to 15°05 W (Fig. 1). The climate is of the semiarid type, characterised by a wet season (approximately 200-mm of rainfall) from July to September, a cold dry season from October to February and a hot dry season from March to June. Dry and warm winds increase evaporative demands and create a disequilibrium in the plant water balance. Average Class A pan evaporation exceeds average rainfall in each month and by over 2000 mm annually.

The Senegal valley was submitted to a recent transgression, called Nouakchottian (or Duinkerke) transgression, which started about 4300 B.P. (Faure et al., 1980) up to Boghé, today located 380 km inland. According to Michel (1973), this transgression is responsible for salt incorporation (neutral chemical facies) in the sediments into which the soil sequences were formed (Maynard and Combeau, 1960). The soils have developed after the post-Nouakchottian (or Taffolian) regression, which was accompanied by a mangrove vegetation, in the roots of which, considerable amounts of pyrite were formed by sulphur fixing bacteria. The salts and the acidity have subsequently been evacuated in part by the river swelling, but traces of salinity are still observed up to 300 km inland. The saline soils are mainly characterised by high variability in the chemical facies of the salinity at small distance. It can be of sodium/chloride, sodium/sulfate, magnesium/sulfate or calcium/sulfate type (Barbiéro et al., 1998).

Two major geomorphological units are distinguished in this region: depression and former river banks (FAO-Sedagri, 1973), respectively occupied by Vertic Xerofluvents and Typic Xeropsamments (USDA, 1975), locally known as Hollaldé and Fondé (Maynard and Combeau, 1960). Fondé soils exhibit a clay content around 30%, and a saturated hydraulic conductivity ranging from 10^{-6} to 10^{-5} m s⁻¹ (Meyer, 1997). Hollaldé soils are characterised by clay contents around 65% (smectite and interstratified: 60%, kaolinite: 30%, illite: 5%, chlorite: 5%) and saturated hydraulic conductivity about 10^{-7} m s⁻¹. These clay soils constitute the best areas for irrigated rice cropping because of their adequate physical and chemical properties.

In the N'Galenka floodplain, where irrigation has never been performed, the water table occurs generally at about a depth of 7 m, but close to the surface under the irrigation schemes. The salt concentration in the groundwater in the middle Senegal valley varies from place to place ranging from 0.2 to 85 g l⁻¹ (Laval, 1996). In the N'Galenka region the electrical conductivity (EC) in the water table ranges from 0.15 to 1 dS m⁻¹.

The irrigation water has a very low Total Dissolved Content (EC ranges from 0.5 to 0.8 dS m⁻¹) and does not therefore reduce the quality of irrigation in terms of secondary salinisation hazard. However, it exhibits a positive calcite residual alkalinity, as it is often the case in continental waters (Valles et al., 1991). Therefore, it could lead to secondary alkalisation if the carbonates brought at each irrigation remained in the soil profiles. The calcite residual alkalinity is lower than in the river Niger, where secondary alkalisation has occurred. Therefore the alkalisation hazard is lower in the

Senegal valley than in the Niger valley. Specific researches about this eventual aspect of soil degradation by alkalisation and about the monitoring of this phenomenon are actually carried out (Hammecker et al., 1998).

The study was carried out prior to the establishment of 48 irrigation schemes along the creek N'Galenka. These perimeters will be constructed on the former floodplain locally known as "walo" areas (Fig. 2). They are already allotted to the surrounding villages.

Material and method

Field salinity measurements

The soil salinity was measured using a portable electromagnetic conductivity meter (Geonics EM38). This portable device is today currently used to monitor spatial changes in soil salinity, hence to delineate saline areas. This instrument measures apparent soil electrical conductivity in millisiemens per metre (mS m^{-1}). The calibration of the EM38 according to soil texture, moisture, and to the type of salinity was subjected to a specific study (Laperrousaz and Barbiéro, 1999).

This work has been carried out in three stages. In a first stage, an area of 73 ha, located at the eastern part of the N'Galenka region around a large winding of the creek (sector VI, Fig.3), has been prospected using vertical measurements according to a 25 x 25 m regular grid. In the vertical mode, 75% of the signal is estimated to come from the top 1.8 m of the soil (McNeill, 1980). These data underwent a geostatistical treatment. In a second stage, 2 ha-area located in the first prospected area (Fig. 3), was subjected to a more detailed survey of the salinity (10 x 10 m regular grid), coupled with topography measurements. Finally, the saline area delineated on the computed map was compared to the aerial photograph of the site (Geotronics, 1980) in order to identify the relationship between the salt distribution and the actual or former geomorphological units. The regional survey of the whole N'Galenka was attempted from EC_m measurements transects, located so as to maximise the intersection with the structures identified on the aerial photograph and that are suspected to be saline. EC_m values over 100 mS m^{-1} are used to delineate the saline areas.

Geostatistical treatments

A chi-squared test showed that the data may not be assumed to have a normal distribution. Therefore, the calculation was performed on a theoretical distribution of the data by lognormal transformation as recommended by Dowd (1984),

$$z(x_i) = \ln(s(x_i) + 0.05) \quad (1)$$

where $s(x_i)$ is the EC_m data at x_i , $z(x_i)$ is the log-transformed data, and 0.05 is a constant because some $s(x_i)$ were equal to 0. An estimate of the sample variogram is given by the formula :

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (z(x_i) - z(x_i + h))^2 \quad (2)$$

where $N(h)$ is the number of pairs of points and $z(x_i)$ and $z(x_{i+h})$ are the log-transformed EC_m value at x_i and x_{i+h} . Raw and directional variogram were calculated to detect an eventual anisotropy in the field salinity. The kriged map is built from a spherical model fitted on the sample variogram. This automatic computation was performed using the GEOSTAT-PC software (Boivin, 1989).

Results and discussion

Structure of the saline area on the prospected zone

High EC_m values are observed, the maximum values being 390 mS/m, with an average value of 55.95 mS/m, and a standard deviation of 71.94 mS/m. The variation coefficient (128.6%) indicates a high dispersion of the data around this average value.

The experimental variogram built from the EC_m data is presented in Fig. 4. The range is about 300 m and the nugget effect is low, indicating that the density of measurements is sufficient to describe the spatial structures at small distance. A slight anisotropy is detected by comparing the raw and directional variogram, but it has not been taken into account for the computation. It indicates a high dependence of the EC_m values in the direction 45° (North East/South West) up to a distance of 300 m.

The computed EC_m kriged map is presented in Fig. 5 and confirms the heterogeneity of the studied site in terms of salinity. A saline area clearly appeared, exhibiting the form of a stripe, which is about 200 m wide, and 800 m long, in the NE-SW direction. This EC_m values distribution is consistent with the anisotropy detected by the directional variograms. Some isolated small saline areas are detected in the south of this main stripe.

The characteristics of this stripe are presented on Figure 6. The detail examination of the saline major stripe reveals that it is actually composed of two parallel minor stripes, which exhibit higher EC_m values. A asymmetry can be detected in the boundary of the saline major strip, which is abrupt in the north and more diffuse in the south. This asymmetry is reinforced by the topographic data. The minor stripe located at north lies in a depression, whereas that located at the south is on a higher ground (Fig. 6 and 7). This distribution of the saline area thus seems to depend on the site morphology, which will be studied from the aerial photographs.

Comparison with the aerial photograph

The salt distribution can be related with the trace of a former creek not easily perceptible in the field but detected on the aerial photograph. The northern minor stripe is located in the former creek bed whereas the southern one is fringing it on the southern bank (Fig. 8). This former creek can be followed on the aerial photograph, which can thus be used as support for a regional survey.

Survey of the whole N'Galenka area

The results of the regional survey, elaborated from EC_m measurements on 11 transects, are presented on the Fig. 8. The saline stripe detected on the prospected area in sector VI is continuous in the north of the present N'Galenka creek bed in the sectors V and IV. This stripe is intersected by the present bed and the most recent non saline deposits of the N'Galenka in two points, the first along the large winding on sector VI, and the second one along another winding located between sector III and IV. These two points are set off by circles on Fig. 8. This organisation of the saline soil distribution indicates that it existed prior to the present N'Galenka and does not correspond to a recent remobilisation of the salt.

The saline stripe appears again down to the sector II, on the other side of the winding, where it is intersected by other deposits coming from the north in which 3 saline stripes were detected. These stripes coming from the north are in continuity with the Pont Gary site where Gascuel-Odoux and Boivin (1994) had also detected a saline stripe. Another saline stripe is detected in sector III on the other side of the N'Galenka. In compensation, the soil in sector VII, located upstream of the futur managed area, is non saline. After this work and the elaboration of the map (Fig. 8), several verifications on the field revealed that all the saline areas have been detected from these 11 transects, located so as to intersect the former geomorphological units. This confirms the efficiency of the method which was implemented on this site.

During this regional prospecting, it appeared that the morphological characteristics of the stripe detected in sector VI were frequently observed and therefore, they are representative of the whole

N'Galenka region. In particular, the major stripe is frequently composed of two minor stripes exhibiting higher EC_m values, the northern one located in a depression and the southern one on higher ground. This detail is not presented on Fig. 8 where only the global saline structure is drawn.

The survey revealed that a large proportion, almost 10% of the future irrigation schemes, is occupied by saline soils. Each irrigation scheme is allotted to the surrounding villages before its establishment. Thus, according to this allotment, it can be noted that some villages will be particularly prejudicated by this saline soils distribution. In detail, the farmers of Nianga, Thiewle (sector V) and Pendaou (sector III) will be strongly prejudicated whereas those of Djamel (sector III) are not concerned with this problem.

Conclusion

As a result of climatological hazard in the past decades, the traditional agriculture in the Senegal valley has shifted to irrigated agriculture in the former floodplain areas. Many irrigation schemes are presently under construction along the creek N'Galenka. One of the first prerequisite, generally lacking, is an inventory of the salt distribution in this area, which appears as a major constraint for a sustainable irrigated agriculture. The systematic survey of the soil salinity using an electromagnetic conductivity meter (EM38), on a 73-ha prospected area, reveals a singular organisation. Indeed, the salt is distributed as a stripe in the SW-NE direction. This saline stripe, inherited from the past, is not correlated with the present but with the former geomorphology, which is detected on the aerial photographs. This relationship being established, it made it possible to survey the whole N'Galenka region from the prospecting on selected transects for EC_m measurements. The regional study confirms that the difference in salinity are quite pronounced and that the saline soil distribution followed a regular pattern as stripes that are more than 10 km long and about 100 to 200 m wide, and related to the former geomorphology. Similar saline stripes were revealed by other prospecting studies in the lower middle valley, for example in Ouromadiou, Nianga, Pont Gary, Guia, M'Boyo (Gascuel-Odoux and Boivin, 1994, Laval, 1996, Barbiéro et al., 1998). This structure appears therefore representative of the salt distribution in the lower middle valley. The specific characteristics of the saline stripes, which are actually composed of two parallel stripes, one in a depression and the other one on a higher ground, must be taken into account to propose a model for the origin of this salt distribution.

This method developed here, far from expensive in time and device, should be recommended for a fast mapping of the saline soil distribution before the establishment of new irrigated areas.

Acknowledgements

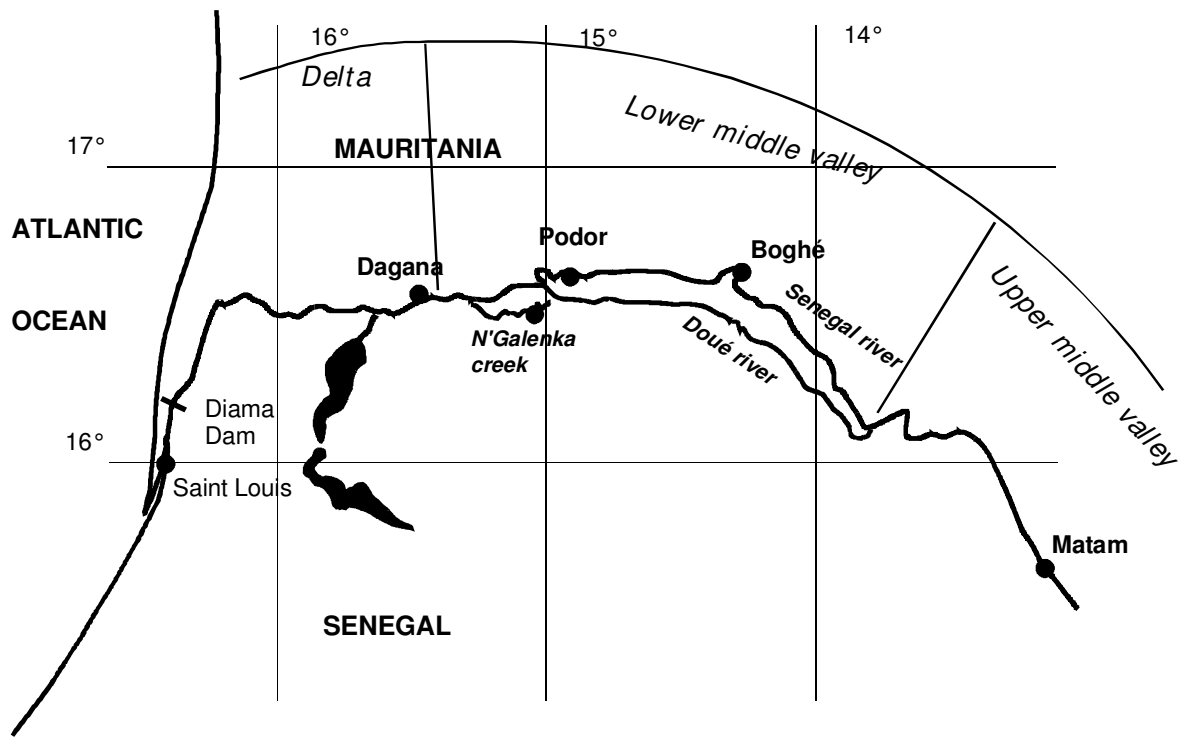
This work was partially supported by the regional pole for research on sudano-sahelian irrigated systems (PSI-CORAF).

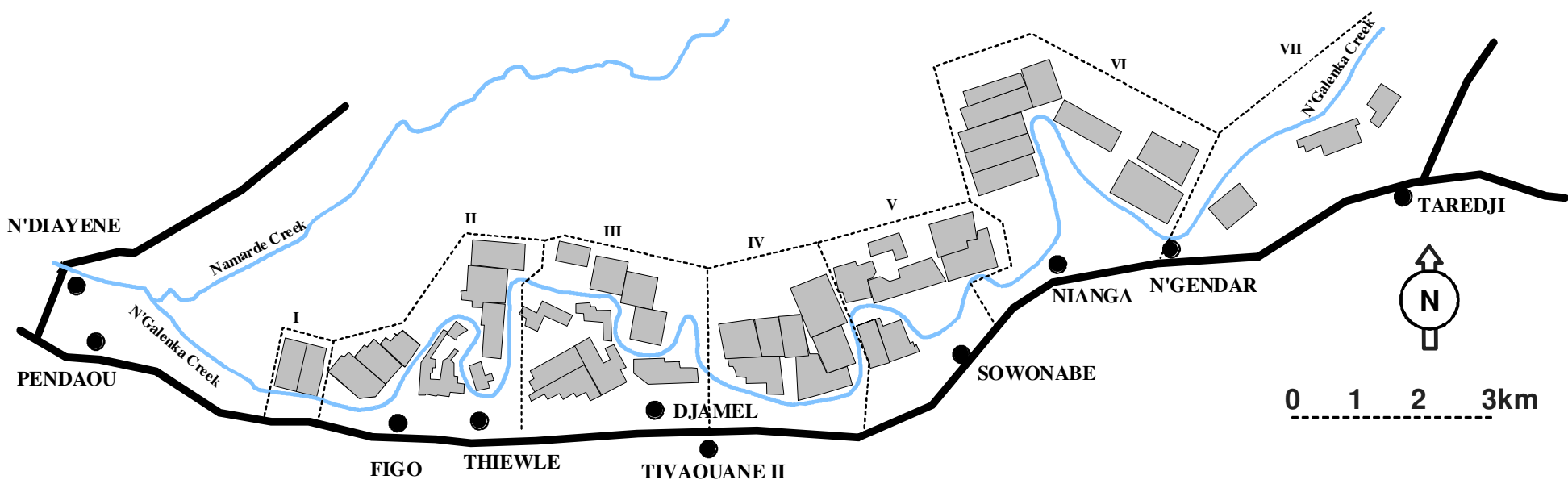
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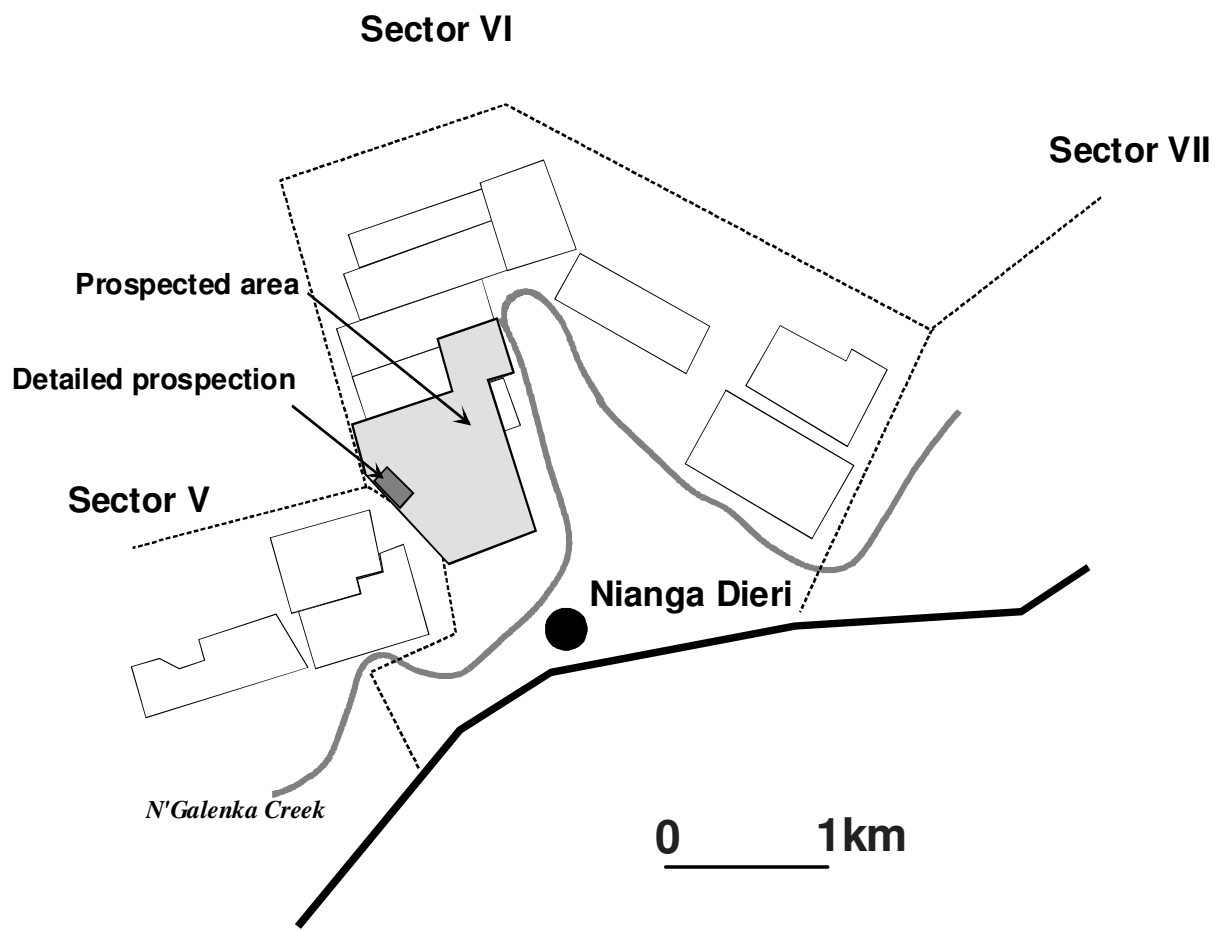
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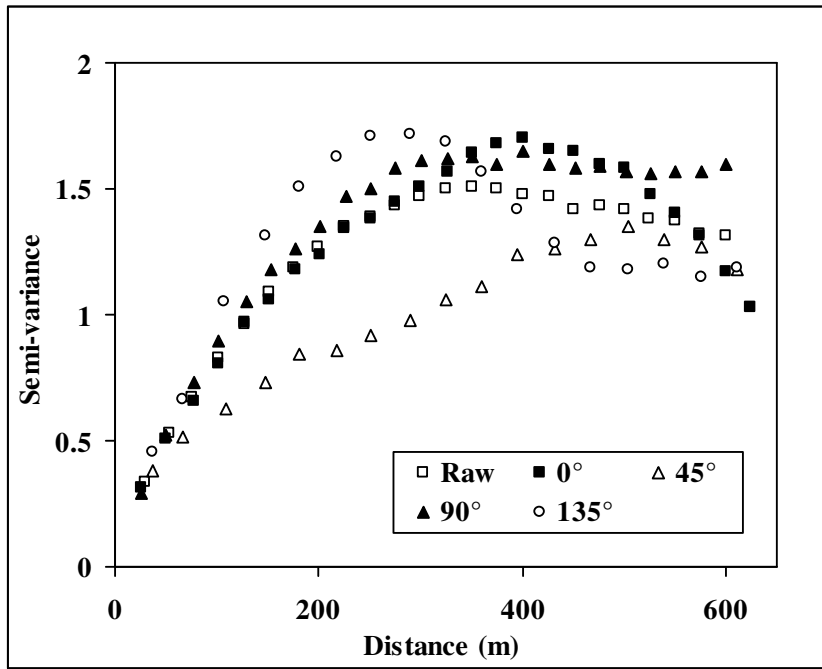
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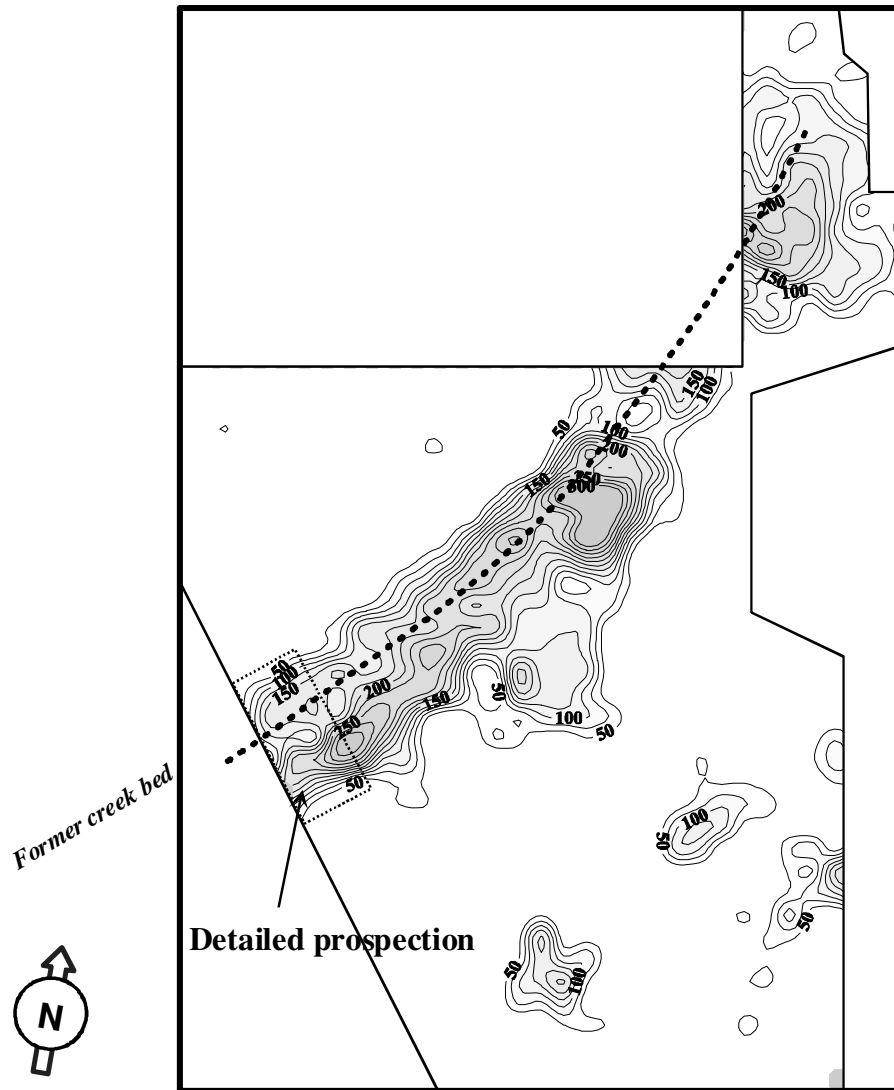
- Fig. 1. Location of the study site in the middle Senegal Valley
- Fig. 2. Distribution of the future irrigation schemes along the N'Galenka creek.
- Fig. 3. Location of the prospected area along the large winding of the N'Galenka.
- Fig. 4. Raw and directional sample variogram.
- Fig. 5. ECm kriged map of the prospected area.
- Fig. 6. Distribution of ECm and topography values in the major saline stripe.
- Fig. 7. Relationship between ECm and topography.
- Fig. 6. Distibution of the saline soils in the whole N'Galenka region.



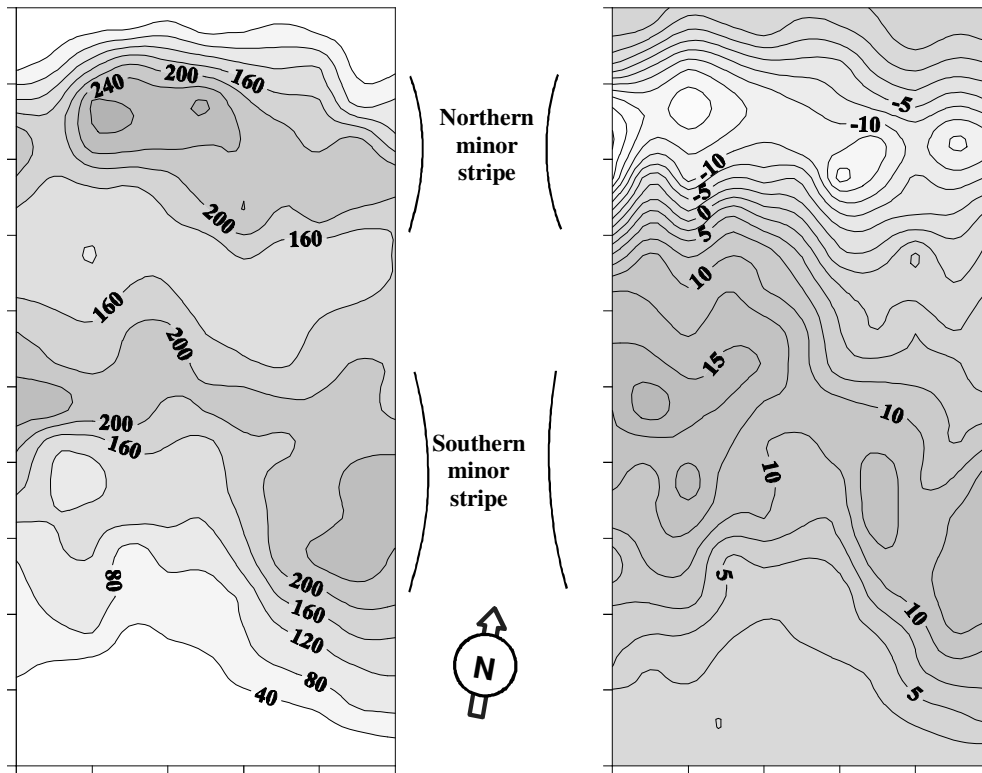








100 m



ECm (mS/m)

Topography (cm)

