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Influence of Saline Soils on Wind Erosion in Lower Mauritania and the Senegal Delta

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INFLUENCE OF SALINE SOILS ON WIND EROSION IN LOWER MAURITANIA AND THE SENEGAL DELTA

Translation of

Influence des sols salés sur la déflation éolienne en Basse Mauritanie et dans le delta du Sénégal

by

J. Tricart

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INFLUENCE OF SALINE SOILS ON WIND EROSION IN LOWER MAURITANIA AND THE SENEGAL DELTA

by

J. Tricart

In French West Africa, the great red sand dunes, regularly stretching from the northeast to the southwest, are paleoforms. They were built up under meteorological conditions which differ from the present ones, presumably during the period of the Saale (Riss) glaciation of northern latitudes. Under natural conditions, with a dense grass vegetation of Cenchrus biflorus and an open forest of Acacia raddiana, their sand is no longer moving. But anthropogenic action can very easily transform them into living forms, the dunes suffering then "caoudeyrization" owing to the difference between present meteorological conditions and the ones under which they originated. The equilibrium is naturally more unstable in the north than in the south, and more humid (350 mm of annual rainfall instead of 200). In the south, great damage from æolian soil erosion has been suffered through uncautious cultivation of peanuts for speculative purposes. In the north, overgrazing results too in soil erosion, so that a policy of well-drilling must be promoted.

Other aeolian phenomena are those which are linked with the endorheic drainage of the sebkha. Two forms of them can be studied in the Aftout es Sahel (Mauritanian coast) and in the Senegal delta. During the dry season, the evaporation provokes the precipitation of the salts contained in the waters of the ponds which originate during the wet season (sebkhas), resulting in solonchak soils completely free of vegetation. Upon these flat surfaces, aeolian deflation is very active, the clay and loam particles being flocculated by salt into aggregates the size of which is just optimum for wind transportation. The wind products are accumulated upon the leeward side of the sebkhas in small dune rims ("bourrelets"). In the Senegal delta, slight differences result from the deltaic conditions. During the long dry season, seawater enters the lower part of the river and, at the beginning of the floods, is pushed into the great shallow basins between the alluvial levees where, during the next season, it is evaporated, as in the sebkhas. These basins bear solonchak soils, but the greater amount of clay brought in by the flood slows the formation of the salt aggregates and diminishes the length of the period of aeolian deflation. Nevertheless, this last effect is sufficient to hamper the alluvial filling of these basins.

These conditions are not peculiar to the Senegal delta but are typical zonal conditions for the deltas of the sahelian zone. They require special recommendations for agricultural development schemes: planting of trees upon the alluvial levees to prevent the breakup of the flood channels by the aeolian aggradation, and cuts in the levees in the upstream part of the basins in order that the flood of fresh water will enter them, instead of seawater, at the beginning of the flood.

The author, as Scientific Adviser of the Mission d'Aménagement du Sénégal, should be pleased to come in touch with colleagues concerned with similar questions.

In Lower Mauritania and the Senegal delta, aeolian phenomena are largely a thing of the past. The region to be studied herein lies between the dune of Tamzak (latitude 17°30'N) and the environs of St. Louis-du-Sénégal (latitude 16°N), and belongs to the sahelian zone. The average annual rainfall is about 200 to 250 mm, which is not very great, but still sufficient to permit the development of a dense vegetation of tall grasses (formation composed of Cenchrus biflorus, which is popularly called kram-kram and is a typical sahelian plant) dominated by light stands of acacias (especially Acacia raddiana). When it is not degraded, this vegetation effectively holds the sandy soils, which comprise old dunes that extend from northeast to southwest parallel to the trades. This immense bed, in which red sands dominate, extends eastward to the Ferlo, where it becomes thinner, and into Brakna, where it becomes a thin, irregular cover over the Eocene limestone and the laterite shield of the Neocene peneplain. Its deposition probably dates from the period characterized in Europe by the Saale or Riss glaciation.

Of course, these immense beds of aeolian sand are very vulnerable to attack by the wind, since owing to their origin, their grain size distribution presents optimum conditions for the development of this attack. Furthermore, whenever the protection of the plant cover begins to fail, the beds undergo considerable alterations and yield living aeolian forms. Naturally, the principal responsibility for this effect is borne by man - the herdsman or the farmer. The denuded, trampled soil of ancient encampments, the cultivated lands - especially those on which trade has

imposed the peanut - and the overgrazed areas, especially those near the unduly scarce watering holes of Trarza, are becoming sites of aeolian removal of sand. Once it begins, the phenomenon tends to intensify and can end in the formation of large, living dunes like those of Méderdra. In most cases, the forms are only minor and consist especially in a caoudeyrization [deflation-hole formation] in old dunes, which shows that their position does not correspond to the present meteorological conditions. Of course, the current aeolian activity increases in importance as the rainfall decreases in the northward direction. Although it is strictly anthropogenic and linked to land use in the region to the southeast of St. Louis, it gradually becomes natural in the vicinity of Tamzak. The sand resumes its movement at any momentary impairment of the vegetation, especially at the top of an old dune that is particularly exposed to the wind. In the south, the present aeolian activity yields only a confused microrelief of the cover. In the north, it leads to the reconstitution of living dunes that sometimes have a different orientation than the old red dunes. Their occurrence is placed at about 17°N, and the immediate approaches to Méderdra offer a particularly clear example of them.

However, other aeolian phenomena observed in the region have a less strictly zonal distribution with less relation to anthropogenic actions and do not affect the old aeolian sands. They belong to the general type that has been described by J. Boulaine in Algeria and are related to the presence of saline soils [1].

They are found in exactly the same form in the Senegal delta, the Aftout es Sahel of coastal Trarza, and in the niayes [clumps of oil palms] on the outskirts of Dakar.

1. Aeolian Activity in the Sebkhas of the Aftout es Sahel

The simplest type is offered by the depressions of the Aftout es Sahel, on the coast of Mauritania. Between the largely living coastal dunes and the continental red-sand dunes, there is a depressed zone 5 to 15 km wide occupied by a chain of sebkhas that collect the rain from local showers intense

enough in places to cause rivulet marks on the Quaternary continental dunes, while the sebkhas also receive the floods of the Senegal. In 1950-1951, the water covered the entire Aftout and advanced northward from there to beyond Nouakchott, which it destroyed in passing [2]. These sebkhas were the result of a process of wind erosion that originally persisted to below the present level of the sea and affected fossiliferous coastal formations comprising a beach of 4 to 6 m and probably dating from the Normannian [3]. The rise of the sea level, accompanied by the formation of the powerful line of coastal dunes, isolated these depressions from the sea and simultaneously deflected the Senegal southward in such a manner that the depressions constitute a typical kind of endorheic sink [4]. The water supply is highly variable. Generally, the outflows of water from the Senegal through the branch channel of N'Diader do not go beyond the southern part of the chain of sebkhas, which is designated as the Marais des Toumbos on the map. Even in this sector, the evaporation of the dry season is sufficient to make the sheet of water disappear every year between February and May, depending on the year. As a function of the conditions of the flood, the water of the Senegal inundates a more or less wide part of the Aftout, but does not persist throughout the dry season unless the flood is exceptional, as was that of 1950-1951 or apparently that of 1890. However, even in such cases, there is no leaching, since the water remains stagnant until it evaporates in the subsequent dry season. On the other hand, the intake of salt is increased, and the local inhabitants who collect it have noted that the yield is greater after rainy years [5].

Accordingly, the bottoms of the sebkhas constitute natural salt marshes that are typical of a domain of seasonal sedimentation characterized by the accumulation in variable year-to-year proportions of clayey and loamy materials that arrive in suspension and of salt that arrives in solution. The latter may be plentiful enough to form bright red crusts (sebkhas of Lemzewid and El Bokharia), which are collected

by the Moors, who remove it from the underlying black loam. However, the deposit usually is not suitable for collection and consists of a very clayey and saline loam. Of course, no vegetation grows on the bottoms of sebkhas formed from live solonchaks. The action of the salt on the aeolian phenomena is therefore twofold. On the one hand, it prevents the development of any protective plant cover, and on the other, it flocculates the clay into aggregates of 50 to 150 μ and gives them an apparent grain size distribution that is much more favorable to wind erosion than their true grain size distribution.

The bottoms of the sebkhas are very flat, due to the sweeping action of the floods and the aggrading action of deposits, and constitute a vast surface for wind erosion where the dust whirls almost incessantly above the ash-like soil, where it is difficult to walk, and where a vehicle bogs down immediately. The homogeneity of the deposits lends this erosion a very regular behavior like peeling, while the irregularities that may be produced are leveled off in each annual flood.

The edges of the sebkhas present an entirely different appearance with a zonal arrangement. Proceeding toward the outside, one encounters a first zone in which the soil is slightly elevated with a concave profile. Since this zone is covered by only the highest floods, the soil is less saline and the edaphic conditions are less unfavorable. Clumps of Salicornia stud it irregularly, and are denser near the top of the zone. Owing to the vegetation, the wind erosion becomes irregular. One observes small nebkas [literally "mounds"] a few centimeters high in the lee of the clumps. This is followed by the rim zone, which is occupied by dunes of saline loam and clay. The profile is convex on the whole and very irregular in its details, owing to small dunes. Their height may reach 2 m (sebkha of Tamzak), and this relief is very appreciable in an unusually flat region. The rain permits a slight leaching of these dunes, with the result that the vegetation on them is less halophitic than in the inner zone of the shore of the sebkha. On the dunes, one finds grasses instead of Salicorniae, as well as clumps of Tamarix that endure despite the accumulation of aeolian deposits.

This sequence is not maintained all around the sebkha. In fact, the dune rim does not form except in a lee. In the Aftout, it emphasizes only the south and southeast edges of the areas of wind erosion and reflects the predominance of the sea breezes. Thus, it constitutes a supplementary proof of the sessile character of the red continental dunes, which were built up by northeasterly winds that corresponded to a different meteorological regime.

The arrangement of the concentric elements around the sebkhas is sometimes transposed. The dunes of the rim may cease to build up, begin to undergo leaching, and become vegetated. New dunes form farther down at the expense of the Salicornia beach, which moves toward the center of the sebkha. However, these movements are limited by the extreme flatness of the sebkha bottoms, and they affect only the shore zone with concave profile. They seem to be related to the greatest variations of the flood level. In fact, an examination of the vegetation shows them to be very recent, and one can conjecture that the exceptional flood of 1950-1951 (with a probability of one occurrence every 200 years) caused a rise of the various coastal elements and yielded the elevated level of small dunes now undergoing leaching. Later, a series of weak annual floods gave rise to a regression of the different zones.

2. Aeolian Activity in the Senegal Delta

With respect to activity, the Senegal delta shows the same processes, but in a different geomorphological setting, in accord with the special dynamics of a subarid delta.

The lower Senegal is known to constitute a typical allogenic river that traverses a quasi-arheic region in which it receives no tributaries. The annual flood is supplied entirely by the upper basin upstream of Bakel. Thus, it is not surprising that the delta exhibits very special features that simultaneously pertain to a classical delta, an arid outflow zone, and an estuary. Hydrologically, the system has two seasons. During the flood

season (August to November), the system is fluviatile. Since the slope is very slight, the flood progresses very slowly, gradually submerges the vastnesses of the delta, and builds up alluvial levees that block the principal beds and isolate some of the basins (the Djoudj, Djeuss, and N'Diael). However, during the rest of the year the supply is insufficient and salt water rises along the principal beds in large amounts that regularly extend over the sector between Richard-Toll and Dagana by the end of the dry season at low water (June). Although the tide is weak, it affects the river even farther upstream. Then, the system is estuarial, and tidal flats form along the arms far into the interior. We observed tidal flats at Keur Macène. At that time, the basins undergo an intense evaporation that dries them up in exactly the same manner as the sebkhas of the Aftout and permits the development of aeolian activity. The saltiness of the soils, which is inseparable from the development of these processes, is accentuated by the special hydrological conditions of these basins. At the end of the flood, they are completely inundated when the water reaches its highest level. During the slow subsidence, they drain progressively - in the downstream direction, of course. In each of them, one sees series of very faint grooves that are reminiscent of the tidal gullies on beaches. The grooves concentrate progressively to form a sizable branch channel of the river that collects all the subsidence water and flows out at the downstream end of the basin, which is usually named after it. This pattern is particularly typical for the Djoudj and the Djeuss and can be seen even on the 1:200,000 map. The subsequent flood rises very slowly, and the water level is still insufficient to spill over the upstream levees of the basins, although it is already high enough to stem the seawater that entered the lower course of the river during the dry season. The clearly outlined branch channels of the basins, which have no water to carry, serve as an inlet for the estuarial water that invades the basins from downstream and is retained in them during the flood, although it is slightly diluted by fresh water that succeeds in spilling in over the levees. The protection offered by the levees is increased by the

presence of a large number of semi-contemporaneous levees that were formed during the Dunkirkian as a function of a sea level that was 1 to 1.5 m higher than the present [3, 6].

As a result of the special zonal-type system that characterizes the basins of the Senegal delta, they function in almost the same way as the sebkhas of the Aftout es Sahel. The difference lies in the nature of the intake of flood material. The Senegal carries a greater load of colloids and loam than does the runoff water of the Aftout. Hence, the accumulation is greater and the grain size distribution is slightly different. The centers of the basins are occupied by extremely compact, blackish clays that are converted into areas of dessication during the early part of the dry season. Their compactness retards evaporation and, hence, crystallization of the salt, which in turn retards both the inception of flocculation of the clay and wind erosion. In January 1954, the central part of the basin of the N'Diael exhibited only compact clays that had fissured completely through dessication, but without a trace of wind erosion, while the loamy edges of the basin were being actively affected by it, as were some of the nebkas in the lee of Salicornia clumps and small beds of loam modified by the wind (which obliterated the runoff marks of the preceding high water) and completely striated with ripple marks. Downstream of the basins, the approaches to the branch channels that function as their drains during the subsidence of the flood are reached by the tide and are in too depressed a position to be exposed to aeolian action. They constitute the region of small tidal flats.

On the whole, the aeolian activity of the dry season in the basins of the delta plays a counteractive role with respect to the fluviatile processes. The erosion that they cause tends to deepend the basins, i.e., to facilitate the penetration of the basins by salt water. This gives rise to an autocatalysis whose only limit is the lowering of the basin bottom to a level close to that of the high seas, which would initiate the replacement of the aeolian activity by an estuarial evolution. The present deepening of the basins by wind erosion seems to exceed the intake of loam and clay from the floods,

at least in certain cases, and results from the recent retreat of the sea, which has lowered the sea level by 1 to 1.5 m since the Dunkirkian maximum of the Flandrian transgression. The conflict between aeolian and fluviatile actions is also observed in the evolution of certain arms of the Senegal. The arms that function only during the floods, such as the branch channel of the N'Diader, may be blocked by aeolian accumulations of material that is brought in from the basins by wind erosion. The phenomenon has been observed on the N'Dig (west of Keur Macène). This branch channel was more active formerly, when the mouth had not migrated so far southward and the Marigot des Maringouins was still open to penetration by the sea. Its levees have a growth of Tamarix. Thus, when they are downwind of the adjacent basin, they constitute a considerable obstacle to the advance of the flocculated loam and clay dislodged from the basin surface by the wind. Hence, these products accumulate in dunes on the levee, bury the trees, and progress little by little into the bed of the branch channel, which contracts and divides, while true aeolian plugs form in the places where the stand of Tamarix is lightest.

3. Morphoclimatic Relevance of These Phenomena

This special evolution of the Senegal delta is a zonal phenomenon that pertains to a single type of delta: that of tropical rivers that end in subarid regions, i.e., sahelian regions. The powerful seasonal alternation of climate, characterized by the contrast between dry season and rainy season, triggers the alternation of contrasting hydrological systems, viz., the estuarial system of the dry season and the deltaic system at high water, and it also triggers conflicting processes, viz., fluviatile processes at the flood and terrestrial processes at low water (especially aeolian processes). It is clear that the equilibrium between the conflicting elements varies as a function of the relative importance of the flood season and the low-water season. For wind erosion to play an important role, the delay in the initiation of wind erosion processes

in the clayey formations of the basins requires that the dry season be notably longer than the wet season, which is completely the case for the Senegal and characterizes the sahelian zone. When the rainy season is protracted in the area farther south, the equilibrium between conflicting factors is modified, while the fluviatile processes progressively come to prevail over the aeolian processes.

Last but not least, we come to the action of the outflows, either endorheic as in the sebkhas of the Aftout, or deltaic-sahelian as in the Senegal delta, which causes a more marked southward extension of the aeolian activity in accord with the double role played by the salt, viz., inhibition of the plant cover and flocculation of the fine products into aggregates that offer an optimum apparent grain size distribution. The extrapolation of the aeolian phenomena to the surface of the entire earth involves a very important fact. The system of erosion pertinent to the sahelian zones, both to the north and to the south of the subtropical deserts, permits the aeolian processes to extend beyond their intrinsic zonal region of the large deserts in association with the temporary outflows and endorheism, in a manner identical in principle to the coastal aeolian phenomena related to the denuded sand beaches, but less extensive in its field of applicability. This association of endorheism and wind erosion is based on the special features of the saline soils and plays a principal role in the morphogenesis of the sahelian zones. In the light of recent research, it constitutes the best explanation of the North African chotts, since it is intensified by autocatalysis.

4. Practical Conclusions

This analysis of the processes must not remain a mere gratification of the intellect. It must not be limited to an academic exercise. It is susceptible of practical application and of serving as a guide to the work projected by the Senegal Management Mission. The conclusions we have drawn imply the following practical consequences.

1) The large red continental dunes constitute very frail paleoforms that are prone to resume their activity and to be modified in order to achieve equilibrium with present meteorological conditions. The result is that wherever it occurs, this resumption of movement takes on a catastrophic appearance, since the readaptation of the forms to the present meteorological conditions requires a considerable displacement of sand. It is this result that lends such a tragic character to the "desertization" of the peanut-growing region, since the morphogenetic equilibrium has been disrupted by the unconsidered extension of a speculative crop at the instance of commercial methods. The natural patrimony is seriously menaced, and with it, the right to life of future generations. Since the sensitivity of these paleoforms to disruptions of the natural equilibrium increases toward the north with the dryness, the same dangers threaten Trarza. There, it is not in the least necessary to plant crops in order to cause the dunes to resume their movement: any overgrazing will have that effect. Accordingly, one must see that the flocks are well distributed, particularly by judicious establishment of watering holes, to keep the flocks from becoming unduly localized. The well-drilling policy now practiced by the water authorities is reassuring in this respect, although it requires some adjustments in its details. On the other hand, the tendency toward settlement on the part of certain tribes is a serious threat. Since it involves keeping the flocks on a small area around a fixed point - usually a well - it may cause an overgrazing that will generate a resumption of movement of the sand. Substantial indications of this danger have been observed about 20 km northwest of Méderdra around a nearly stationary encampment.

2) The management of the Senegal delta presupposes a battle against the zonal mechanisms of basin evolution, which resemble those of the sebkhas. The planting of crops requires a desalination of the soil and a limitation of wind erosion, since it would be pointless to undertake great water projects to irrigate a soil that at the same time would be

moving away in clouds of dust. Actually, this wind erosion is capable of menacing the water-supply systems themselves by causing aggradation or plugging of the canals by drifts. These problems can be solved only on an overall basis, due to the interaction of the natural processes. It is important to combine the following measures:

The banks of the branch channels, whose drainage it is desirable to safeguard, should be protected by tree planting dense enough to prevent the aeolian accumulations downwind of the basins from encroaching on the beds of the basins in the dry season or from building up into plugs in them. It would be relevant to study the natural stands and complement them. For example, if it is desired to use the branch channel of N'Diader as an overflow basin for the flood in the direction of the sebkhas of the Aftout, it is urgent to put an end to the progressive disorganization of the N'Diader by the aeolian accumulations.

The hydrological system of the basins should be modified to enhance the fluviatile actions at the expense of the combination of processes of sebkha type. One must approach this solution through breaching of the levees at selected points on the upstream ends of the basins, so that they will be entered directly by the flood water and not by estuarial backwater. In this way, the detrimental effect of the Dunkirkian alluvial levees would be eliminated. One can also study the installation of dams with sluice gates at the outlets of the basins to prevent the penetration of estuarial water from downstream when the topography does not lend itself to flooding from upstream. Thus, one could retard the emptying of the basins and, accordingly, accentuate the deposit of clay and loam, and retard the time of onset of wind erosion that tends to deepen the basins.

It is clear that these principles of management, which have been derived from a preliminary geomorphological analysis, cannot be implemented without new research in greater depth. It will be indispensable to proceed to the stage of quantitative study, to measure the intensity of the detected processes, to determine their variations, and to determine

exactly the modalities of their interactions. One will have to delimit the various relief forms and the fields of action of the different processes very precisely on a geomorphological map. And there is a presentiment of everything that such efforts can contribute to our theoretical knowledge through a close connection with practical requirements.

Our proposed specifications of dates were adopted in accord with A. Guilcher, J. Dubois, and M. Maymard after comparison of mostly separate observations.

Literature Cited

1. Boulaine, J. "The sebkha of Ben Ziane and its lunette: example of a morphological complex formed by aeolian degradation of saline soils" (La sebkha de Ben Ziane et sa lunette, exemple de complexe morphologique formé par dégradation éolienne des sols salés), Revue de Géomorphologie Dynamique, 5: 102, 1954. This article reached us in manuscript form between the time when we were doing our field work and when the present paper was being prepared. The convergence of the results presented in the two papers simply lends greater weight to both.

2. Duchemin, G. J. "Flooding of the Aftout es Sahel and post of Nouakchott (western Trarza, Mauritania)" (L'inondation de l'Aftout es Sahel et du poste de Nouakchott [Mauritanie, Trarza occidental]), Institut Français d'Afrique Noire, Bulletin, 13: 1303-1305, 1951.

3. Tricart, J. and J. Dubois. "Outline of a stratigraphy of the Senegalese Quaternary" (Esquisse d'une stratigraphie du Quaternaire Sénégalais), Société Géologique de France, Comptes Rendus Sommaires, 1954.

4. Guilcher, A. [No further specification in original: Tr. note.]

5. Duchemin, G. J. "Recovery of salt and working conditions in the saltworks of western Trarza, Mauritania" (La récolte du sel et les conditions de travail dans les salines du Trarza occidental [Mauritanie]), Institut Français d'Afrique Noire, Bulletin, 13: 853-867, 1951.

Gruvel, A. and Chudeau. Across Western Mauritania (A travers la Mauritanie occidentale). Paris. Larose, 1909. 2 vols.

6. Tricart, J. "Geomorphological aspects of the Senegal valley" (Aspects géomorphologiques de la vallée du Senegal) [no further specification in original: Tr. note].