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Sedimentary dynamics of the South Lagoon of Tunis (Tunisia, Mediterranean Sea).

Estudio de la dinámica sedimentaria de la Laguna costera del Sur de Túnez (Túnez, Mar Mediterráneo)

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ABSTRACT

The South lagoon of Tunis, a shallow Mediterranean lagoon, had undergone an important restoration management (during the period 1998-2001), leading to structural and functional changes of this coastal ecosystem. In this work, a comprehensive study of sedimentary dynamic based on hydrodynamic data, granulometric analysis, mineralogy and impact evaluation is presented. Restoration project, especially the establishment of two groups of inlets gates of the channel of Rades and Tunis (recalibrated during the restoration management), imposed an east-west water flow direction, created from high tide submersion, with an average flow exchanged with the sea about 80 m^3s^{-1}. This current control local sediment sorting. The grain sizes analysis of superficial sediment shows that the lagoon bottom characterized by fine sediments (<63 µm, 50-90%). The sediment dynamic is controlled by the lagoon water currents inducing an east-west grain-size sorting. The extreme eastern side of the lagoon, close to the inlet gate, is lined by medium sand, moderately sorted and transported by saltation. The central and western sides of the lagoon are covered by fine sand, poorly sorted, and deposed in relatively calm hydrodynamic conditions. Mineralogical results reveal the following association: quartz (13 to 69%), biogenic calcite, (15 to 81%), aragonite (0 to 8%), pyrite (0 to 1,75%) and accessory magnetite, smectite, illite and kaolinite. The lagoon seems to be a protected zone as a result of restoration project that forms a physical barrier for sedimentary materials amount from Gulf of Tunis.

Keywords: South lagoon of Tunis; sediment dynamics; mineralogy; granulometry; restoration project; Tunisia.

RESUMEN

La laguna sur de Túnez, una laguna costera mediterránea poco profunda, se sometió a importantes trabajos de restauración durante el período 1998-2001, lo que ha llevado a cambios estructurales y funcionales de este ecosistema costero. En este trabajo se presenta un estudio integral de dinámica sedimentaria basado en datos hidrodinámicos, análisis granulométrico, mineralogía y evaluación de impacto. El proyecto de restauración, especialmente el establecimiento de la puerta de entrada de los canales de Rades y Túnez, impuso una dirección de flujo de agua este-oeste controlando la clasificación local de sedimentos. El análisis de tamaño de grano del sedimento superficial muestra que el fondo de la laguna está revestido por sedimentos finos (<63 µm, 50-90%). El transporte de sedimentos está controlado por las corrientes de agua de la laguna que inducen una clasificación de tamaño de grano este-oeste. El extremo oriental de la laguna, cerca de la entrada, está bordeado por arena mediana, moderadamente clasificada y transportada por saltación. Los lados central y occidental de la laguna están cubiertos por arena fina, mal clasificados y acumulados en condiciones hidrodinámicas relativamente tranquilas. Los resultados mineralógicos revelan la siguiente asociación: cuarzo (13 a 69%), calcita biogénica (15 a 81%), aragonita (0 a 8%), pirita (0 a 1,75) y magnetita accesoria, esmectita, ilita y caolinita. La laguna parece ser una zona protegida como resultado del proyecto de restauración que forma una barrera física para la cantidad de materiales sedimentarios del Golfo de Túnez.

Palabras clave: Laguna costera; dinámica de sedimentos; mineralogía; granulometría; proyecto de restauración; Túnez.

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Introduction

Coastal lagoons are characterized by high biodiversity and intense primary productions that lead to both ecological and economical considerable importance. Moreover, the close link between human population and coastal zones, consequently coastal lagoons, is particularly evident since approximately two-third of human total population live in these areas. As a matter of fact, since several decades, increasing human wastes have created important problems (Martin Plus *et al*., 2006).

Mediterranean coastal areas suffer from a continuous anthropogenic pressure, resulting from human growth and an increase of industrial and urban activity, (touristic activity, hardboard, and fish farming…) (European Commission, 1991). These activities have dramatically increased the amount of toxic pollutants, that may exceed the limit of the environmental consumption capacity and lead to a degradation of the ecosystems structure (Diaz, 2001), threating human health and causing imbalance for biota (UNEP/MAP, 2012; Belabed *et al*., 2013; Zaaboub *et al*., 2015).

The coastal lagoons seem to be the most vulnerable ecosystem (Souchu et al., 2000). They are considered as dynamic and complex biogeochemical systems (Lankford, 1977; Nicklos & Allen, 1981; Bidet *et al.,* 1982). Continental supply and marine contribution interactions give rise to multiple processes influencing the sedimentology and geochemistry of the lagoon. The lagoon can be naturally fed by sediments transported by the flow of its many streams from eroded watershed outcrops. Indeed, urbanization and industrial expansion have put remarkable ecological stress, by the discharge of the industrial and municipal wastewater and urban runoff. For this reason, the assessment of the lagoon water quality requires understanding the geochemical processes that controlled the exchanges between the different interfaces of this ecosystem. The study of the bottom sediments presents the most useful tool to identify the spatio-temporal evolution of the chemical elements. The latter are in close relation with the sedimentary dynamics and the transport pathways of the chemical compounds towards the receiving environment (Perriaux, 1972; Tricart, 1965; Miskovsky, 1974).

In order to counteract pollution and eutrophication risk, an investigation of sediment dynamics of this shallow area (the spatial distribution, composition and size of mineral particles, currents influence, transport and deposition of particles) may be crucial to the interpretation of sediment transportation and accumulation mechanisms. Indeed, the presence of pollutants in sediments is affected by sediment particle size and composition with metals potentially toxic to living organisms often more associated with fine-grained sediments due to their high surface-to-volume ratios and adsorption capability (Szava-Kovats 2008 Belabed *et al.,* 2013; Zaaboub *et al.,* 2015; Oueslati *et al.,* 2017).

Tunisian coastal lagoons, like lagoon of Tunis, Bizerte lagoon and Ghar el Melh (southern basin of the Mediterranean Sea) have served for final repositories of anthropic waste (Ben garali, 2011; Oueslati, 2010; Zaaboub *et al*., 2015). The lagoon of Tunis (Northeast of Tunisia) is one of four major lagoons in Tunisia; this lagoon is subdivided into both: North and South lagoon of Tunis (Zaouali, 1983; Harbridge *et al.,* 1976). In This study, we focus on South lagoon of Tunis, which was used to receive raw sewage from different industrial and urban areas that contributed to its degradation (Ben Souissi *et al*., 2000).

Giving the high importance of the South lagoon of Tunis, due to its location, near to the capital, the lagoon has received an important government concern and few professional scales have been conned out to find major solution of pollution.

For this purpose, a restoration and development project was carried out between April 1998 and July 2001 by the South Tunisian Studies and Promotion Corporation society, under the control of the Ministry of Infrastructure, Housing and Development planning of the Tunisian Republic. The project was financed mostly by a credit from the European Investment Bank (EIB) and by The Lake Group (group of private banks).

The project consists of enhancing water circulation by widening channels, deepening the lagoon (dredging the bottom sediments), and pumping sea water into the lagoon by building one-way tide gates to remove areas of water stagnation. After this restoration work, the lagoon structure has radically changed and new ecosystem was given rise (SPLT- STUDI/SOGREAH, 1998; Jouini *et al.,* 2005).

In this paper we present a comprehensive study of the new sedimentary dynamics in the South lagoon of Tunis after its restoration. The purposes of this work are:

- to characterize the sediments,
- to assess the conditions of their transport and deposition,
- to determine the natural and anthropogenic factors that affect the surface sedimentary dynamics.

These objectives are obtained through hydrodynamic data, granulometric and mineralogical study.

Such studies would undoubtedly be of paramount importance, not only regarding the sedimentary dynamics of the lagoon artificially modified, sustained development and quality control of the managed area, but also in the prospect of the future to predict the effects of similar restoration's interventions on other sites to be cleaned and valorized for further use.

Study area

The South lagoon of Tunis is the south basin of the lagoon of Tunis. It is a shallow coastal area, located at longitude 10°12' et 10°16' E and 36°46' to 36°48' N latitude, covering a surface of about 720 hec (Fig. 1). It communicates with the Gulf of Tunis, via Rades channel and channel of Tunis. Also, the lagoon receives water from draining the urban area of Megrine, runoff of newly developed areas after their planning, as well as a channel called the belt channel (DHU- Equipment Ministry, 2015). It received about 5500 m^3/day of

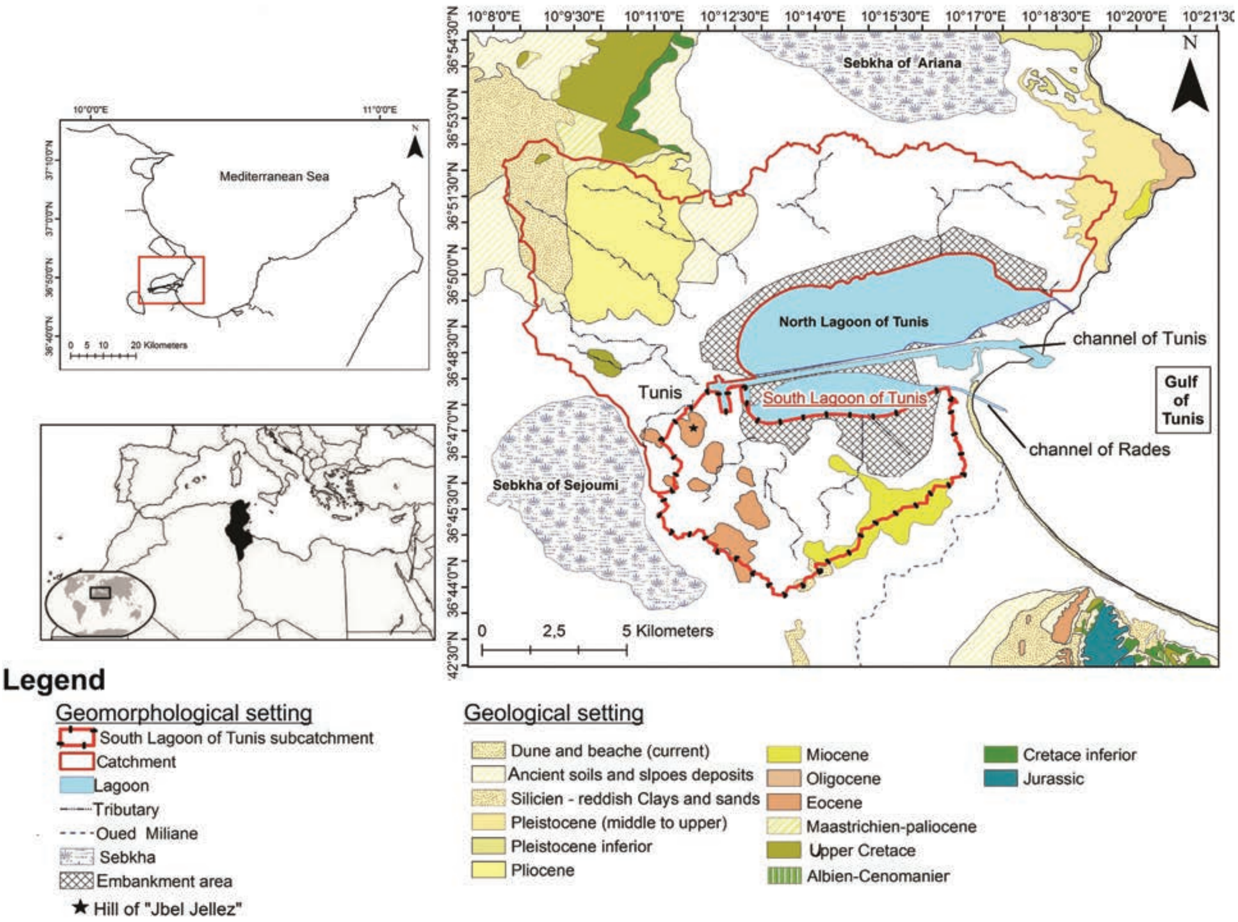

Figure 1.—Location map and geological setting of South lagoon of Tunis.

wastewater on its south side and south-west side from urban and industrial areas (Jouini *et al*., 2005).

The lagoon is under a semi-arid climate, characterized by a high evaporation rate; it ranges between 62 and 201 mm, in January and July respectively. Wind is a very important meteorological parameter given its hydrodynamic effects. It's involved in wave generation, propagation and sediment transport. The Rose of the Wind, spanning 2007 to 2011 at the Tunis-Carthage station, shows the dominant winds are from N, NW in winter and S, SE, SW in summer (INM, 2012).

Generally, the coastal lagoons formation is related to the latest glacioeustatic variations, by the drop of the sea level and the development of ice caps (Tastetu, 1974; Lankford, 1977; Nicklos & Allen, 1981; Bidet *et al.,* 1982). The lagoon of Tunis had taken its current form during the end of the last glaciation until the Holocene.

According to Pimienta (1959), Warmington (1967), Brogan (1967), Craig (1967), Coque (1967), sediment supply from Medjerda river and Meliane river have contributed to filling of the Gulf of Tunis leading the isolation of the lagoon from the open marine system of the Gulf. In 1855 a large channel, Channel of Tunis, was built which divided the lagoon into two lagoons: The North lagoon and The South Lagoon of Tunis.

The catchment is represented mainly by the Quaternary alluvium (complex of muddy sand and sandy loam) and by Oligocene (fine sandstones separated by small levels of clay) outcrops at Rades and Bir El Kassâa, and also by the Eocene hills of Jbel Ejellez (Pimenta, 1959; Paskoff *et al.,* 1983; geological maps 1/50000) (Fig. 1).

Hydrodynamic parameters

The lagoon has a regular depth of about 2.1 m, except in some restricted areas, on the eastern side, where it reaches a maximum of 5 m.

The hydrodynamic's lagoon is mainly controlled by the combination of tide and wind effects. Indeed, the tide by the variation of the level of water, control the opening and the closing of the locks. The seawater enters, via Rades channel in rising tide and comes out from the lagoon to the Gulf by channel of Tunis when tide is down. The total exchange of water volume with the sea via the channel of Rades is about 2.57 million m^3/day (Jouini, 2005).

Its bank lines are straight; they are divergent to channel of Rades and become converging towards the Tunis Channel, favoring better fluid water circulation in the lagoon.

The tidal regime of this area is dominated by semi-diurnal cycle and is characterized by low amplitude that vary from 0.09 m to 0.26 m, with an average 0.20 m (Jouini *et al.,* 2005).

According to the studies conducted by Kochlef (2003) (Fig. 2), the current velocities recorded in the lagoon are variable. It varies from 65 cm/s to 5 cm/s, going from the channel of Rades to the channel of Tunis, leading to the appearance of little stagnation zones in the northwestern part of the lagoon especially on summer.

In order to ensure the proper functioning of the redeveloped lagoon, recalibration works of the lagoon-Gulf hydraulic communication channels (channel of Rades and Tunis channel of Tunis) have been carried out:

- Channel of Rades (2 Km length and 4 m deep), ensures the sea water passage from the Gulf to the lagoon. It is protected by a dike that acts against the swell action, the evolution of the shore, and it limits the reintroduction of the materials carried by the marine currents, later it reduces the risk of silting.
- Channel of Tunis (10 Km length and 4.5 m deep), ensures the evacuation of the waters of the lagoon.

The waves generated by wind can affect the function of the locks and the lagoon-sea exchange volume of water. Only eastern winds are important. They promote the supply of seawater into the lagoon to 10% by 10 ms^{-1} of speed. Other winds directions generate short fetches without effects (Jouini *et al.,* 2005).

The present work is of fundamental importance in connection with the protection of this coastal environment from terrestrial pollution that may alter or affect it. Sediments collected from the South Lagoon of Tunis are used to understand the complex interactions between the grain-size pattern and the hydrodynamic process, under urban and natural effects. It would be very interesting to deduce a textural parameter that is characteristic of the lagoon.

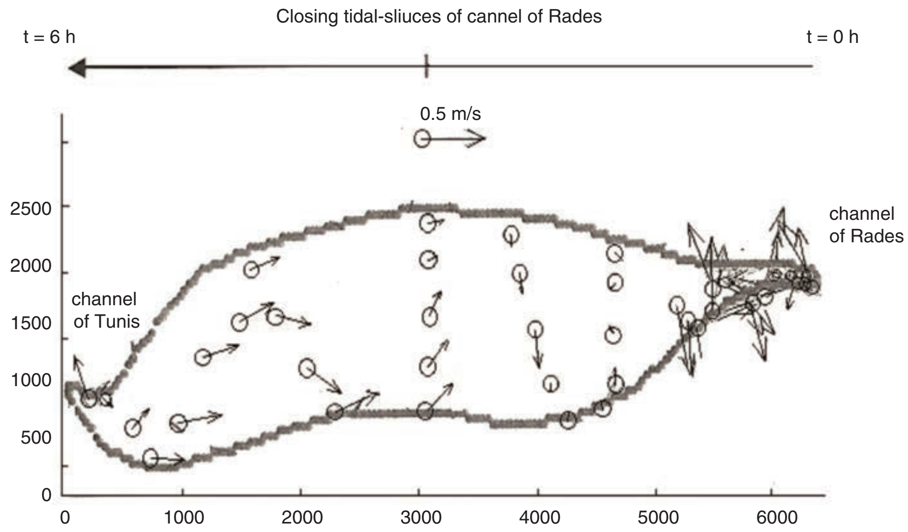

Figure 2.—Currents speed and direction of the South Lagoon of Tunis (Kochlef 2003).

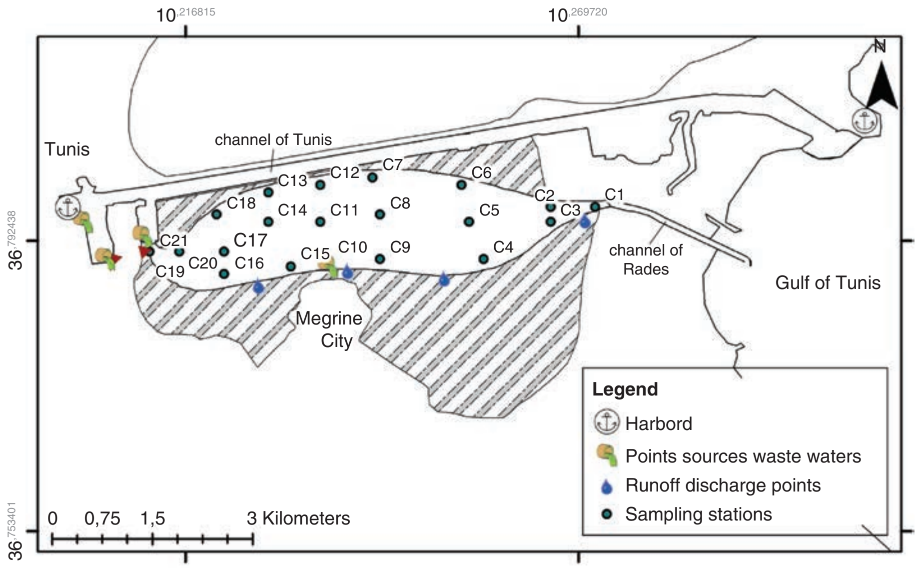

Figure 3.—The surface sediment sampling site map.

The distribution of such parameter could be used to predict sediment behavior and its dispersion over the lagoon, in response to new inputs of sediment from natural or man-induced processes.

Sampling and analysis

In order to assess the hydrodynamic characteristics of the South Lagoon of Tunis, 21 surface sediment samples were collected, over the lagoon (Fig. 3). Samples were collected using a Van Veen grab sampler operated from aboard boat.

In order to study samples distribution and surface sediment transport we used grain-size (Folk & Ward, 1957) and mineralogical (Riviere, 1952, 1953) analysis were carried out.

Granulometric analysis

All samples were wet-sieved (63 µm sieve mesh) to separate the silty and sandy sediment fractions (<63 µm and >63 µm, respectively). The obtained sandy sub-samples were then oven dried at 50°C and granulometric analysis was performed by means of successive sieving from 63 to 2000 μm (AFNOR type). Semi-logarithmic grading curves were established, that permit to distinguish different ways of sediment deposition. Calculations of grain-size parameters such as Units of sediment size mean (Phi), Mean grain sizes (Mz), the standard deviation (φ), skewness (Ski) and kurtosis was carried out based on Folk & Ward (1957) equations.

Then, grain-size types are represented in the C-N Passega diagram (Passega, 1957, 1964), wherein the values of the first percentile (C) are plotted against the median (M). This diagram is applied to the study of coastal depositional environments and to differentiate the deposits of various modes of transport (uniform suspension, graded suspension, rolling).

Mineralogical analysis

Mineralogical analysis for clay and non-clay minerals were conducted via X-ray diffraction (XRD), using X'Pert Pro diffractometer.

Clay minerals were identified, with only 10 samples, on oriented mounts of non-calcareous clay-sized (<2 μm) particles (Holtzapffel, 1985). The oriented mounts were obtained following the methods described in detail by Liu *et al.* (2003). Three XRD runs were performed, following air-drying, ethylene-glycol solvation for 24 h, and heating at 500 °C for 2 h. Semi-quantitative estimation of peak areas for the main clay mineral groups of smectite (including mixed-layers) (15–17 Å), illite (10 Å), and kaolinite/chlorite (7 Å) were carried out on the glycolated curve.

Results and discussion

Sedimentary dynamics of the South Lagoon of Tunis

Results show significant variation for both silty and sandy fractions. Their percentages vary between 33 and 94% for between 6 and 67%, respectively. According to the distribution map of the fine fraction (Fig. 4), the lagoon can be divided into 3 zones:

- Eastern side of the lagoon: is dominated by sandy fraction (> 63 μm) (D_{50} vary between 140 and 300 μm).
- Central zone of the lagoon: sediments are composed by 50 to 75% of silty fraction (< 63 μm).
- Western and southern-east sides of the lagoon: are dominated by fine fraction.

The dominance of silty fraction is due to the current flow direction. Fine sediments from marine supply, terrigenous input (watershed erosion, suspended solid contained in the wastewater (ONAS, 2008) are transported and deposit in a low energy environment where current velocity does not exceed 5 cm s-1.

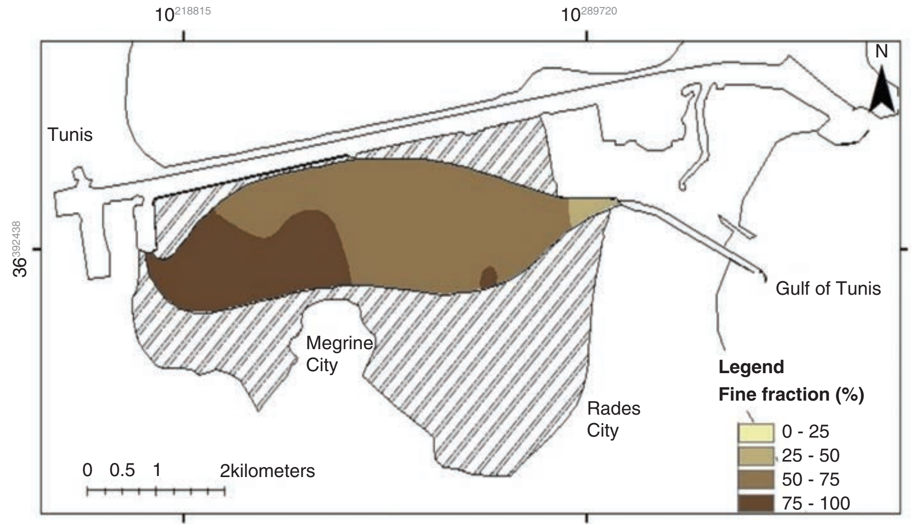

Figure 4.—The silty Fraction (%) distribution map of South Lagoon of Tunis surface sediments.

Various particle size indices are calculated (Table 1) and cumulative curves are established.

Cumulative curves reveal presence of two facies types (Fig. 5):

- The cumulative semi-logarithmic curves show S-shaped facies: found in the eastern side of lagoon (off the channel of Rades) this indicates that these sands are transported within a relatively turbulent environment, corresponding to the gulf sediment supply.
- The cumulative semi-logarithmic curves show hyperbolic-shaped facies: were found in the majority of the samples from the South lagoon of Tunis. This indicates that these sands are transported within relatively calm hydrodynamic conditions. These sediments are deposited by settling and they show a predominance of the fine fraction.

Granulometric indices

From the cumulative curves, we calculated the particle size indices surface sediments of the South Tunis lagoon (Table 1).

Mean grain sizes:

Mean grain size range from 1.85 to 2.94µm. These facies consist of fine to medium sand (Folk & Ward, 1957). According to calculated values, there are two groups:

- Medium sand is present in samples from the eastern side of the lagoon.
- Fine sand is found in the majority of the lagoon.

Standard deviation

The standard deviation values, ranging from 0.18 to 1.12, indicate that the most of sand of the lagoon is moderately sorted to poorly sorted in the eastern side of the lagoon, near to channel of Rades.

Coefficient of skewness

The skewness of the surface sediment varies from -0.43 to 0.22. Skewness variation shows a decreasing trend from the east towards the west. Its variation coefficient indicates:

Table 1.—Granulometric indices of surface sediments of South lagoon of Tunis

Samples	X	Y	Sandy fraction (%)	Silty fraction (%)	Mean size	Standard deviation	Coefficient of Skewness (Ski)
C1	10.272	36.797	67	33	2,78	0,81	-0,15
C2	10.266	36.797	45	55	1,85	1,11	0,13
C3	10.266	36.795	52	48	1,99	1,12	0,14
C4	10.257	36.79	7	93	2,3	1,08	0,08
C5	10.255	36.795	33	67	2,19	1,06	0,1
C6	10.254	36.8	6	94	2,16	0,96	0,16
C7	10.242	36.801	52	48	2,35	0,98	0,04
C8	10.243	36.796	50	50	2,24	1,06	-0,01
C9	10.243	36.79	40	60	2,37	1,01	0
C10	10.236	36.79	14	86	2,14	1,05	0,11
C11	10.235	36.795	6	94	2,12	0,94	0,09
C12	10.235	36.8	41	59	2,26	1,06	0,05
C13	10.228	36.799	23	77	2,21	1,09	-0,05
C14	10.228	36.795	38	62	2,15	0,92	0,22
C15	10.231	36.789	10	90	2,56	0,89	-0,07
C16	10.222	36.788	9	91	2,76	0,82	-0,14
C17	10.222	36.791	24	76	2,58	0,92	-0,07
C18	10.221	36.796	26	74	2,46	1	-0,11
C19	10.216	36.791	15	85	2,67	0,82	-0,15
C20	10.216	36.788	6	94	2,57	0,91	-0,1
C21	10.212	36.791	19	81	2,94	0,87	-0,43

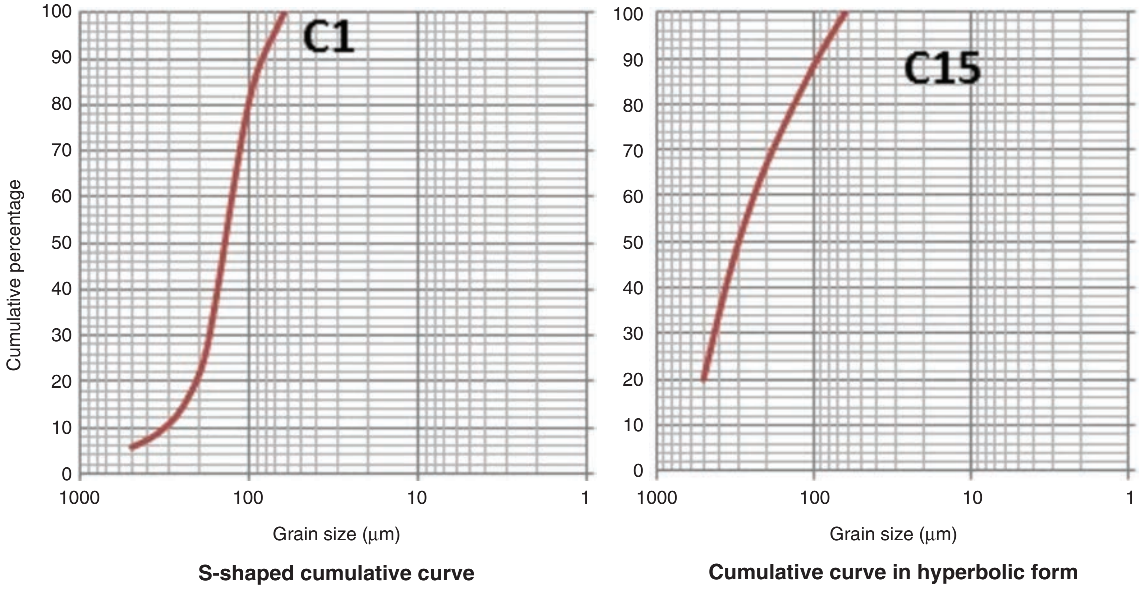

Figure 5.—Example of cumulative curves of South Lagoon of Tunis surface sediments Tunis.

- Very asymmetric frequency curves of coarse sands, for samples located near to the two locks.
- Symmetric frequency curves of coarse sand for the central part of the lagoon.
- Asymmetric frequency curves of coarse sand, for samples located in western zone of the lagoon. It seems to be an intermediate facies area between the two extreme zones.
- Asymmetric frequency curves of fine sand, mainly in the eastern part and near the water discharge points.

The Passega diagram

The Passega diagram (Passega, 1957) of representative points in surface sediments of South lagoon of Tunis shows the first percentile values ranging from 815 to 971 µm, with the median percentile values ranging from 110 to 299 µm (Fig. 6). Based on this representation the following modes of sediment transport were distinguished:

- Sediments transport by thrust, represented by PO segment, it concerns sediments taken near the banks of the lagoon.
- Fine sand is transported by saltation, represented by the QP segment. It concerns almost the majority of sediments in the central areas of the lagoon and the west side near to the lock.

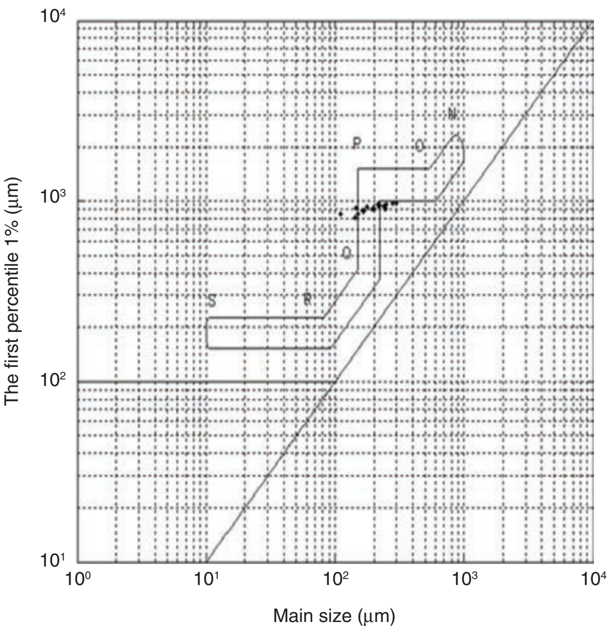

Figure 6.—Passega diagram: Surface sediment transport modes.

Mineralogical analysis

Results of the semi-quantitative mineralogical analysis are given in Table 2. They showed that the main non-clay minerals are quartz, calcite, aragonite, pyrite and magnetite. Analysis indicates that the calcite and quartz are predominant whit highest proportions, whereas aragonite, pyrite and magnetite are

Table 2.—Relative percentages of non-clay minerals in South Tunis Lagoon sediments

Samples	Quartz	Calcite	Aragonite	Pyrite	Magnetite
C1	69.49	30.51	0	0	0
C2	49.85	42.69	0	0	0
C3	40.21	59.79	0	0	0
C4	43.7	50.42	0	0	0
C5	45.56	48.79	0	0	0
C6	43.7	56.96	0	0	0
C7	56.81	42.7	6.57	0.94	0
C8	60.71	35.67	3.31	0.49	0
C9	67.76	25.3	8.2	0	0
C10	51.71	48.03	0	1.28	0
C11	46.46	48.19	0	1.18	0
C12	57.55	35.94	8.02	0.94	0
C13	51.97	44.48	0	1.31	0
C14	48.77	35.74	7.79	0.82	0
C15	12.9	81.94	0	0.65	0
C16	46.12	44.57	0	1.16	0
C17	59.22	34.47	0	0.49	0
C18	53.63	31.55	2.7	1.31	1.35
C19	33.7	49.02	0	1.75	1.35
C20	46.64	43.08	1.58	0.79	1.35
C21	50.83	38.75	5	0	0

detected in few samples. The distribution of semi-quantitative percentages of these minerals (Fig. 7) shows that:

Quartz is the most abundant mineral, with relatively high contents ranging from 13 to 69%. Its content increases from the east lock to the west of the lagoon. The quartz in the lagoon originated mainly from Quaternary lithological formations outcropping in the catchment.

Calcite is abundant in all samples, with proportions varying from 25.3 to 81.94%, which may have originated chemically through direct precipitation of biogeochemical limestone (Harbridge *et al*., 1976; El Arrim, 1996; Essonni, 1998). The prevailing semi-arid conditions have given rise to extensive carbonate deposition. The highest values are recorded in front of discharges wastewaters discharges points and in the south part of the lagoon due to the current direction and the effect of terrigenous detrital inputs (Harbridge *et al.,* 1976; El Arrim, 1996; Essonni, 1998; Oueslati *et al.,* 2018).

Pyrite is present in majority of collected samples with low level ranging from 0.49 to 1.75%. This mineral is generally associated to fine fraction and characterize reducing conditions in the depositional environment.

Aragonite is present in some sediment samples collected in the central zone of the lagoon and close to the banks, at percentage of 8.2%. Aragonite is common in biogenic marine sediments.

Magnetite is present in few samples close to the wastewater discharge points at a percentage of 1.35%, reflecting the important role of water discharge as a source of iron input.

For clay minerals, the lagoon sediments consist mainly of kaolinite (ranging from 27 to 72%.), illite (between 15 and 48%) and with a few samples containing less than 40% of smectite (Fig. 7). The dominance of kaolinite content in clay mineral components in the lagoon suggest the influence of catchment sediments supply. They are transported by low hydrodynamic and then deposited by gravity.

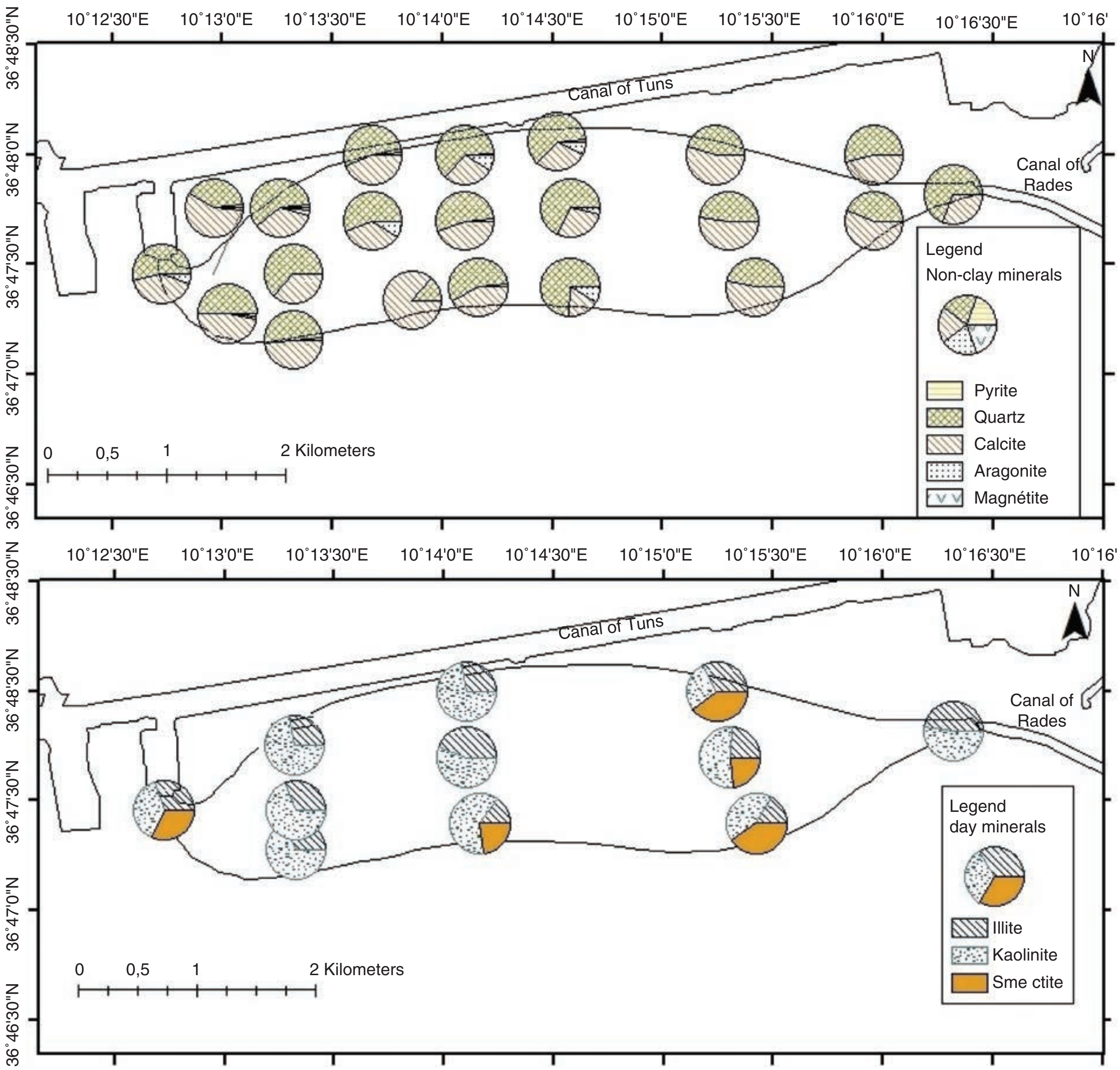

Figure 7.—Clay and non-clay minerals distribution map of the South Lagoon of Tunis surface sediments.

These minerals tend to settle in quite areas. At some locations, near the banks, smectite are detected and reached 40%. The deposition of this mineral is usually due to the phenomenon of electrochemical and/or organomineral flocculation.

Impact of the restoration project

Before the restoration project, the lagoon was covering 1300 hec. Its shape was irregular. The bathymetry was less than 1m. Water circulation in the lagoon was dominated by wind and was very sluggish. Anthropogenic activities generate most of the lagoon sediment. Sludge is the most abundant sediment (Harbridge *et al.,* 1976). Bottom sediment is mainly calcareous sandy mud with rich organic material. Sand-size grains commonly include quartz, dolomite, gypsum, and pyrite. Principal sources of sediment sewage sludge and fill, calcareous marine organisms, including abundant worm reefs, and local intermittent streams (Harbridge *et al.,* 1976).

The restoration project (1998-2001) has put remarkable structural modifications on the lagoon (Fig. 8). The South lagoon of Tunis became a

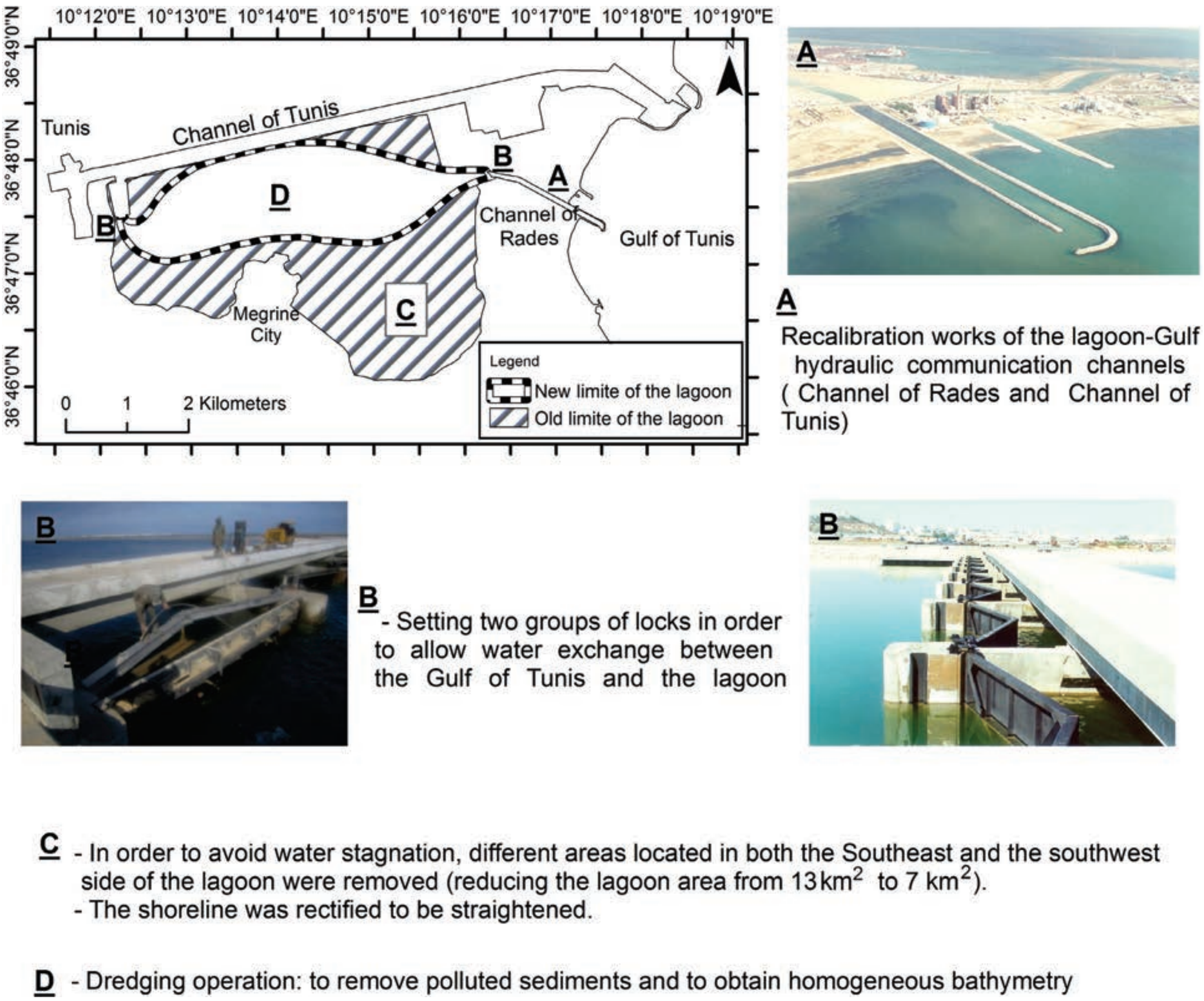

Figure 8.— Plan of restoration works.

protected zone, especially from the material supply from the Gulf of Tunis. The influence of the lagoon's currents seems to be limited in the eastern zone of the lagoon (in front of the channel of Rades). Thus, the sitting process seems to dominate over sedimentation which produces sediments enriched in fine fraction. On other hand, sand supplies contribution from the Gulf via channel of Rades, appears to be limited to reach the entire lagoon. Further, the current into the lagoon favors a selective deposition of the fine fraction. Therefore, a relative fine material enrichment of sediment is of the western deposition zone.

Sediments derived from various source rocks have different mineral assemblages (Chen et al., 2000; Liu et al., 2008), so they can be used for determining sediment provenance (Shao et al., 2001, 2009). The sediment of the South lagoon of Tunis doesn't show significant compound variations, it's mainly composed of calcite and quartz for non-clay mineral and by illite, kaolinite and smectite for clay mineral. After the restoration project, pyrite and magnetite are detected into the front zone of the urban (industrial and domestic) wastewater, enriched by organic matter (sulfides, iron oxides...) and heavy metals.

Similar case to the South lagoon of Tunis, the lagoon of Venice suffered from environmental problems caused by human pression and the exponential industrial development in its watershed (Brambati *et al.,* 2003). In order to resolve this environmental deterioration, a program was undertaken to restore the morphology and to improve the water quality of the lagoon. Like the South lagoon of Tunis, the restoration project is based in dredging activities controlling polluted supply and improving water circulation. They try to control the incoming for materials from the Gulf and from the catchment area by intercepting rivers flow and force them to bypass. This intervention was followed by the construction of breakwaters at the lagoon inlets (number of three). They dredged the lagoon channels (or inlets). However dredging action was limited in space and did not cover the entire lagoon (Bettinetti *et al.,* 1996, Solidoro *et al.,* 2010).

Those actions have not complied the expected goals. A negative sediment balance was established: appearance of erosion phenomena, in a side, and filling of the channels in other side of the lagoon, unlike the South lagoon of Tunis that seems to be equate equilibrium.

Hence, the choice of intervention depends on the objectives of restoration, also the success of any project must be discussed regarding different parameters of the ecosystem. A preliminary multidisciplinary study can help in orienting further restoration activities in order to fill the major gaps and to improve opportunity to success in long terms.

Conclusions

The analysis of grain size shows that the fine fraction (>63 μm) cover the majority of the bottom lagoon.

The calculation of the fine fraction proportion and the interpretation of the semi-cumulative curves of coarse fraction lead us to a subdivision the lagoon in two zones: the extreme eastern side of the lagoon that is covered by medium to fine sand, and the rest of the lagoon, characterized by fine fraction. This grain-size sorting is governed by the east-west lagoon currents. The sediment transport is related to lagoon water current, causing appears of relatively calm areas that can be place of suspended materials accumulation.

The limited amount of sand is under the effect of infrastructure construction (the dike of channel of Rades) which acts as a physical barrier. Thus, it noticeable that after the restoration project the sedimentary behavior of the lagoon seemed to be fairly stable.

The mineralogy of the studied samples showed that calcite and quartz are the main non-clay minerals and illite, kaolinite and smectite, as clay mineral, are dominants. The lagoon is essentially fed by sedimentary supply from the surrounding areas.

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