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Grain Size Data Analysis of Marine Sediments from the Gulf of Oran (Algerian West Coast)

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ABSTRACT

Background and Objective: The characterization of sediment grain sizes and their spatial distributions are key input parameters to study the nature and texture of the seabed substrate. The aim for analysis of these parameters makes it possible to identify the distribution of sediments and a better understanding of the spatial distribution of benthic communities in the soft bottoms of the Gulf of Oran. **Materials and Methods:** Sediment samples were collected and studied from the sampling of 36 stations, ranging in depth from -30 to -106 m. All samples were analysed for their grain size distribution and statistical relationships. **Results:** The study area is mainly composed of sand and gravel. The sand content of the stations studied is between 19.14 and 89.71% and that of the gravel is between 80.0 and 2.14%. Most stations in the Gulf of Oran contain less than 5% muddy sediment. Five important sedimentary facies and a small zone of reduced mud are identified. **Conclusion:** Sand is found often mixed with gravel. The sediments of the stations near the coasts are very affected by urban and industrial pollution. The sediments at all stations are generally varied and influenced by hydrodynamics, turbidity and wave dynamics.

KEYWORDS

Grain size, spatial distribution, soft bottom, sediments, benthic communities, Gulf of Oran, Algerian West Coast

INTRODUCTION

The grain size analysis of marine sediments is considered a basic tool in marine environmental research. This information on sediment characteristics is needed, for studies on sediment contamination and the ecology of benthic communities[1-3]. The grain size is considered a basic feature of the marine environment, which have to be characterized because it influences biotic and abiotic aspects[4,5].

Grain size analysis is a fundamental tool for classifying unconsolidated materials and sediments and sedimentary environments. Quantitative analysis of the percentages of different particle sizes yields one of the most fundamental physical properties of soft-bottom sediments. Coastal sediment data analyses play a role in understanding coastal habitats and help determine the extent, nature and transport of pollutants[6,7].

It should be noted that few works have been carried out on the sedimentary cover of the Algerian West Coast[8,9].

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In this context, our research analyzes the grain-size distribution of the soft bottom of the Oran Coast to investigate the sedimentary environment of the Gulf of Oran and to better understand then the spatial distribution of the benthic fauna.

MATERIALS AND METHODS

Study area: The study area is located in the Gulf of Oran, from the Algerian West Coast and was carried out at the laboratory of Eco-development of Space of the University of Sidi Bel Abbès, Algeria, from February to May, 2019. This coastal water is exposed to different pollution whose origin is the urban concentration and socio-economic development: Harbours activities, urban and industrial wastewater discharges. This marine ecosystem is also under threat because of amplified tourism activities[10-12].

The Gulf of Oran is supplied by waters originating from the Atlantic Ocean. The circulation seems to be very turbulent along the African Continent[13]. These turbulences favour the dispersion of eventual pollution sources and permit a so relative important food chain development[14,15].

Sediment sampling: According to the bathymetry of this zone, 36 stations prospected sites in winter during February, 2019. Aberdeen benne (Smith McIntyre) has been used for the sediments sampling operations. Sediments were collected from 0.2 m^2 and preserved in plastic bags. For bottom measurements of temperature and salinity, the Niskin bottle was used. The nearest coast station was at 30 m depth and the most far was at 110 m depth (Table 1).

Sediment grain size measurements: The collected surface sediment samples were subjected to grain-size analysis in May, 2019 in the laboratory of eco-development of space (University of Sidi Bel Abbès). Collected sediments were dried in sunlight and 100 g of sediment from each of the fifty locations was further dried in an oven for 1 hr at 50°C temperature. The method used consists of passing the dried sediment (100 g) through a column of 16 superimposed sieves. Various mesh sizes have been used for grain size analyses, which are 2500, 1600, 1250, 630, 500, 400, 315, 250, 200, 160, 125, 100, 80, 63, 50 and 40 µm. After 15 min of sieving using a "Fritsch" type vibrator, the residue from each sieve is weighed and then converted into a cumulative percentage (%) by weight, into cumulative masses and then into a cumulative percentage.

Data analysis: To compare sedimentary environments with each other quantitatively, it is necessary to calculate measures of the median (Q2 mm) and sorting coefficient (So.phi), of samples taken. Surface sediments are generally composites of various grain sizes. Thus, we divided sediments in the study area into three classes: Sand (S), gravel (G) and mud (M). The nature of the sediment grain varies according to the median: Gravel (Q2>2 mm), Sand (2>Q2>0.05 mm) and mud (Q2<0.04). The sands are divided into 4 fractions: Very coarse sand (2>Q2>1 mm), coarse sand (1>Q2>0.5 mm), medium sand (0.5>Q2> 0.25), fine sand (0.25>Q2>0.125)[16].

Trask sorting (So), is a sediment classification index. If its value is low, the sediment is well classified by hydrodynamic actions[17]:

- **So <2:** Very well classified sediment
- **2≤ So ≤2.6:** Well to moderately well-classified sediment
- **So >2.6:** Poorly to very poorly classified sediment

The contents of organic matter in the sediments are estimated using the combustion technique. About 5 g (P_1) of sediments dried in the oven at 80°C, for 24 hrs, are incinerated at 600°C in a muffle furnace for 2 hrs, then we weigh again (P_2). The difference between the two weights (P_1-P_2) represents the quantity of organic matter contained in the analyzed sediment, transformed into a percentage (MO %).

Table 1: Geographical coordinates and physical characteristics of the studied sites

Site	Coordinates (N)	Coordinates (E)	Depth (m)	Surface temperature (°C)	Bottom temperature (°C)	Surface salinity (mg L^{-1})	Bottom salinity (mg L^{-1})
1.10	35°47'95"	00°41'55"	102	15	14	36.4	37.7
2.1	35°44'23"	00°41'08"	46	15	15	36.4	36.7
2.2	35°44'95"	00°40'05"	73	15	15	36.4	37.0
2.3	35°45'80"	00°40'90"	81	15	14	36.4	37.2
2.4	35°46'70"	00°40'60"	82	15	14	36.5	37.2
2.6	35°48'50"	00°40'35"	98	15	14	36.4	37.7
3.1	35°44'38"	00°40'25"	61	15	15	36.4	36.8
3.2	35°45'05"	00°40'00"	73	15	15	36.4	36.9
3.3	35°45'85"	00°39'80"	81	15	14	36.5	37.1
3.4	35°46'90"	00°39'50"	82	15	14	36.4	37.3
3.5	35°47'90"	00°39'25"	91	15	14	36.1	37.3
3.6	35°48'50"	00°38'80"	91	15	14	36.4	37.5
4.1	35°42'00"	00°39'03"	42	14	15	36.3	36.5
4.2	35°43'05"	00°39'00"	66	14	15	36.4	37.0
4.3	35°44'05"	00°39'00"	74	14	15	36.4	37.1
4.4	35°44'09"	00°38'09"	77	15	15	36.4	37.1
4.5	35°46'05"	00°38'05"	77	15	14	36.4	37.2
4.6	35°47'03"	00°78'01"	82	17	14	36.4	37.2
4.7	35°48'02"	00°73'05"	84	15	14	36.4	37.1
4.8	35°49'50"	00°37'40"	110	15	14	36.4	35.6
6.4	35°44'68"	00°35'67"	39	15	15	36.3	36.6
6.5	35°45'42"	00°35'70"	55	15	15	36.4	36.7
6.6	35°47'55"	00°35'85"	61	15	14	36.4	36.7
7.4	35°47'10"	00°34'60"	60	15	15	36.4	36.6
7.5	35°46'77"	00°34'45"	70	15	15	36.4	36.5
7.6	35°48'96"	00°34'50"	60	15	15	36.4	36.70
7.7	35°47'10"	00°34'60"	60	15	15	36.4	37.1
7.9	35°48'50"	00°35'50"	80	15	15	36.4	36.8
7.10	35°49'15"	00°35'55"	100	15	15	36.4	37.3
8.3	35°47'10"	00°33'30"	32	15	15	36.4	36.6
8.4	35°47'40"	00°33'50"	41	15	15	36.5	36.5
8.5	35°47'60"	00°33'65"	49	15	15	36.4	36.6
8.6	35°48'20"	00°34'00"	61	15	15	36.3	36.8
8.7	35°48'70"	00°34'75"	70	15	15	36.4	36.8
8.8	35°49'20"	00°34'55"	80	15	14	36.4	37.2
8.10	35°49'78"	00°34'95"	95	15	14	36.4	37.2

We used R 3.5.2 (R Development Core Team 2019) to analyze our data. Non-parametric Statistical tests are performed to support the interpretation of the results, such as Spearman's rank correlation coefficient. Spearman's rank correlation coefficient (Rho de Spearman) is used to understand the strength of the relationship between two variables (depth and grain size percentage).

We used Folk ternary diagrams and grain size analysis data and maps of sediment spatial distribution were produced by Geographic Information Systems (GIS) software: *MapInfo* (version 8).

RESULTS

Sediment distribution characteristics: The granulometric analysis allows the size and distribution evaluations of the particles constituting the sediment. As presented in the results, the sand comprised the largest fraction of surface sediments, followed by gravel and mud. For all stations, the sediment is well classified by the hydrodynamic actions (So <2). For the other stations in the Gulf of Oran, the values of organic matter are between 58.00% at station 4.3 and 21% at station 7.9. For the coastal stations (2.4, 2.6, 3.6 and 4.8), the values are zero (Table 2).

The characteristics of sedimentary environments within the study area could then be determined based on the spatial distribution of the three grain-size fractions.

Table 2: Sediment grain sizes characteristics

Site	Median Q2. (mm)	Median Q2. (phi)	Sort. So. (phi)	Gravel (%)	Sands (%)	Muddy (%)	Organic matter (%)
1.10	0.292	1.778	0.000	26.43	58.71	14.86	33.00
2.1	0.263	1.928	0.559	2.14	89.71	8.14	46.00
2.2	0.234	2.093	0.000	14.57	62.56	22.87	43.00
2.3	0.347	1.527	1.032	14.43	76.87	8.70	29.00
2.4	0.346	1.531	0.888	12.43	74.03	13.54	0.00
2.6	0.340	1.556	0.000	64.43	31.29	4.29	0.00
3.1	0.372	1.425	0.000	30.14	59.71	10.14	42.00
3.2	0.177	2.496	0.000	56.43	34.29	9.29	48.00
3.3	0.560	0.836	0.000	45.29	50.86	3.86	33.00
3.4	0.466	1.102	0.000	37.29	60.71	2.00	35.00
3.5	0.461	1.119	0.000	39.00	53.43	7.57	35.00
3.6	0.348	1.521	0.000	59.86	26.86	13.29	0.00
4.1	0.173	2.531	0.250	10.29	86.43	3.29	46.00
4.2	0.215	2.218	0.000	31.57	51.71	16.71	55.00
4.3	0.343	1.546	0.000	15.57	75.00	9.43	58.00
4.4	0.209	2.261	0.000	54.14	42.71	3.14	53.00
4.5	0.379	1.398	0.000	27.14	66.14	6.71	40.00
4.6	0.328	1.608	0.000	48.86	46.70	4.44	37.00
4.7	0.389	1.361	0.000	24.57	72.43	3.00	44.00
4.8	0.357	1.487	0.000	61.71	37.74	0.54	0.00
6.4	0.305	1.711	0.423	6.00	93.57	0.43	27.00
6.5	0.186	2.425	0.000	48.86	45.71	5.43	35.00
6.6	0.363	1.462	0.000	23.14	74.43	2.43	27.00
7.4	0.339	1.559	0.000	73.14	26.43	0.43	24.00
7.5	0.624	0.680	0.000	48.29	49.00	2.71	38.00
7.6	0.372	1.426	0.000	52.86	47.14	0.00	13.00
7.7	0.496	1.012	0.000	77.29	22.70	0.01	37.00
7.9	0.400	1.322	0.000	67.00	32.71	0.29	21.00
7.10	0.340	1.557	0.000	67.86	30.29	1.86	26.00
8.3	0.514	0.961	0.000	19.43	80.29	0.29	32.00
8.4	0.186	0974	0.000	48.86	45.71	5.43	41.00
8.5	0.551	0.861	0.000	80.00	19.14	0.86	43.00
8.6	0.399	1.325	0.000	67.00	30.86	2.14	38.00
8.7	0.411	1.283	0.000	31.29	67.14	1.57	44.00
8.8	0.326	1.618	0.000	54.00	43.43	2.57	42.00
8.10	0. 462	1.114	0.000	72.86	25.86	1.29	33.00

Table 3: Distribution of muddy sediment

Zone	Mud (%)	Stations
1	<5	8.3, 8.5, 8.6, 8.7, 8.8, 8.10, 7.4, 7.5, 7.6, 7.7, 7.9, 7.10, 6.4, 6.6, 6.6, 4.1, 4.4, 4.6, 4.7, 4.8, 3.3, 3.4, 2.6
2	5-10	2.1, 2.3, 3.2, 3.5, 4.3, 4.5 , 6.5
3	10-15	1.10, 2.4, 3.1, 3.6
4	>15	2.2, 4.2

Spatial distribution of muddy sediments: All stations contain muddy sediment. The Gulf of Oran is subdivided into 4 areas according to their percentage. The mud rate is very low in the Gulf of Oran, except at stations 2.2, 4.2, 2.4 and 3.6, where we note, respectively 22.87, 16.71, 13.54 and 13.29%. The lowest rates of mud are noted at stations 7.7 (0.01%), 7.9 (0.29%) and 8.3 (0.29%).

The Gulf of Oran is subdivided into 4 areas according to the mud percentage (Table 3). Zone 1 occupies most of the bottom of the Gulf of Oran, with 23 stations, which extend from Cape Kristel to the port of Oran, between 32 and 42 m in depth. This same area also exists off Mers El Kébir between 70 and 106 m depth. Zone 2, is much less important than the first. The 7 stations in this area, which extend offshore to a depth of 100 m, are located mainly in the Western part of the gulf. Zone 3 and Zone 4 occupy a very small area, with respectively 4 and 2 stations located near the two ports of the Gulf. Most of the stations in the Gulf of Oran contain less than 5% muddy sediment (Fig. 1).

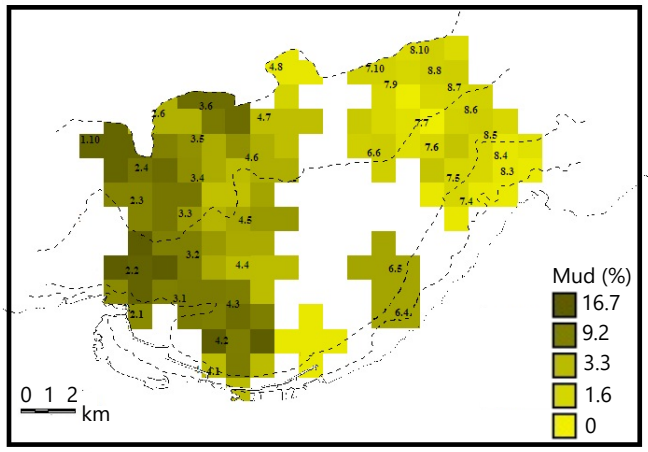

Fig. 1 : Distribution of muddy sediment in the Gulf of Oran

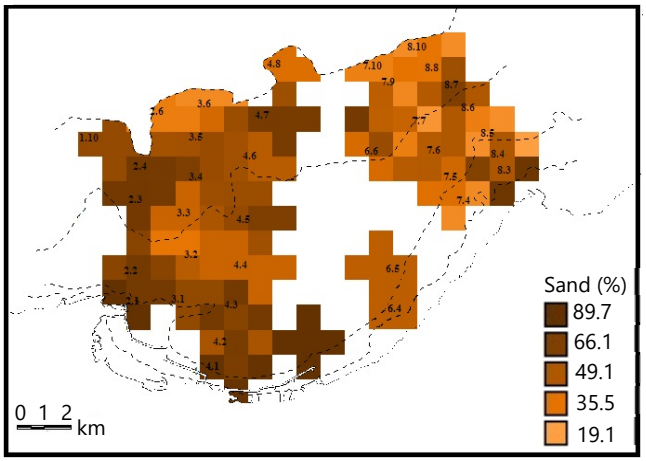

Fig. 2: Distribution of sand sediment in the Gulf of Oran

Spatial distribution of sand: The sands have a median between 0.5 and 2 mm. The maximum value of the median is located at station 7.5 (0.624 mm) and the minimum value is recorded at station 4.1 (0.173 mm). The sand content of the stations studied is between 19.14 and 89.71%. The highest rate of sands (89.71%) is noted at stations 2.1 and 4.1 (86.43%), near the port of Mers El Kebir and the lowest rate (19.14%) at station 8.5. Fine sands cover a small part of the bottom of the gulf, near the ports (stations 4.1 and 6.5). Coarse sands also cover a small part of the gulf, off Kristel between -32 and -49 m (8.3, 8.5 and 7.5) and off the port of Mers El Kebir at 81 m depth (station 3.3). Medium sands occupy the rest of the Gofe d'0ran, from 40-106 m deep. The sand is associated with gravel and the shells of gastropods, bivalves and Bryozoairs, in all stations (Fig. 2).

Spatial distribution of gravels sediment: Gravels are found in all the stations studied. The highest rate of gravel (80.0%) is noted at station 8.5, East of the Port of Oran, near the cliffs of canastel and the lowest rate (2.14%) at station 2.1 (Fig. 3).

The statistical analysis showed that there is a significant correlation only between the depth and the sands (Sig. <0.05), for the 36 stations studied in the Gulf of Oran (Table 4).

According to the results of grain-size analysis, the classification and naming of sediments in the study area were determined according to the Folk ternary diagram triangle method and nomenclature (Fig. 4).

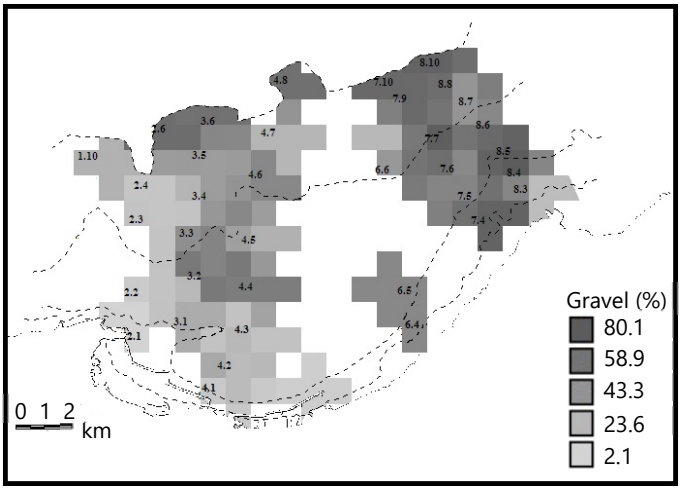

Fig. 3: Distribution of gravel sediment in the Gulf of Oran

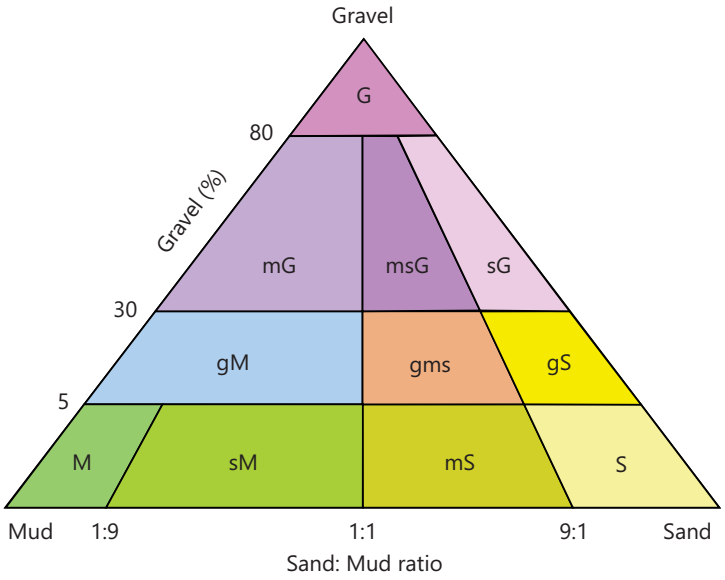

Fig. 4: Folk ternary diagram[4]

M: Mud, sM: Sandy mud, mS: Sandy mud, S: Sand, gM: Gravelly mud, gms: Gravelly muddy sand, gS: Gravelly sand, mG: Muddy gravel, msG: Muddy sandy gravel, sG: Sandy gravel and G: Gravel

The analysis of the sediments made it distinguish in order of importance five important sedimentary substrates and a small area of reduced mud and the sedimentary cover were obtained using the *MapInfo* software (Fig. 5):

- Muddy sandy gravel (msG), spread throughout the gulf, along the coast from the harbour of Mers El Kébir to Kristel and throughout the central part of the port of Oran
- Gravelly sand (gS), is found in the Eastern part of the Gulf between -49 and -100 m and off the harbours of Mers El Kébir and Oran, between -77 and -100 m deep
- Sand gravel (sG), is found off the port of Mers El Kébir, between -61 and -90 m and in the Western part of the extension of Mers El Kébir between 80 and 100 m deep
- Fine sands (S), is located near the port of Mers El Kébir
- Muddy sandy (mS), occupies a small area to the East of the port of Oran, opposite the cliffs of Canastel at a depth of 39 m
- Reduced mud (M) is located near the main urban wastewater discharge of the city of Oran

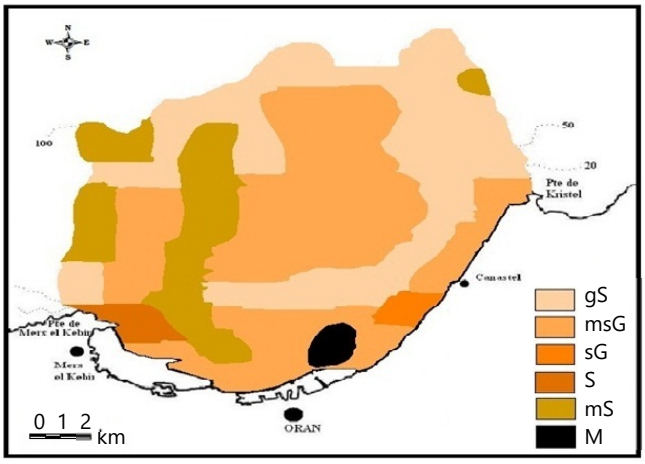

Fig. 5: Sedimentary cover of the Gulf of Oran
gS: Gravelly sand, msG: Muddy sandy gravel, sG: Sandy gravel, S: Sand, mS: Sandy mud and M: Mud

Table 4: Spearman's rank correlation coefficient correlation (Rho de Spearman)

	Depth/sand	Depth/mud	Depth/gravel
N	36	36	36
Rs	-0.3433	0.2138	0.2603
Sig.	0.040*	0.211	0.125

*Values are significant at $p<0.05$

DISCUSSION

The granulometric analysis allows the size and distribution evaluations of the particles constituting the sediment. As presented in the results, the sand comprised the largest fraction of surface sediments, followed by gravel and mud. Sands appear in the majority of the stations in the Gulf of Oran. Five important sedimentary facies are identified and all are composed of sand. Pure mud is rather absent accepting a small area near the port of Oran and urban wastewater discharge. Most stations in the Gulf of Oran contain less than 5% muddy sediment. The absence of terrestrial materials, given the non-existence of rivers in the area[18], explains the rare fine sedimentary elements (fine sand and mud). Deep-marine soft-bottom in the Gulf of Oran, show a variety of facies types, which are characterized by grain size, hydrodynamic, depth and anthropic activities. The deep-marine environment is a complex setting in which numerous processes (settling of pelagic and hemipelagic particles in the water column, sediment gravity flows and bottom currents) determine sediment deposition, hence a variety of facies[19]. The majority of the sediments are constituted by shelly fragments, in particular of benthic malacofauna (Gastropods and Bivalvia)[3,20]. This biogenic sedimentation was reported on the Algerian Coast[21,22]. The benthic sedimentation is very important[23].

Contaminations which impact littoral ecosystems result mainly from human activities (industrial, agricultural, or urban). The whole region is submitted to an important anthropic activity and waste is often introduced to the sea without further purification[12]. Intense agricultural activities in this area contribute to a more pronounced deterioration of the seawater quality. Urban and industrial (in particular petrochemicals) equipment for purification purposes does not exist in this area[10]. Thus, the particles exported and accumulated in the coastal sediments are accurate anthropic pressure gauges in this kind of environment[9]. Industrial and urban discharges (glass, plastic, iron, wood, etc.), have been reported in the sediments sampled at almost all the stations near the coast[24,25].

This study is aimed at improving the understanding of deep-marine sedimentation and indicates variation in facies types[26]. Analysis of sediment provides baseline information for global modelling of environmental change. The particle size can affect the rate a substance will dissolve[27]. Coastal sediment data analyses play

a role in understanding coastal habitats[28] and help determine the extent, nature and transport of pollutants. It is suggested to deploy the coastal sediment sample collection in the Oran Gulf area in different months of the year to decipher the temporal variation of sediment distribution and identify potential seasonal sediment flux. In perspective, other sediment sampling campaigns must be carried out to map the sedimentary cover of the coast and to define the benthic habitats for better coastal management.

CONCLUSION

The grain size distribution and statistical and basic statistics have made it possible to determine the percentage of 3 sedimentary fractions (gravel, sand and mud) and to calculate the median, Trask sorting to highlight the nature and texture of the soft bottoms of the Gulf of Oran. Sand is found in most gulf resorts, often mixed with gravel. The muddy sediments of all the stations of the Gulf of Oran are not significant. The sediments of the stations near the coasts are very affected by urban and industrial pollution (wastewater and various debris). The sediments from all the stations were in general varied and are influenced by three key factors: Marine hydrodynamics due to the current of Atlantic origin, turbidity and wave dynamics, which function to control the distribution pattern of the various sediments. Finally, this study allowed the definition of five sedimentary facies: The muddy sandy gravel, the gravelly sand, the sand gravel, the fine sands and the muddy sandy.

SIGNIFICANCE STATEMENT

This study made it possible to update the sedimentary nature of the Gulf of Oran, which can be beneficial for all researchers in marine ecology. This study will help researchers better understand the structure and distribution of benthic communities in this area. Thus, a new sedimentary database will be made available to users of the Oran Coast.

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