Computers & Geosciences 92 (2016) 104–116

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

Case study

SANDY: A Matlab tool to estimate the sediment size distribution from a sieve analysis

Gabriel Ruiz-Martínez [a,*], Germán Daniel Rivillas-Ospina [b], Ismael Mariño-Tapia [a], Gregorio Posada-Vanegas [c]

[a] Departamento de Recursos del Mar, Centro de Investigación y de Estudios Avanzados del IPN, Mérida 97310, Yucatán, México
[b] Departamento de Ingeniería Civil y Ambiental, Instituto de Estudios Hidráulicos y Ambientales (IDEHA), Universidad del Norte, Barranquilla 1569, Colombia
[c] Laboratorio de Procesos Costeros, Instituto de Ecología, Pesquerías y Oceanografía del Golfo de México, Campeche 24029, México

ARTICLE INFO

Article history:
Received 20 February 2016
Received in revised form
13 April 2016
Accepted 20 April 2016
Available online 22 April 2016

Keywords:
Sand
Sediments
Size distribution
Sieving
Coast
Rivers

ABSTRACT

This paper presents a new computational tool called SANDY© which calculates the sediment size distribution and its textural parameters from a sieved sediment sample using Matlab®. The tool has been developed for professionals involved in the study of sediment transport along coastal margins, estuaries, rivers and desert dunes. The algorithm uses several types of statistical analyses to obtain the main textural characteristics of the sediment sample (D_{50}, mean, sorting, skewness and kurtosis). SANDY© includes the method of moments (geometric, arithmetic and logarithmic approaches) and graphical methods (geometric, arithmetic and mixed approaches). In addition, it provides graphs of the sediment size distribution and its classification. The computational tool automatically exports all the graphs as enhanced metafile images and the final report is also exported as a plain text file. Parameters related to bed roughness such as Nikuradse and roughness length are also computed. Theoretical depositional environments are established by a discriminant function analysis. Using the uniformity coefficient the hydraulic conductivity of the sand as well as the porosity and void ratio of the sediment sample are obtained. The maximum relative density related to sand compaction is also computed. The Matlab® routine can compute one or several samples. SANDY© is a useful tool for estimating the sediment textural parameters which are the basis for studies of sediment transport.

1. Introduction

The size distribution (SD) and textural characteristics (TC) of sediments are fundamental tools in Sedimentology, Geomorphology and Soil sciences. This involves the estimation of the cumulative mass percentage of established size fractions of the total mass of sediment. However, the quantification of SD and TC depends on the shape and density of the sediments, for this reason different techniques have been developed to compute them, which include: sieving, pipette-hydrometer, X-ray attenuation, scanning electron microscopy and laser diffraction. In the particle size analysis with sieves, the particles pass through a set of woven wire screens, with square apertures (rigidly mounted in a shallow cylindrical metal frame), and according to their size the sediments are retained in the sieves. The sieving technique is useful when the sizes of the sediment sample are between 2000 and 50 μm. The main advantages of this technique are that it can be performed at almost any location, and sieving is a simple, quick and reliable method of size analysis. On the other hand, the disadvantage of this technique is related to the size range of fine sediments since particles < 50 μm need to be analyzed using other techniques (Gee and Bauder, 1986). The pipette and hydrometer techniques are used for particles with a size of < 50 μm (clays and silts). The X-ray attenuation technique is based on the pipette method: in a vertical container with water, the number of particles which are settling is inferred by measuring the attenuation of an X-ray over time. The quantification of the attenuation allows the concentration of the particles to be determined. The X-ray attenuation technique can be applied to samples with a size range of 0.1–100 μm (McCave and Syvitski, 1991). In the scanning electron microscopy technique, the particle sample is scanned with a high-energy beam of electrons which produces an image of the surface of the sample. Using image analysis methods, the particles can be classified in different size fractions. The size range analyzed with this technique is 1–0.005 μm (Cheetham et al. 2008).

The laser diffraction technique involves the analysis of the patterns of scattered light produced when particles of different size are exposed to a beam of light. The size distribution is computed when the composite scattering pattern is analyzed by measuring the angular variation in intensity of light scattered; the

---

[*] Correspondence to: Ant. Carretera a Progreso km. 6, Cordemex, Merida 97310, Yucatan, Mexico.
E-mail address: gruizm@mda.cinvestav.mx (G. Ruiz-Martínez).

http://dx.doi.org/10.1016/j.cageo.2016.04.010
0098-3004/

relative amplitude of each angular variation is a measure of the relative volume of equivalent spherical particles of that size. The laser diffraction technique is suitable for particle sizes between 0.017 µm and 2000 µm. Underestimation of the particle sizes can occur for finer grains when the sediments have a lower sphericity (Hayton et al., 2001).

In order to compute the statistical parameters of sediment samples, graphical and statistical methods are used (Folk, 1964). These allow the properties of the sediment sample to be expressed in terms of statistics of deviations with respect to the normal distribution function. It is also possible to express the frequency analysis on the basis of statistical-mathematical principles which cover the entire distribution of sample sizes, without practical or theoretical limitations (Inman, 1952). Parameters that depend on statistical measures, including the median, sorting, skewness and kurtosis are applied with great ease using different methodologies (moments, quartiles, logarithmic graphics methods, etc.).

A methodology adopted to analyse the size distribution and textural characteristics of sediments is to compute the statistical parameters through a logarithmic expression which describes the conversion of the diameter (d) in millimeters to a function of phi-units (ϕ), using the equation $\phi = -\log_2 d$ (Krumbein, 1936). In the case of sediments, the mean diameter of the sample is taken as a measure of central tendency. In a normal distribution, the mean is the diameter that represents the center of gravity of the frequency distribution (Inman, 1952). On the other hand, the dispersion of the sediment size distribution of the sample can be measured by means of the sorting, which is a measure of the degree of uniformity or classification of the particles of sediment. The relevance of estimating this statistical variable lies in the desire to measure the dispersion of the sediment diameters with respect to the mean. Skewness is a statistical parameter that measures the degree of asymmetry of a distribution function, and indicates the proportion of coarse (positive asymmetry) or fine (negative asymmetry) material in the sample. This characteristic is also a measure of the distribution's deviation from normality. Kurtosis is a parameter that is used to measure the peakedness of the statistical distribution. It relates to the flatness/peakedness of the distribution in comparison to a normal distribution, and therefore also represents a measure of the deviation from normality e.g. when the sediments are poorly sorted, there is a tendency for the distribution curve to be flat and therefore the kurtosis will be considered platykurtic. If the distribution curve is strongly peaked, it can coincide with sediment exhibiting a good sorting and its kurtosis is leptokurtic (Friedman and Sanders, 1978).

The use of statistical parameters such as the skewness and kurtosis serve as a mechanism for identifying the origin of sediment or sedimentary environments. Furthermore they can help to identify whether there is a source of sediment that prevails in quantity with respect to other sources or conversely, all the sources of the area have sediment types with similar characteristics (Folk and Ward, 1957; Selley, 2000).

The process for establishing the size distribution tends to be a tedious task, since it requires setting the frequency distribution of the particle size and using a graphical method or statistical moments, to determine the different percentiles of the size of the sediment. However, with the advent of calculators and personal computers, the procedure for determining the size distribution of sediment and its textural characteristics from a sample has become simple (Kane and Hubert, 1963; Schlee and Webster, 1967; Mayo 1972; Slatt and Press, 1976; Sawyer, 1977; Benson, 1981; Pye, 1989; Poppe and Elisaon, 1999; Awad and Al-Bassam, 2001; Poppe, Eliason and Hastings, 2004). Moreover, the evolution of programming languages, the development of mathematical software and the growth of the internet have enabled the scientific community to create and share computational routines that help them to rapidly process the data. At present, Excel®, Matlab®, Python™ and R™ are the most commonly used software to perform numerical calculations. For example, Blott and Pye (2001) created a macro in Visual Basic® named GRADISTAT® that is an easy-to-use tool for users who are familiar with the management of spreadsheets; furthermore, Gallon and Fournier (2013) developed G2SD® which is a library for R™; the main advantage of G2SD® is that the code has been written for freely available software.

This paper presents the computer program SANDY©, a novel tool which allows the use of statistical analysis to determine the size distribution and the main textural properties of the sediment, using Matlab®. The functioning principles are based on data from a sieved sample of sediment taken from coastal and riverine environments.

The aim of this computational routine is to estimate the main percentiles and statistical parameters of the sediment sample. In the statistical analysis it is possible to define the parameters of the distribution with the Trask (1932), Inman (1952), Folk and Ward (1957), Kondolf and Wolman (1993) methodologies. The significant moments of the distribution function are computed with arithmetic, geometric and logarithmic procedures. SANDY© employs the Wentworth (1922) and ASTM (2011) scales to classify the sediment based on the skewness and kurtosis moments, and based on the Unified Soil Classification System (SUCS) it is possible to identify whether the sample is well or poorly sorted. SANDY© is an innovative code developed with a powerful programming tool (Matlab®), which is very easy to use and has many applications that can make the calculation of sediment sample parameters efficient.

In the first section of the paper general considerations related to SANDY© are provided. The next section describes the computational routine as well as its implementation process in Matlab®. In order to validate the results of the program, in the section of calibration and validation, the results of a RMSE and MSE analysis are given. As a case study, the characterization of sands in the Riviera Maya (Mexico) is presented. The characterization was carried out using the results that were obtained with the program SANDY©. In order to study the sediment, 107 sand samples were extracted from 35 measuring stations along the coast of the Riviera Maya; the sediment samples were subjected to field and laboratory analyses. SANDY© proved to be a great tool when estimating the textural sediment parameters

2. General considerations

SANDY© is a computer program that has been developed for coastal engineers, geologists, sedimentologists, coastal oceanographers and other professionals involved in projects related to sediment transport along coastal and river margins, where sand is the predominant beach material. SANDY© is a Matlab® script which allows the user to perform a size distribution analysis of sediment from a sieved sample of sand from a beach profile, the bed of a river, an estuary, the seafloor, or inland. The computation routine has been tested for Matlab® version 6.5 (R13) to version 9.0 (R2016a). Furthermore, the tool is programmed as a user function which does not require any special toolbox and requires only that Matlab® is installed on a personal computer with an Intel® Centrino® Duo or higher microprocessor. The user license is free and the script is available on the website for this paper (Appendix B).

In order to compute the sediment parameters, the computer program considers sediment and rock sizes ranging from large boulders to very fine sand (Table 1), hence only the results of the sieve technique are used as input data. Sieving is the most accurate method for the general analysis of sand and gravel. Sediments such as silts and clays should not be analyzed by the program. Moreover, countries such as France (AFNOR), Great Britain (BS) and the US (ASTM) have standard specifications regarding the wire

Table 1
SANDY© considers the sediment size from the Udden–Wentworth scale (from Wentworth (1922)).

From (in mm and ϕ-units):	To (in mm):	Size terms:
256(−8)	128	Large boulders
128(−7)	64	Medium boulders
64(−6)	32	Small boulders
32(−5)	16	Very small boulders
16(−4)	8	Very coarse boulders
8(−3)	4	Very coarse gravel
4(−2)	2	Granular gravel
2(−1)	1	Very coarse sand
1(0)	0.5	Coarse sand
0.5(1)	0.25	Medium sand
0.25(2)	0.125	Fine sand
0.125(3)	0.063	Very fine sand

cloth and sieves used for testing purposes; the program recognizes the ANFOR ISO 3310, BS 410-1 and ASTM E11-95 nominal sieve openings standards (Table 2).

SANDY© requires two input parameters: nominal sieve openings and cumulative mass of material retained on each sieve. This information is provided to the program through a plain text file (*.txt) arranged in two columns, which should be separated by a tab space and must be located in a subfolder. This subfolder should be in the same folder where the script is located. The data in the first column correspond to the nominal sieve openings (in mm) and the second column must refer to the mass of material retained on each sieve (in grams). The data must be arranged in descending order, following the nominal sieve openings. On the other hand, material in the pan after sieving should be listed in the last row of the input file. Due to the program algorithm which solves the method of moments, on the last row, which corresponds to the pan after sieving, the value of the nominal sieve opening immediately below will be used and the mass deposited in the pan will be listed in the second column.

Based on the statistical parameters of the distribution of sand sizes, the script calculates the discriminant parameters in order to identify depositional environments, as suggested by Sahu (1964). In addition, the program provides the maximum relative density of clean sand as a function of the 50th percentile grain size and compaction energy (Patra et al., 2011); this latter parameter is particularly important for beach nourishment projects. All the equations used in the program are listed in Appendix A.

3. Sandy

SANDY© was developed in Matlab® because this numerical software is commonly used at universities, research centers and enterprises.

The data are loaded in scientific software as a numerical matrix, where the first two columns contain the input parameters. From the input data, the script generates a third column with values of the fraction retained on each of the sieves as percentages of the original test sample weight; in the fourth and fifth columns, the cumulative percentages of oversized and undersized materials are computed. The results can be readily analysed using graphical methods; SANDY© uses a piecewise cubic interpolation for computing percentiles from cumulative undersize distribution and the nominal sieve opening values; once these percentiles are known (5, 10, 16, 25, 30, 50, 60, 75, 84, 90, and 95, in mm and phi-units), their values are plotted on a semi-log graph and statistical parameters are computed using Trask (1932), Inman (1952), Folk and Ward (1957), Kondolf and Wolman (1993) methodologies. Statistical parameters are also computed with arithmetic, geometric and logarithmic approaches and the method of moments (Krumbein and Pettijohn, 1938). The program uses the Folk and Ward's (1957)

Table 2
Standard nominal sieve openings recognized by SANDY©.

Sieve (mm)	ASTM E11-95	BSI 410-1	NF ISO 3310	Sieve (mm)	ASTM E11-95	BSI 410-1	NF ISO 3310	Sieve (mm)	ASTM E11-95	BSI 410-1	NF ISO 3310
125	x	x	x	8	x	x	x	0.5	x	x	x
112		x	x	7.1		x	x	0.45		x	x
106	x	x	x	6.7	x	x	x	0.425	x	x	x
100	x	x	x	6.3	x	x	x	0.4		x	x
90	x	x	x	5.6	x	x	x	0.355	x	x	x
80		x	x	5		x	x	0.315		x	x
75	x	x	x	4.75	x	x	x	0.3	x	x	x
71		x	x	4.5		x	x	0.28		x	x
63	x	x	x	4	x	x	x	0.25	x	x	x
56		x	x	3.55		x	x	0.224		x	x
53	x	x	x	3.35	x	x	x	0.212	x	x	x
50	x	x	x	3.15		x	x	0.2		x	x
45	x	x	x	2.8	x	x	x	0.18	x	x	x
40		x	x	2.5		x	x	0.16		x	x
37.5	x	x	x	2.36	x	x	x	0.15	x	x	x
35.5		x	x	2.24		x	x	0.14		x	x
31.5	x	x	x	2	x	x	x	0.125	x	x	x
28		x	x	1.8		x	x	0.112		x	x
26.5	x	x	x	1.7	x	x	x	0.106	x	x	x
25	x	x	x	1.6		x	x	0.1		x	x
22.4	x	x	x	1.4	x	x	x	0.09	x	x	x
20		x	x	1.25		x	x	0.08		x	x
19	x	x	x	1.18	x	x	x	0.075	x	x	x
18		x	x	1.12		x	x	0.071		x	x
16	x	x	x	1	x	x	x	0.063	x	x	x
14		x	x	0.9		x	x	0.056		x	x
13.2	x	x	x	0.85	x	x	x	0.053	x	x	x
12.5	x	x	x	0.8		x	x	0.05		x	x
11.2	x	x	x	0.71	x	x	x	0.045	x	x	x
10		x	x	0.63		x	x	0.04		x	x
9.5	x	x	x	0.6	x	x	x				
9		x	x	0.56		x	x				

scale to classify the sorting, skewness and kurtosis measures.

Taking into account the mean diameter of the sand sample, SANDY© classifies the sediment using the Wentworth (1922) and ASTM (2011) scales. The script was subsequently written to establish the coefficients of uniformity and curvature. From these coefficients, 1) the type of sand is identified according to the Unified Soil Classification System (SUCS) either as well graded sand (SW) or poorly graded (SP) (ASTM, 2011), and 2) the hydraulic conductivity is obtained (Carrier, 2003).

On the other hand, the percentage of gravel, sand and fine sand determined by the computer program is set by the Wentworth scale. The depositional environments are obtained using the equations of Sahu (1964).

When the seabed or river bottom are studied in order to understand how the currents and bed interact to create ripples, sand waves, dunes, antidunes and plane beds, it is necessary to determine the depth-averaged current speed, which is a function that relates the height above bed, frictional velocity, Von Karman's constant and the dimensions of the physical roughness of the bed (Soulsby, 1997). Using the size distribution, the script computes the Nikuradse equivalent sand-roughness with the 50th percentile; subsequently, the bed roughness length value, for a hydrodynamically rough flow, is calculated by the program.

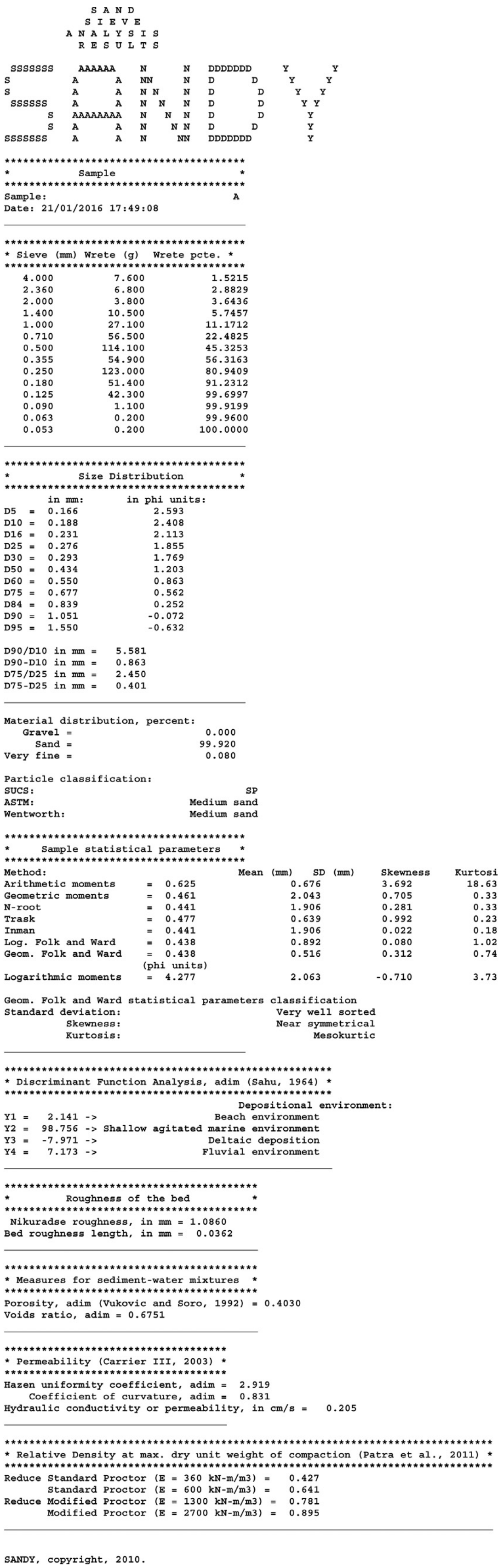
SANDY© calculates the porosity using the Vukovic and Soro (1992) equation and the sediment voids ratio is a function of the porosity. The final parameter obtained is the maximum relative density of clean sand.

At the end of the analysis, a table of results with analyses of the percentage weight of the sediment, the values of the different percentiles, the statistical parameters, as well as the classification of the sample, are exported to a plain text file (*.txt) (Fig. 1).

The routine provides the user a bar chart of sediment sizes and the graphs related to: frequency, cumulative arithmetic and arithmetic probability, cumulative logarithmic and semilogarithmic probability, the Folk and Shepard ternary diagrams, and a bar plot with the gravel, sand and fine sand percentage (Fig. 2). For plotting ternary diagrams, SANDY© incorporates the Arsenault (2006), Waite (2006) and Richards (2006) m-functions in its code. All the graphs created by the computer program are automatically exported as enhanced metafiles (*.emf) and these files are moved to the subfolder where the input file of the sediment sample is located.

In order to perform the sieve analysis of one or several samples of sediment, it is necessary to create a folder; this is the main folder for the program. For each sediment sample that requires analysis, a subfolder of the sample should be created and the input file should be within this subfolder. The main folder should contain the SANDY© program and one or more subfolders. When the program starts, the main folder is reviewed to determine whether one ("a sample") or several subfolders (multiple samples) should be analysed. The routine performs a size distribution analysis for each of the subfolders. When the calculations and plots have been completed, the results are automatically exported to the sample folder. The analysis and export of results will be repeated in a loop depending on the number of subfolders identified by the program. This feature allows the computational script to analyse multiple samples of sand in a short processing time which depends on the RAM memory and computer processor. For example, SANDY© performs the full analysis of one sand sample in 4 s on a computer with an Intel® Pentium® 4 processor and 3.00 GB of RAM, Windows platform® XP SP3 and Matlab® R2012a.

When the computational script identifies that several analyses have been performed, at the end of the calculation the program automatically provides summary graphs of the 50th percentile (D_{50}), sorting, skewness and kurtosis. SANDY© also creates plots to show the relationship between the mean and statistical measures of all samples, such as sorting, skewness and kurtosis (Fig. 3). The



```
              S A N D
             S I E V E
           A N A L Y S I S
            R E S U L T S

 SSSSSSS    AAAAAA    N      N   DDDDDDD     Y       Y
S          A      A   NN     N   D      D     Y     Y
S          A      A   N N    N   D       D     Y   Y
 SSSSSS    A      A   N  N   N   D       D      Y Y
      S    AAAAAAAA   N   N  N   D       D       Y
      S    A      A   N    N N   D      D        Y
SSSSSSS    A      A   N     NN   DDDDDDD         Y

***************************************
*           Sample                    *
***************************************
Sample:                              A
Date: 21/01/2016 17:49:08
_______________________________________

***************************************
* Sieve (mm) Wrete (g)  Wrete pcte. *
***************************************
   4.000          7.600          1.5215
   2.360          6.800          2.8829
   2.000          3.800          3.6436
   1.400         10.500          5.7457
   1.000         27.100         11.1712
   0.710         56.500         22.4825
   0.500        114.100         45.3253
   0.355         54.900         56.3163
   0.250        123.000         80.9409
   0.180         51.400         91.2312
   0.125         42.300         99.6997
   0.090          1.100         99.9199
   0.063          0.200         99.9600
   0.053          0.200        100.0000
_______________________________________

***************************************
*           Size Distribution         *
***************************************
       in mm:       in phi units:
D5  =  0.166            2.593
D10 =  0.188            2.408
D16 =  0.231            2.113
D25 =  0.276            1.855
D30 =  0.293            1.769
D50 =  0.434            1.203
D60 =  0.550            0.863
D75 =  0.677            0.562
D84 =  0.839            0.252
D90 =  1.051           -0.072
D95 =  1.550           -0.632

D90/D10 in mm =   5.581
D90-D10 in mm =   0.863
D75/D25 in mm =   2.450
D75-D25 in mm =   0.401
_______________________________________

Material distribution, percent:
   Gravel =                       0.000
     Sand =                      99.920
Very fine =                       0.080

Particle classification:
SUCS:                                SP
ASTM:                       Medium sand
Wentworth:                  Medium sand

***************************************
*     Sample statistical parameters   *
***************************************
Method:                              Mean (mm)   SD (mm)    Skewness    Kurtosis
Arithmetic moments       =  0.625             0.676       3.692      18.637
Geometric moments        =  0.461             2.043       0.705       0.339
N-root                   =  0.441             1.906       0.281       0.335
Trask                    =  0.477             0.639       0.992       0.232
Inman                    =  0.441             1.906       0.022       0.183
Log. Folk and Ward       =  0.438             0.892       0.080       1.022
Geom. Folk and Ward      =  0.438             0.516       0.312       0.742
                        (phi units)
Logarithmic moments      =  4.277             2.063      -0.710       3.735

Geom. Folk and Ward statistical parameters classification
Standard deviation:                       Very well sorted
          Skewness:                       Near symmetrical
          Kurtosis:                             Mesokurtic
_______________________________________

*****************************************************
* Discriminant Function Analysis, adim (Sahu, 1964) *
*****************************************************
                                    Depositional environment:
Y1 =   2.141 ->                    Beach environment
Y2 =  98.756 -> Shallow agitated marine environment
Y3 =  -7.971 ->                   Deltaic deposition
Y4 =   7.173 ->                  Fluvial environment
_____________________________________________________

*****************************************
*         Roughness of the bed          *
*****************************************
 Nikuradse roughness, in mm = 1.0860
Bed roughness length, in mm =  0.0362
_________________________________________

*****************************************
* Measures for sediment-water mixtures  *
*****************************************
Porosity, adim (Vukovic and Soro, 1992) = 0.4030
Voids ratio, adim = 0.6751
_________________________________________

************************************
* Permeability (Carrier III, 2003) *
************************************
Hazen uniformity coefficient, adim =  2.919
    Coefficient of curvature, adim =  0.831
Hydraulic conductivity or permeability, in cm/s =   0.205
____________________________________

****************************************************************************
* Relative Density at max. dry unit weight of compaction (Patra et al., 2011) *
****************************************************************************
Reduce Standard Proctor (E = 360 kN-m/m3) =   0.427
       Standard Proctor (E = 600 kN-m/m3) =   0.641
Reduce Modified Proctor (E = 1300 kN-m/m3) =  0.781
       Modified Proctor (E = 2700 kN-m/m3) =  0.895
____________________________________________________________________________


SANDY, copyright, 2010.
```

Fig. 1. This figure shows the SANDY© standard output file. The results of SANDY© are exported to a plain text file that can be opened with any text editor.

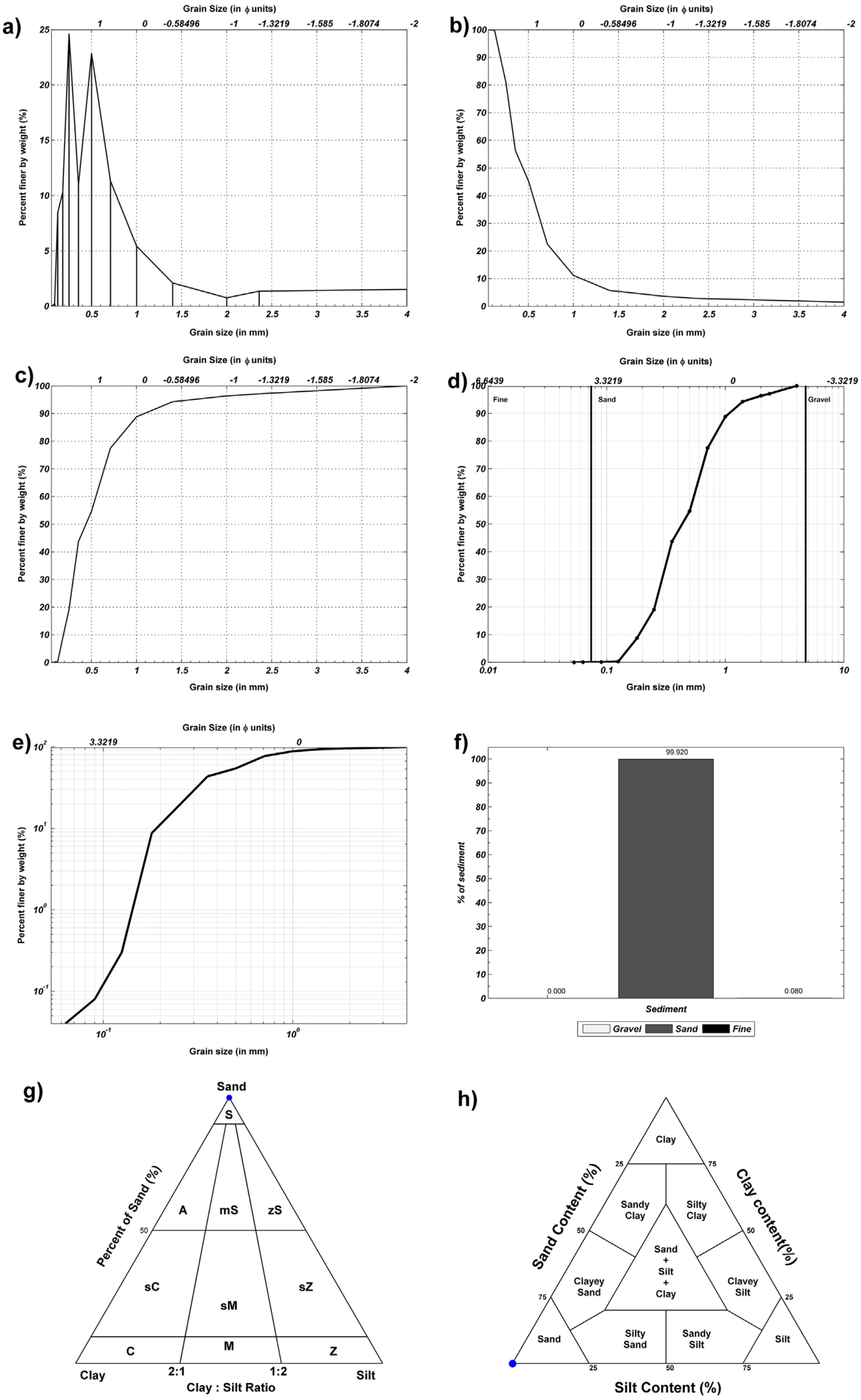


Fig. 2. Graphs generated by SANDY© to analyse the textural characteristics of a sample of sand: a) Bar plot, b) Cumulative Probability plot, c) Cumulative Arithmetic plot, d) Cumulative Probability plot (log–log), e) Cumulative Probability plot (semi-log), f) Percent of sediments plot, panels g) and h) Ternary plots.

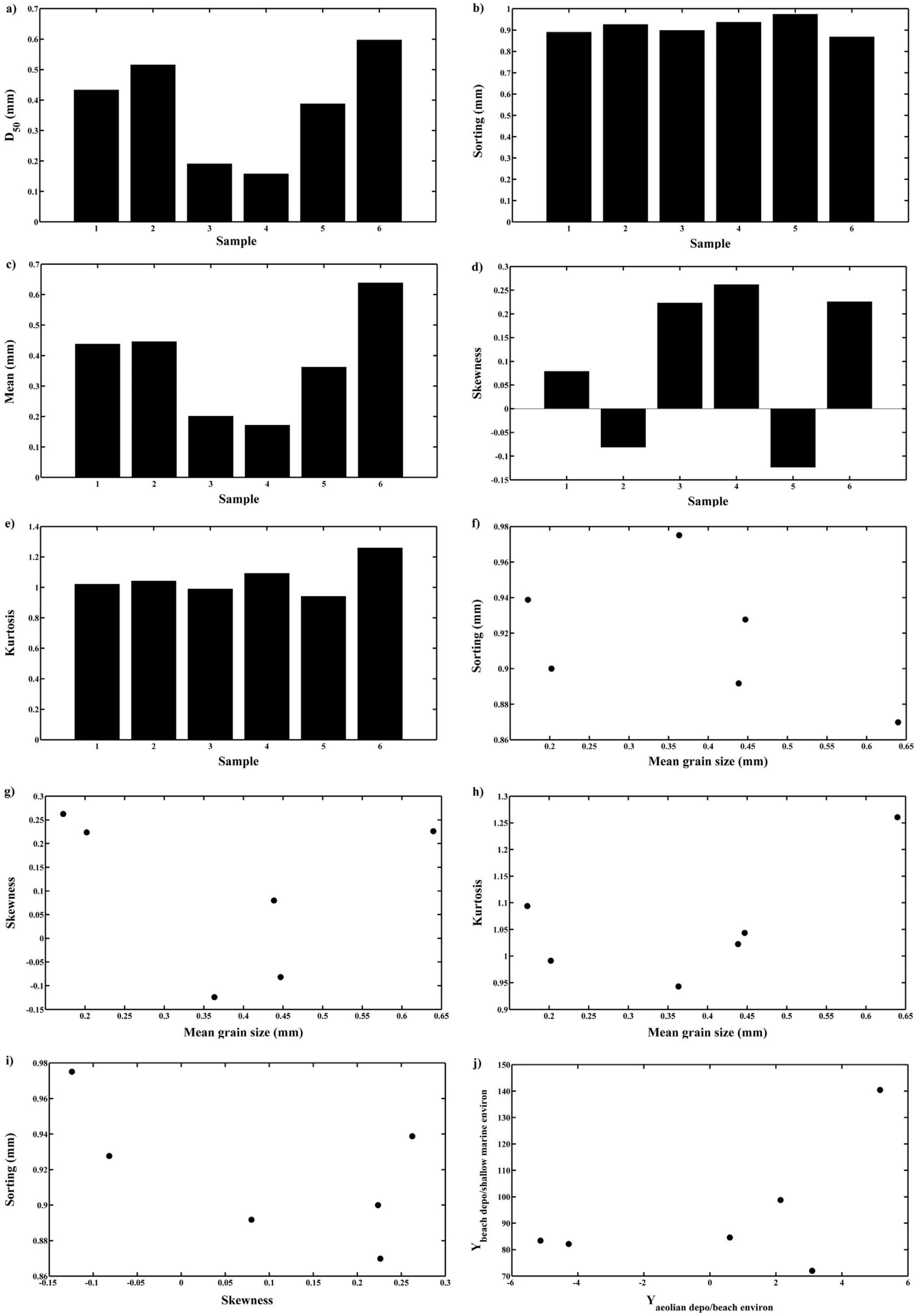


Fig. 3. SANDY© output plots for multiple samples: a) D$_{50}$, b) sorting, c) mean, d) skewness, e) kurtosis, f) mean grain size vs. sorting, g) mean grain size vs. skewness, h) mean grain size vs. kurtosis, i) skewness vs. sorting, and j) Discriminant functions.

graphs are saved as *.fig files, allowing the user to edit them later. SANDY© is coded in a high-level mathematical analysis program which uses a programming language that is very easy to learn; in addition it uses functions that allow the user to export the results in different file formats, which can be opened with other types of software.

4. Calibration and validation of sandy

During the calibration and validation process, the 10th (D_{10}), 50th (D_{50}) and 90th (D_{90}) percentiles were selected in order to evaluate the level of accuracy of SANDY©. These parameters were chosen because their values are frequently used in the sediment transport equations for beaches and rivers (Van Rijn, 2006). The calibration and validation procedure was carried out by comparing the results of SANDY© with the GRADISTAT® spreadsheet (Blott and Pye, 2001). Five test samples were analysed using both programs; the results are shown in Fig. 4. The Root Mean Squared Error (RMSE) and the Mean Absolute Error (MAE) were used to evaluate the level of accuracy of the Matlab® routine. Good agreement of the SANDY© results were obtained for the 10th, 50th and 90th percentiles. With regards to D_{90} (Fig. 4a), only sample four presented a small difference, but RMSE and MAE were still small (2.44E-03 mm and 1.88E-03 mm, respectively). The D_{50} (Fig. 4b) for both models shows similar behavior, with only one test presenting small differences; the RMSE and MAE for D_{50} were $7.59E-03$ mm and $5.6E-03$ mm respectively. In the case of D_{10} (Fig. 4c), some differences were observed for tests one and three. Values of 5.11E-03 mm and 4.28E-03 mm were obtained in the D_{10} percentile analysis, for RMSE and MAE respectively.

It is difficult to obtain an exact value of D_{50} with either of the computational routines when using the sieve methodology.

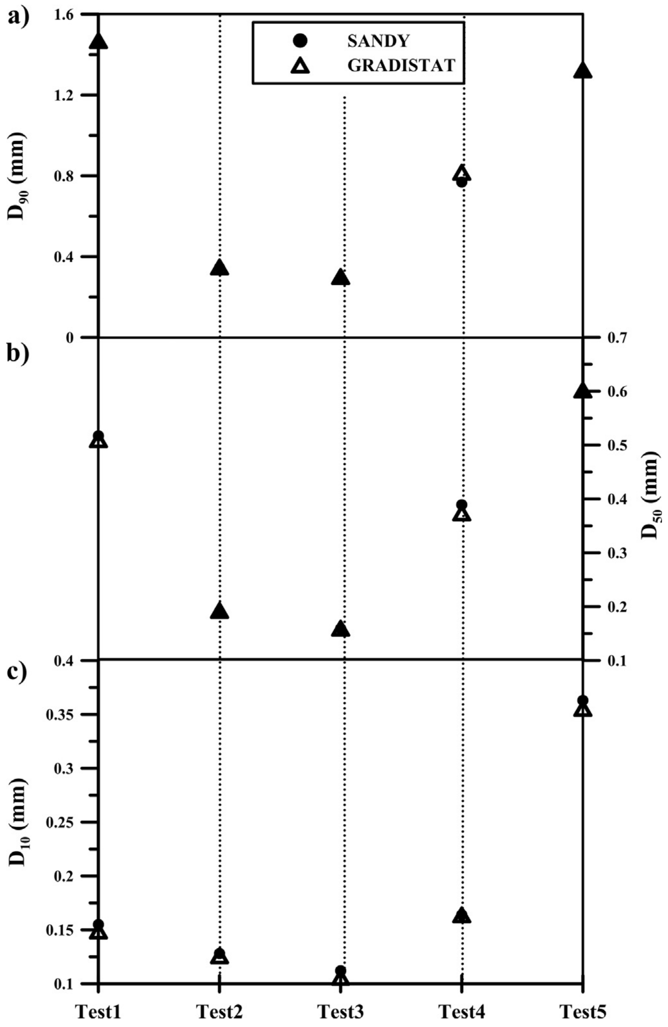


Fig. 4. The D_{10}, D_{50}, D_{90} of five sand samples calculated by SANDY© (triangles) and with GRADISTAT© (black dots). a) the comparison of D_{90}, b) the D_{50} values and c) the D_{10} percentile value.

Different methods can be used to obtain the percentiles of a sediment sample, either graphically, using a logarithmic or semi-logarithmic scale, or by applying a mathematical equation. The small differences observed between SANDY© and GRADISTAT® is due to the fact that the first routine uses graphical interpolation (piecewise cubic interpolation) to compute the different percentiles, whereas the second uses a mathematical relation where the 16th (D_{16}) and 84th (D_{84}) percentiles are calculated, and from these values other different percentiles are obtained. Overall, SANDY© proved to be a good tool for estimating the statistical parameters of sediment, the calibration and validation results demonstrate the capabilities and skills of the program in the characterization of a sediment sample.

5. Case study: characterization of sediments in Cancun and the Riviera Maya

Mexico offers great cultural and natural richness, which make it one of the the most popular tourist destinations in the world. The most important tourist destinations in the country are the beaches of Cancun and the Riviera Maya, on the Caribbean coast of the Yucatan Peninsula. However, the degradation of the coastal ecosystem caused by the excessive growth of tourist infrastructure along the coast and its natural vulnerability to hurricanes causes the state of balance of the beaches to become unstable, resulting in severe erosion (Murray, 2007). Since the textural properties of sediments are a tool used for the characterization of beach morphodynamics (Rice and Church, 2009; Trindade and Pereira, 2009; Rajganapathi et al., 2013), a total of 107 sand samples were collected from 35 beaches in Cancun and the Riviera Maya in order to describe the sediments of the region and contribute to the knowledge of beach dynamics.

5.1. Study site

The Riviera Maya and Cancun are located between the coordinates 20°01′ and 21°10′ N and 86°48′ and 86°65′ W, in the eastern part of the Yucatan Peninsula. The territorial extension of the study area is bounded by Yucatan State to the northwest, the Gulf of Mexico to the north, Campeche State to the west, Belize to the south and by the Caribbean Sea to the east (Fig. 5). The coastline is approximately 160 km long with geomorphological features including beaches with coastal sand dunes (Sian Kaan), restricted lagoons (Laguna Nichupte), beaches protected by coral reefs (Akumal, Puerto Morelos, Punta Brava) and dissipative beaches (Cancun).

5.2. Materials and methods

In order to characterise the sand in Cancun and the Riviera Maya, 35 sampling stations where distributed along the coast. At each station, three sand samples were collected, corresponding to the backshore (berm zone), swash and surf (littoral) zone of all beaches. The sediment was extracted from the surface of the beach profile to avoid any effects of stratification. The collected samples were subjected to a drying process, and then sieved to determine the mass of sand retained by each mesh (Bunte and Abt, 2001). The value of the different size percentiles of the particles of sand, as well as the mean, the standard deviation, skewness and kurtosis of the sample were obtained using the SANDY© routine. For the characterization of sediments from Cancun and the Riviera Maya the statistical parameters of the geometric method by Folk and Ward (1957) were considered.

According to the geomorphological features observed along the beaches where the sediments were collected, the sampling stations were grouped into 5 groups (Table 3). For each group, only

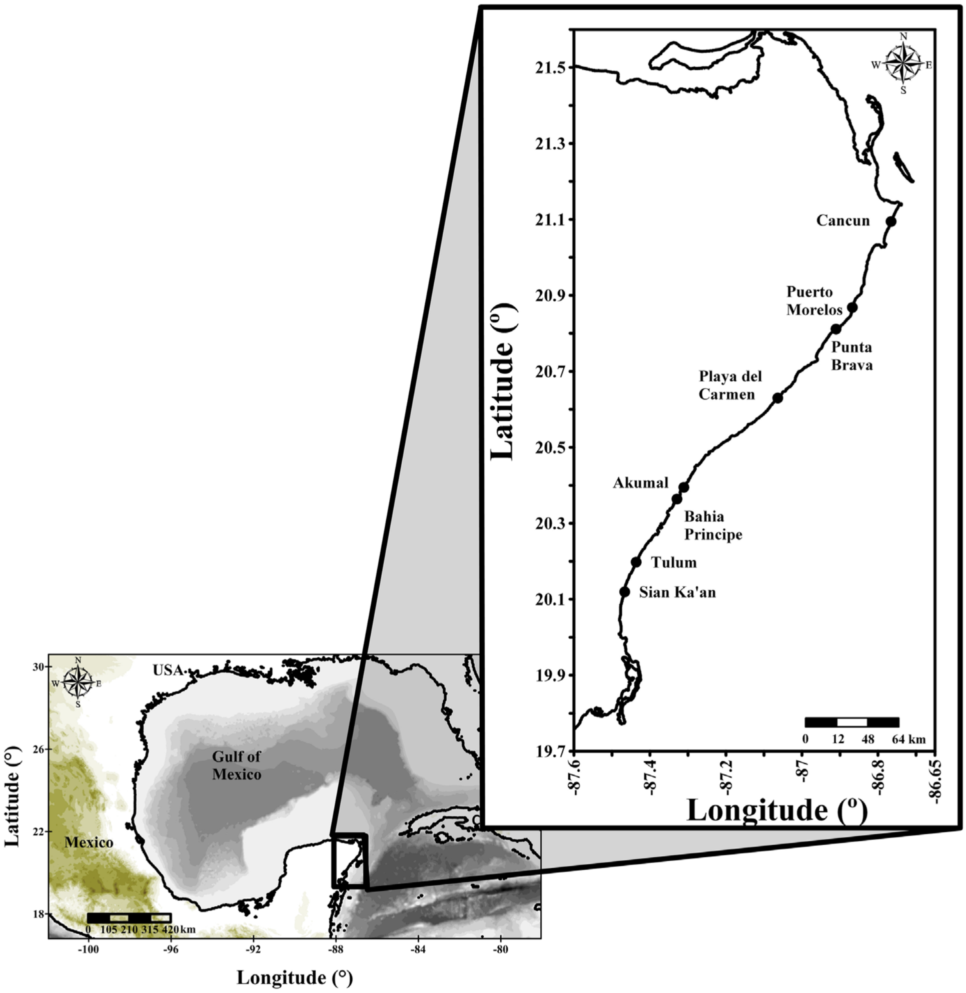


Fig. 5. Study site: Cancun and the Riviera Maya.

Table 3
Classification of the sand extraction sites related to geomorphological features.

Group	Geomorphological feature	Site of sand sample extraction
A	Straight shore with degraded coral reef in front of the beach	Sian Kaan, Puerto Morelos
B	Beaches influenced by a healthy coral reef	Tulum
C	Straight shore with no coral reef in front of the beach	Playa del Carmen, Punta Brava
D	Hyperstable or metastable beaches	Cancun
E	Pocket beaches with degraded coral reef	Akumal, Bahia Principe

the values of the 50th percentile of each of the stations were considered and these values were averaged to obtain a representative value for the group. The samples corresponding to the surf zone of the beach were used to characterize the beaches of Cancun and the Riviera Maya, according to their geomorphological features.

5.3. Results and discussion

Fig. 6 shows a scatter diagram which relates the mean sand size (*X* axis) and the standard deviation (*Y*-axis). For Cancun and the Riviera Maya, the graph shows that the sand is of medium size and the grains are very well classified. On the other hand, it is clear that the swash zone is an energetic region, where wave breaking

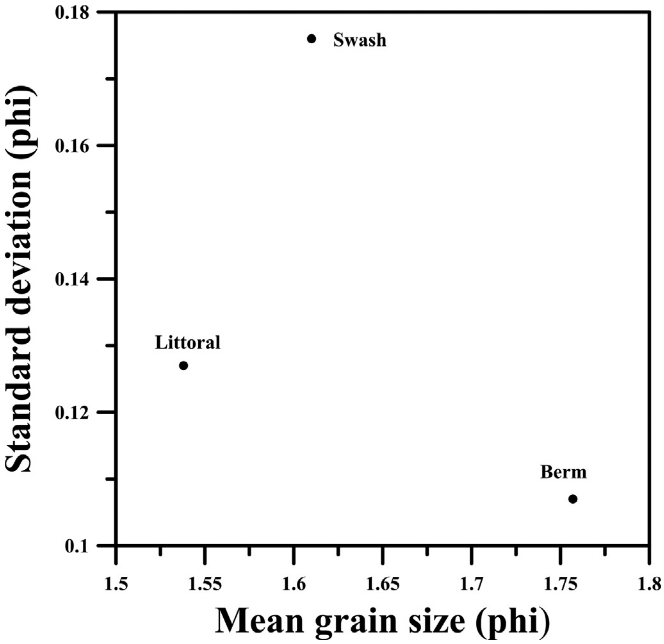


Fig. 6. Relationship between the standard deviation and the mean size of the sand; the samples were grouped according to the area from which they were obtained on the beach: the backshore (Berm), swash and surf zone (Littoral).

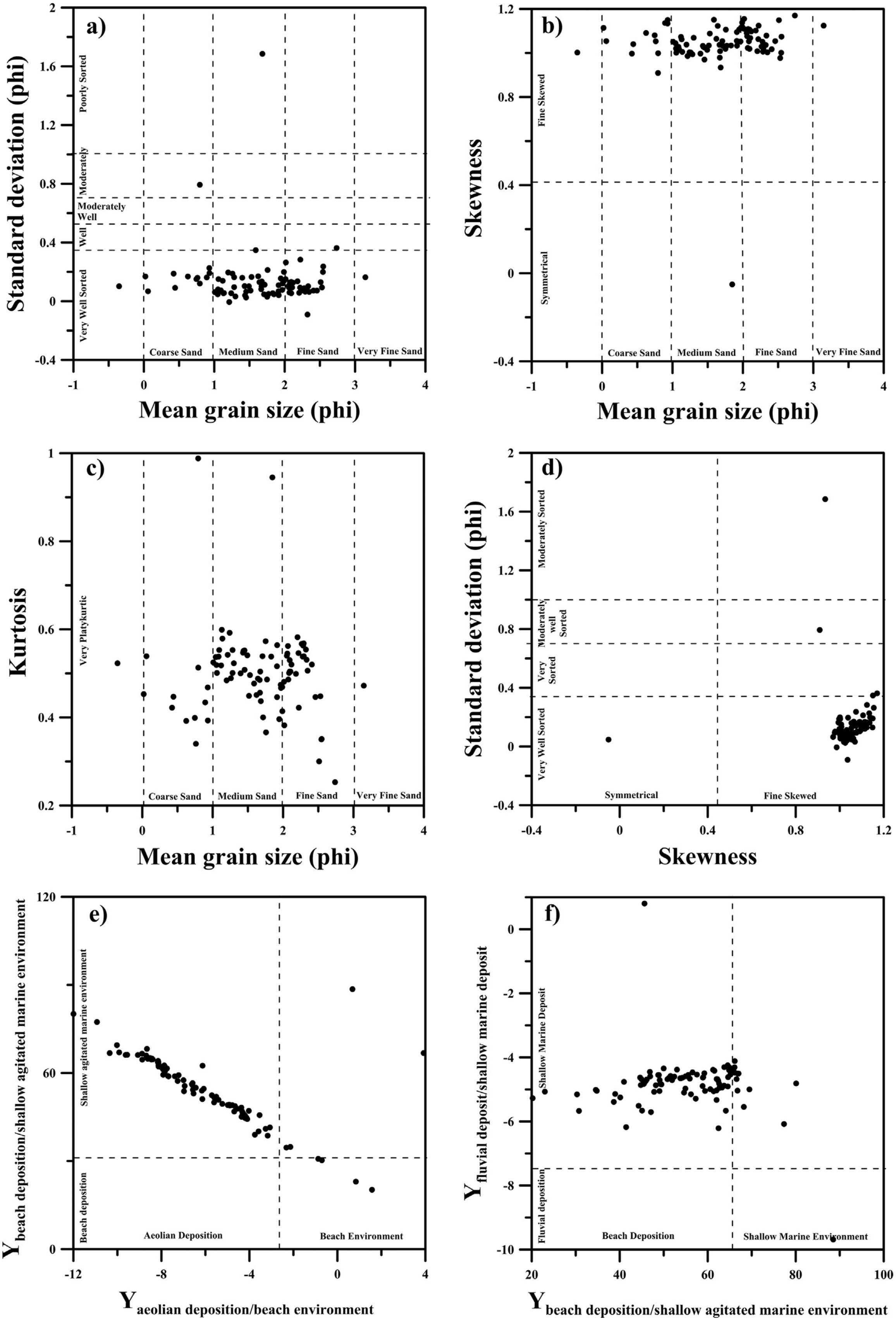


Fig. 7. Scatter plots from a multi-analysis performed with SANDY© showing the relationship between: a) grain size vs. standard deviation, b) grain size vs. skewness, c) grain size vs. kurtosis, d) skewness vs. standard deviation, e) and f) behavior of discriminant functions to establish the depositional environments.

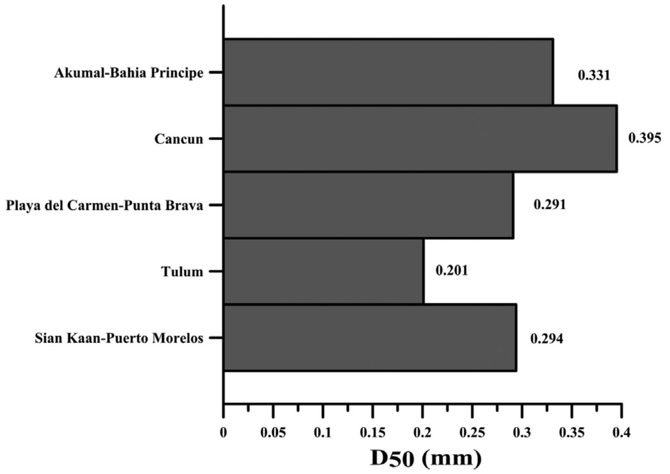


Fig. 8. Characterization of the 50th percentile of the sand size distribution in the Riviera Maya and Cancun.

and littoral currents move the sediment along the seabed or result in the suspension of the grains, causing the arrangement of particles to be less homogeneous in comparison to the backshore.

Fig. 7 is composed of 6 scatter diagrams, which relate the statistical parameters of the sand samples to the depositional environments (Moiola and Weiser, 1968). Fig. 7a shows that the sediments along Cancun and the Riviera Maya coastline are medium to fine sand and very well classified. The ratio between the mean grain size and the standard deviation reveals that the sediments deposited on the beaches are mostly driven and selected by the waves that reach the coasts, as well as the littoral currents. On the other hand, Fig. 7b shows the relationship between the mean sand size vs. skewness; the graph indicates that in the size distribution the coarse particles predominate with respect to the fine particles, and the skewness classification indicates fine sediments and is predominantly positive. Fig. 7c shows the relationship between the fourth moment and the statistical mean of the sand size; the diagram shows that the sediments are classified as very platykurtic, indicating that the sand of the beach is mature. The analysis of the standard deviation vs. skewness (Fig. 7d) reveals that the sand particles are very homogeneous and the grain size in the study zone is considered as medium. To differentiate the depositional environments of the sand samples, the linear discriminant function analysis proposed by Sahu (1964) was performed, where, on the basis of the statistical parameters of the size distribution of sand, it is possible to infer the depositional environments through the interpretation of energy variations and how the sediment flows over surfaces. In order to establish whether the sediments had been stored by the action of wind or coastal processes, Fig. 7e shows all the sand samples that were extracted from the swash zone and backshore. The graph demonstrates the relevance of wind on the deposition of the particles. To analyse whether the sand samples correspond to a river or marine environment, the trend in the values of the discriminant functions of all the samples are presented in Fig. 7f. In the study area there are no surface rivers; terrigenous sediment input to the coast is null, as demonstrated by the behavior shown in the graph, which shows that the predominant depositional environment is marine and that coastal processes are the natural mechanisms responsible for depositing sediment along the beaches.

According to the sampling stations of geomorphological features, the results of the sand samples were grouped to establish the degree of similarity between the sizes of the sand particles according to their zone of extraction from the beach. For each zone the average of the mean sand size and the standard deviation or sorting were calculated. Fig. 8 presents a bar plot which corresponds to the characterization of the 50th percentile of the sand size distribution, and it shows that the greatest diameter sands are found in the Cancun area. In October 2005, hurricane Wilma passed across the beaches of Cancun and as result, the coast suffered substantial erosion. The Mexican Government conducted beach nourishment in order to rescue the beaches; prior to hurricane Wilma the beaches had a D_{50} of 0.317 mm. The increase in sand size in Cancun is mainly due to the characteristics of the sand used in the beach nourishment. In contrast, the smallest D_{50} was identified in Tulum where the depositional environment is influenced by segments of healthy coral reef. The protection offered by coral reefs in Sian Kaan and Puerto Morelos makes the D_{50} smaller than Akumal and Puerto Principe; however in the two pocket beaches studied, the coral reef is highly degraded. From this comparison of $D_{50,}$ in beaches where the coral reef is considered healthy, finer sand is produced compared to beaches with a degraded coral reef.

6. Conclusions

SANDY© is a computational routine that has been developed in Matlab® to optimize the estimation process of the statistical size distributions of sediment. This routine is useful when the data on sediment size distribution have been obtained using the dry sieving technique. Textural parameters of the sediment sample, for example the mean, sorting, kurtosis and skewness can generally be identified using five methodologies. The software calculates the main percentiles of the sand size distribution in order to evaluate sediment transport. SANDY© provides results and plots of the textural parameters of sand from coastal or river environments, which can help engineers, geologists, sedimentologists or professionals whose studies involve the coast or rivers, to understand the manner in which the sediments are deposited. However, correct interpretation of the results will be the responsibility of the user. SANDY© takes advantage of the data storage structures and the programming language of Matlab® to export the results and plots as separate files.

A short case study application was presented in order to show the type of studies that can be carried out using the results that SANDY© offers to the user. The main conclusions from the case study are: a) the study sites assessed show a mean size of 3.05 mm with well classified grains of sand in the swash zone; b) the sediments that comprise the surf zone are medium sands (2.85 mm), where the physical forces responsible for depositing the sediment on the beaches are the waves and littoral currents; and c) the material of the berm on the beach consists of fine sands.

Acknowledgment

Our sincere thanks to the reviewers for their comments and suggestions, which enriched and helped to improve this manuscript and thanks to Gemma Franklin for reviewing the English grammar and her comments about it.

Appendix A. Equations used in SANDY©

Table A1 shows the equations used by SANDY© to compute the textural and physical parameters of the sediment sample.

Appendix B. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.cageo.2016.04.010.

Table A1
Equations used by SANDY© to calculate the statistical parameters of sediments and physical parameters.

Graphical methods					
	Mean	Sorting	Skewness	Kurtosis	Approach
Inman (1952)	$\phi_c = \frac{\phi_{16}+\phi_{84}}{2}$	$\sigma_\phi = \frac{\phi_{84}-\phi_{16}}{2}$	$\frac{\phi_c-\phi_{50}}{\sigma_\phi}$	$\frac{(0.5)(\phi_{95}-\phi_5)-\sigma_\phi}{\sigma_\phi}$	Arithmetic
Folk and Ward (1957)	$M_z = \frac{\phi_{16}+\phi_{50}+\phi_{84}}{3}$	$\sigma_I = \frac{\phi_{84}-\phi_{16}}{4} + \frac{\phi_{95}-\phi_5}{6.6}$	$Sk_I = \frac{\phi_{16}+\phi_{84}-(2)(\phi_{50})}{(2)(\phi_{84}-\phi_{16})} + \frac{\phi_5+\phi_{95}-(2)(\phi_{50})}{(2)(\phi_{95}-\phi_5)}$	$K_G = \frac{\phi_{95}-\phi_5}{(2.44)(\phi_{75}-\phi_{25})}$	Arithmetic
Folk and Ward (1957)	$\exp\frac{\log D_{16}+\log D_{50}+\log D_{84}}{3}$	$\exp\left(\frac{\log D_{16}-\log D_{84}}{4}+\ldots + \frac{\log D_5-\log D_{95}}{6.6}\right)$	$\frac{\log D_{16}+\log D_{84}-(2)(\log D_{50})}{(2)(\log D_{84}-\log D_{16})}+\ldots + \frac{\log D_5+\log D_{95}-(2)(\log D_{50})}{(2)(\log D_{95}-\log D_5)}$	$\frac{\log D_5-\log D_{95}}{(2.44)(\log D_{25}-\log D_{75})}$	Geometric
Kondolf and Wolman (1993)	$\left[(D_{16})(D_{84})\right]^{0.5}$	$\left(\frac{D_{84}}{D_{16}}\right)^{0.5}$	$\left[\frac{(D_{16})(D_{84})}{D_{75}/D_{25}}\right]^{0.5}$	$\left(\frac{D_{16}/D_{84}}{D_{75}/D_{25}}\right)^{0.5}$	Geometric
Trask (1932)	$\frac{D_{25}+D_{75}}{2}$	$\left(\frac{D_{25}}{D_{75}}\right)^{0.5}$	$\frac{(D_{25})(D_{75})}{(D_{50})^2}$	$\frac{D_{75}-D_{25}}{(2)(D_{90}-D_{10})}$	Mixed
Moments method (Krumbein and Pettijohn, 1938)					
Arithmetic	$\bar{x}_a = \frac{\Sigma f x_i}{100}$	$\sigma_a = \left(\frac{\Sigma f(x_i-\bar{x}_a)^2}{100}\right)^{0.5}$	$\frac{\Sigma f(x_i-\bar{x}_a)^3}{(100)(\sigma_a)^3}$	$\frac{\Sigma f(x_i-\bar{x}_a)^4}{(100)(\sigma_a)^4}$	
Geometric	$\bar{x}_a = \frac{\Sigma f \log x_i}{100}$	$\sigma_a = \left(\frac{\Sigma f(\log x_i-\log\bar{x}_a)^2}{100}\right)^{0.5}$	$\frac{\Sigma f(\log x_i-\log\bar{x}_a)^3}{(100)(\log\sigma_a)^3}$	$\frac{\Sigma f(\log x_i-\log\bar{x}_a)^4}{(100)(\log\sigma_a)^4}$	
Logarithmic	$\bar{x}_\phi = \frac{\Sigma f x_\phi}{100}$	$\sigma_\phi = \left(\frac{\Sigma f(x_\phi-\bar{x}_\phi)^2}{100}\right)^{0.5}$	$\frac{\Sigma f(x_\phi-\bar{x}_\phi)^3}{(100)(\sigma_\phi)^3}$	$\frac{\Sigma f(x_\phi-\bar{x}_\phi)^4}{(100)(\sigma_\phi)^4}$	

Discriminant function analysis of depositional environments (Sahu, 1964):

$$Y_1 = -3.5688M_z + 3.7016\sigma_I^2 - 2.0766SK_I + 3.1135K_G$$
$$Y_2 = 15.6534M_z + 65.7091\sigma_I^2 - 18.1071SK_I + 18.5043K_G$$
$$Y_3 = 0.2852M_z - 8.7604\sigma_I^2 - 4.8932SK_I + 0.0482K_G$$
$$Y_4 = 0.7215M_z + 0.403\sigma_I^2 + 6.7322SK_I + 5.2927K_G$$

Relative Density Max. dry unit weight of compaction (Patra et al., 2011)

Test Type	E(kN/m/m^3)	A	B
Reduced Standard Proctor	360	0.3786	0.145
Standard Proctor	600	0.5864	0.107
Reduced Standard Proctor	1300	0.7332	0.075
Modified Proctor	2700	0.8321	0.087

$$D_r = AD_{50}^{-B}$$

Nikuradse roughness: $k_s = 2.5D_{50}$

and bed roughness length: $z_0 = \frac{D_{50}}{12}$

Coefficient of curvature: $C_c = \frac{D_{30}^2}{D_{10}D_{60}}$

Table A1 (*continued*)

$$\text{Hazen Uniformity coefficient: } C_u = \frac{D_{60}}{D_{10}}$$

$$\text{Porosity: } n = 0.255\left(1 + 0.83^{C_u}\right)$$

$$\text{Void ratio: } \xi = \frac{n}{1-n}$$

Taking into account a water temperature of $T_w = 20°C$, $N = 8.3x10^{-3}$ and $g = 980\ \text{cm/s}^2$

$$\rho_w = 3.1x10^{-8}T_w^{\ 3} + 7.0x10^{-6}T_w^{\ 2} + 4.19x10^{-5}T_w + 0.99985$$

$$\mu = -7.0x10^{-8}T_w^{\ 3} + 1.002x10^{-5}T_w^{\ 2} - 5.7x10^{-4}T_w + 0.0178$$

$$\varphi(n) = \frac{n^3}{(1-n)^2}$$

$$\text{Hydraulic Conductivity: } K = \frac{\rho_w g}{\mu} N\varphi(n)D_{10}^{\ 2}$$

References

Arsenault, M., 2006. Folk_S_Classification. URL: 〈http://www.mathworks.com/matlabcentral/fileexchange/10483-folk-s-classification〉 (assessed 03.08.14).

ASTM, 2011. ASTM D2487-06: Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). American Society for Testing Materials International, West Conshohocken, PA. http://dx.doi.org/10.1520/D2487-11.

Awad, H.S., Al-Bassam, A.M., 2001. HYDCOND: a computer program to calculate hydraulic conductivity from grain size data in Saudi Arabia. Int. J. Water Resour. Dev. 17, 237–246. http://dx.doi.org/10.1080/07900620120031298.

Benson, D.J., 1981. Textural analyses with Texas Instruments 59 programmable calculator. J. Sediment. Petrol. 51, 641–642. http://dx.doi.org/10.1306/212F7D06-2B24-11D7-8648000102C1865D.

Blott, S.J., Pye, K., 2001. GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surf. Proc. Landf. 26, 1237–1248. http://dx.doi.org/10.1002/esp.261.

Bunte, K., Abt, S.R., 2001. Sampling surface and subsurface particle-size distributions in wadable gravel-and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring. General Technical Report RMRS-GTR-74. Fort Collins, CO, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 428 p.

Carrier, W.D., 2003. Goodbye, Hazen: Hello, Kozeny-Carman. J. Geotech. Geoenviron. Eng. 129 (11), 1054–1056. http://dx.doi.org/10.1061/(ASCE)1090-0241(2003)129:11(1054).

Cheetham, M.D., Keene, A., Bush, R.T., Sullivan, L.A., Erskine, W.D., 2008. A comparison of grain-size analysis method for sand dominated fluvial sediments. Sedimentology 55, 1905–1913. http://dx.doi.org/10.1111/j.1365-3091.2088.00972x.

Folk, R.L., 1964. A review of grain size parameters. Sedimentology 6 (2), 73–93. http://dx.doi.org/10.1111/j.1365-3091.1966.tb01572.x.

Folk, R.L., Ward, W.C., 1957. Brazos River bar - a study in the significance of grain size parameters. J. Sediment. Petrol. 27, 3–26.

Friedman, G.M., Sanders, J.E., 1978. Principles of Sedimentology. John Wiley and Sons, United States, p. 792.

Gallon, R.K., Fournier, J., 2013. G2Sd: Grain-size statistics and description of sediment. URL: 〈http://cran.r-project.org/web/packages/G2Sd/index.html〉 (assessed 03:08:14).

Gee, G.W., Bauder, J.W., 1986. Particle-size analysis. In: Klute, A. (Ed.), Methods of Soil Analysis Part 1: Physical and Mineralogical Methods. American Society of Agronomy Inc. and Soil Science Society of America, Madison, WI, pp. 383–411.

Hayton, S., Nelson, C.S., Ricketts, B.D., Cooke, S., Wedd, M.W., 2001. Effect of mica on particle-size analyses using the laser diffraction technique. J. Sediment. Res. 71, 507–509. http://dx.doi.org/10.1306/2DC4095B-0E47-11D7-8643000102C1865D.

Inman, D.L., 1952. Measures for describing size of sediments. J. Sediment. Petrol. 19, 51–70. http://dx.doi.org/10.1306/D42694DB-2B26-11D7-8648000102C1865D.

Kane, W.T., Hubert, J.F., 1963. FORTRAN program for the calculation of grain-size textural parameters on the IBM 1620 computer. Sedimentology 2, 87–90. http://dx.doi.org/10.1111/j.1365-3091.1963.tb01201.x.

Kondolf, G.M., Wolman, M.G., 1993. The sizes of salmonid spawning gravels. Water Resour. Res. 29, 2275–2285. http://dx.doi.org/10.1029/93WR00402.

Krumbein, W.C., 1936. Application of logarithmic moments to size frequency distributions of sediments. J. Sediment. Petrol. 6, 35–47. http://dx.doi.org/10.1306/D4268F59-2B26-11D7-8648000102C1865D.

Krumbein, W.C., Pettijohn, F.J., 1938. Manual of Sedimentary Petrology. Appgleton-Century and Crofts, New York, USA 549 p.

Mayo W., A computer Program for Calculating Statistical Parameters of Grain Size Distributions Derived from Various Analytical Methods, 1972, Department of Mineral and Energy. Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia, 54 p.

McCave, I.N., Syvitski, J.P.M., 1991. Principles and methods of geological particle size analysis. In: Syvitski, J.P.M. (Ed.), Principles, Methods and Applications of Particle Size Analysis. Cambridge University Press, Cambridge, pp. 3–21.

Moiola, R.J., Weiser, D., 1968. Textural parameters; an evaluation. J. Sediment. Res. 38, 45–53. http://dx.doi.org/10.1306/74D718C5-2B21-11D7-8648000102C1865D.

Murray, M., 2007. Constructing paradise: the impacts of big tourism in the Mexican coastal zone. Coast. Manag. 35, 339–355. http://dx.doi.org/10.1080/08920750601169600.

Patra, C.R., Sivakugan, N., Das, B.M., Atalar, C., 2011. Maximum relative density of clean sand as a function of median grain size and compaction energy. In: Proceedings of the 15th European Conference on Soil Mechanics and Geotechnical Engineering, pp. 1185–1191. 〈doi: http://dx.doi.org/10.3233/978-1-60750-801-4-118〉.

Poppe, L.J., Eliason, A.H., Hastings, M.E., 2004. A visual basic program to generate sediment grain-size statistics and to extrapolate particle distributions. Comput. Geosci. 30, 791–795. http://dx.doi.org/10.1016/j.cageo.2004.05.005.

Poppe, L.J., Elisaon, A.H., 1999. An interactive computer program to extrapolate the clay fraction distributions of truncated grain-size data. U.S. Geological Survey Open-File Report 99-27, 44 p.

Pye, K., 1989. GRANNY: a package for processing grain size and shape data. Terra Nova 1, 588–590. http://dx.doi.org/10.1111/j.1365-3121.1989.tb00436.x.

Rajganapathi, V.C., Jitheshkumar, N., Sundararajan, M., Bhat, K.H., Velusamy, S., 2013. Grain size analysis and characterization of sedimentary environment along Thiruchendur coast, Tamilnadu, India. Arab. J. Geosci. 6, 4717–4728. http://dx.doi.org/10.1007/s12517-012-0709-0.

Rice, S.P., Church, M., 2009. Grain-size sorting within river bars in relation to downstraming along a wandering channel. Sedimentology 55, 232–251. http://dx.doi.org/10.1111/j.1365-3091.2009.01108.x.

Richards, T., 2006. LinkTopAxisData. URL: 〈http://www.mathworks.com/matlabcentral/fileexchange/12131-linktopaxisdata〉 (accessed 03.08.14).

Sahu, B.K., 1964. Depositional mechanisms from the size analysis of clastic sediments. J. Sediment. Petrol. 34, 73–83. http://dx.doi.org/10.1306/74D70FCE-2B21-11D7-8648000102C1865D.

Sawyer, M.B., 1977. Computer program for the calculation of grain-size statistics by the method of moments. U.S. Geological Survey Open-File Report 77-580. 15 p.

Schlee, J., Webster, J., 1967. A computer program for grain-size data. Sedimentology 8, 45–54. http://dx.doi.org/10.1111/j.1365-3091.1967.tb01305.x.

Selley, R.C., 2000. Applied Sedimentology. Academic Press, San Diego, California 523 pp.

Slatt, R.M., Press, D.E., 1976. Computer program for presentation of grain-size data by the graphic method. Sedimentology 23, 121–131. http://dx.doi.org/10.1111/j.1365-3091.1976.tb00042.x.

Soulsby, R., 1997. Dynamics of Marine Sands. Thomas Telford Publications, London, UK 249 pp.

Trask, P.D., 1932. Origin and Environment of Source Sediments of Petroleum. Gulf Publication Company, Houston, US 323 pp.

Trindade, J., Pereira, A.R., 2009. Sediment textural distribution on beach profiles in a rocky coast (Estremadura-Portugal). J. Coast. Res. SI 56, 138–142.

Van Rijn, L., 2006. Principles of Sediment Transport in Rivers, Estuaries, and Coastal Seas, Part 2. Aquapublications, Netherlands 500 pp.

Vukovic, M., Soro, A., 1992. Determination of Hydraulic Conductivity of Porous Media from Grain-Size Composition. Water Resources Publications, Littleton, Colorado 54p.

Waite, W., 2006. Shepard_Ternary_plot. URL: ⟨http://www.mathworks.com/matlabcentral/fileexchange/10139-shepard-ternary-plot/content/Shepard.m⟩ (accessed 03.08.14).

Wentworth, C.K., 1922. A scales of grade and class terms for clastic sediments. J. Geol. 30 (5), 377–392.