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Revisiting the derivation of bulk longshore sediment transport rates using meta-heuristic algorithms

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ABSTRACT

During recent decades, different formulas have been developed to estimate longshore sediment transport rates through calibration using a wide variety of datasets, applicable for a range of particular wave and beach conditions. The equations that have shown the best capability to predict Bulk Longshore Sediment Transport Rate (BLSTR) are the formulas derived by CERC and by Kamphuis. In the present study, the five process parameters as used in the Kamphuis formula are accepted. The CERC formula includes only two of the five process parameters used in Kamphuis' formula. A renewed optimization to derive the power of the five Kamphuis' process parameters using an extensive dataset by Bayram was performed by Mil-Homens. In addition to this valuable effort, our contribution introduces two innovations. Firstly, the power coefficients of the five Kamphuis process parameters are optimized using a broad range of meta-heuristic algorithms. Secondly, the optimization is not based on the Bayram dataset as carefully collected and reviewed from published manuscripts but on a methodologically more homogeneous Iranian dataset acquired for port design and port management purposes. Independently from the results by Mil-Homens derived from the Bayram dataset, our study confirms these findings based on a totally different dataset. Specifically, the weaker impact of wave period and the stronger impact of the median grain diameter are in accordance with each other. The latter finding provides a stronger support for the mutual cancellation of the impact of slope and grain diameter in BLSTR, lending explanatory support to the CERC formula once beach slope and grain size are not known.

Descriptors: Longshore sediment transport, Meta-heuristic optimization, Persian Gulf, Caspian Sea.

INTRODUCTION

An important cause of coastline erosion and accretion is due to alongshore gradients in longshore sediment transport (CERC, 1984, Fernandez et al., 2015). Alongshore sediment transport gradients on coasts, not interrupted by headlands, outcrops or inlets, and caused by structural interventions, such as ports, are generally an order of magnitude larger than gradients caused by variations in natural coastline orientation (Bosboom and Stive, 2021). Also, there exists an order-of-magnitude difference in longshore sediment transport rates between relatively higher or lower longshore transports in sandy or shingle environments, respectively. Hence, accurate estimates of the longshore sediment transport rates, especially for sandy coastal systems, are of high importance both for engineering and for managing these systems in a sustainable way.

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During recent decades, different formulas have been developed to estimate the bulk longshore sediment transport rate (BLSTR). Formulas that have shown the best capability to predict BLSTR are the formulas of CERC (CERC, 1984), Kamphuis (Kamphuis, 1991) and Kamphuis-MilHomens (Mil-Homens, 2016). These formulas have been calibrated on broadly differing datasets applicable for a range of particular wave and beach conditions (Mil-Homens et al., 2013). Bayram et al. (2007) shared the reviewed and extended Bayram dataset with Mil-Homens (2016), who used the Bayram dataset to reevaluate the Kamphuis formula (here indicated as Kamphuis-MilHomens). The accuracy of the estimation of BLSTR is assumed to be suffering from the data being rather inhomogeneous due to methodological differences in data collection, believed to be one reason for an order-of-magnitude difference in estimates (Mil-Homens, 2016).

As observed by Fernandez et al. (2015), both the CERC and Kamphuis formulas can be expressed by a generic equation that includes all physical parameters that have been suggested to determine the longshore sediment transport on sandy beaches, but with different power values for the parameters. In the present study, the same generic equation is adopted.

Two innovations will be introduced here in comparison to the aforementioned studies. Firstly, the power coefficients of the most relevant BLSTR estimates are not optimized with traditional optimization algorithms but with twelve different meta-heuristic algorithms, with the expectation that this leads to improved accuracy or at least improved insights in the accuracy. Secondly, the optimization is not based on the extensive existing database from published manuscripts but rather on a new and methodologically more homogeneous Iranian dataset acquired for port design, engineering and management purposes. The results lead to converging insights regarding the accuracy of the earlier derivations of the data-fit for bulk longshore sediment transport rates.

METHODS

BLSTR Formulation Reviewed

In this section, two major BLSTR formulations are reviewed based on their success as perceived from published manuscripts. All suggestions made in the past are still in place, and this confirms that this issue is fairly difficult to improve. This research is focused on increasing insight into the accuracy of BLSTR. Alternative approaches, detailing the longshore sediment transport as a function of the cross-shore location such as LITPACK (Deigaard et al., 1986) and UNIBEST (Bosboom and Stive, 2021) are valuable once they incorporate additional data that are not considered in the BLSTR approach. In cases where these data do not exist, it does not necessarily lead to better accuracy to estimate BLSTR. Hence, there is practical justification for the use of BLSTR in engineering and management projects (Bosboom and Stive, 2021).

CERC Formula

The CERC formula (introduced in earlier editions of the Shore Protection Manual (CERC, 1984)) is the "mother" of all formulations derived to estimate the BLSTR. This formula was obtained based on the assumption that the BLSTR is proportional to the "longshore component of wave power". The physical interpretation of this parameter remained unclear until 1970 when Longuet-Higgins (1970) presented a close relation of this parameter with the cross-shore gradient of the alongshore radiation stress integrated over the surfzone. Using the wave height and wave incidence angle at the breakerline, the CERC formula can be written as follows, where the k coefficient is dimensional and BLSTR (Q) is in (m ^ 3/s) (Mil-Homens et al., 2016):

$$Q = k\frac{\rho g^{1/2}}{16\sqrt{\gamma_b}(\rho_s-\rho)(1-p)}H_{sb}^{5/2}\sin 2\theta_b \qquad (1)$$

It is noted that this formula has only two physical process parameters lacking including sediment grain size.

Under the above conditions, the k coefficient was obtained through linear regression by Komar and Inman (1970) from field measurements on Silver Strand (USA) and at El Moreno (Mexico), resulting in k = 0.77 based on the root mean square of the wave height at the breaking point or k = 0.34 using the significant wave height at the breakpoint. CERC (1984) updated the k value in 1984 using an additional dataset. However, the remaining scatter (Rosati et al., 2002) suggests that k should not be a constant but a function of other potentially relevant physical parameters. Below, several suggestions are reviewed but none of these have been accepted on a general basis.

Indeed, even before the earlier suggestion, several attempts were made to find the impact of potentially important parameters. The relationship of BLSTR with the surf similarity parameter also known as the Iribarren number (Battjes, 1974) was suggested by Kamphuis and Readshaw (1987). A second attempt to include more physical parameters in the expression for k was introduced through an energy-based model (Bailard, 1981). This author suggested the value of k should increase with larger incident wave angles and larger values of the Dean parameter.

A third attempt was due to Komar (1998), who critically reviewed the BLSTR data and introduced data from the Adra River Delta in Spain. The wide range of sediment grains ranging from 0.4 to 1.5 mm led to an experimental relation based on the mean diameter of grains.

Later evaluations by Schoones and Theron (1996) and Smith et al. (2009) concluded that the first attempt to relate the value of k to the surf similarity parameter was the most successful. However, these suggestions, although interesting, are considered not relevant in the context of the present work.

Kamphuis Formula

Kamphuis (1991) developed a formula for BLSTR for an extensive range of data that included all earlier field data and a large new laboratory dataset acquired by that author, which may have led to a bias. Through dimensional analysis and using physics principles, this author obtained the following equation for the bulk volume of longshore sediment transport I_m in kg/s and valid for regular waves:

$$\frac{I_m}{\left(\frac{\rho H^3}{T}\right)} = K^*\left(\frac{H}{L^*_0}\right)^p m^q{}_b\left(\frac{H}{D_{50}}\right)\sin^s(2\propto_b) \tag{2}$$

where H: wave height, T: wave period, d: depth of water, ρ: fluid density, m: beach slope, p and q and r and s are experimentally determined, k^* is a calibration coefficient, L^*_0 is the wavelength in deep water (for regular waves), and D_{50} is the median sediment grain diameter. The beach slope in the surf zone region is calculated according to:

$$m_b = \frac{d_b}{\lambda_b} \tag{3}$$

where λ_b is the distance from the coastline to the breaking point. The bulk longshore sediment transport rate $(Q{:}\frac{m^3}{s})$ is expressed by:

$$Q_l\,\frac{I_m}{(\rho_s-\rho)(1-p)} \tag{4}$$

For irregular waves, where the subscript b refers to the wave parameters at the breakerline, Kamphuis (1991) also presented the following formula:

$$\frac{Im}{\left(\frac{\rho H_{sb}{}^3}{Tp}\right)} = 1.3^*10^{-3}\left(\frac{H_{sb}}{L_0}\right)^{-1.25} m_b^{0.75}\left(\frac{H_{sb}}{D_{50}}\right)^{0.25}\sin^{0.6}(2\propto_b) \tag{5}$$

where H_{sb} is the wave height at the breakerline, T_p is the wave period and $L_0 = \frac{gT_p^2}{2\pi}$ is for deep water.

The above relation in a simplified form with k=k* $\rho\left(\frac{gT_p^2}{2\pi}\right)^{1.25}$=2.27 can be written as follows:

$$I_M = 2.27H_{sb}^2 T_p^{1.5} m_b^{0.75} D_{50}^{-0.25}\sin^{0.6}(2\propto_b) \tag{6}$$

However, using the same data, a new value for the calibration coefficient is equivalent to the values $k_{s\&T}$=2.27 for Q_l ($m^3/_s$)and K*=50,000 in terms of m^3/year.

Kamphuis (1991), besides wave height and wave incidence at the breakpoint, considered three more process parameters, viz. coastal slope, wave period and median sediment grain size; in the CERC formula, these latter parameters are not considered. Interestingly, coastal slope and sediment grain size are related using the positive correlation between bed slope and the median grain size (Klein, 2003). As grain size decreases the coastal slope decreases, so these effects can cancel each other out, which is often explained as the justification for the absence of these parameters in the CERC formula.

Recent optimizations

Using the improved Bayram dataset, Mil-Homens (2013) derived best fits for CERC and Kamphuis with improved results in terms of bias and RMSE compared to all earlier studies mentioned.

The best fit for the CERC formula was achieved with a polynomial function,

$$K_{CERC} = \left[2232.7\left(\frac{H_{sb}}{L_0}\right)^{1.45} + 4.505\right]^{-1} \quad (7)$$

The best fit achieved for the Kamphuis formula reads:

$$I_{m \cdot new} = 0.149 H_{sb}^{2.75} T_p^{0.89} m_b^{0.89} D_{50}^{-069} \sin^{0.5}(2 \propto_b) \quad (8)$$

The above results were based on the extensive Bayram dataset; although accuracy improved, still only 53% to 56% of the data points fell within a factor of between 0.5 and 2 from the best fit. This can be attributed to the data being both inhomogeneous due to hydrodynamics, morphological and geological differences in the regions where the data are generated and the methods with which these are generated, leading to an order-of-magnitude difference in estimates.

CERC, Kamphuis and Kamphuis-Milhomens can all be expressed in the following form (Fernandez et al., 2015):

$$Q_s = C\frac{H_{sb}^{a1} T_p^{a} m_b{}^{a3} D_{50}^{a4} \sin^{a5}(2\theta_b)}{(\rho_s - \rho)(1 - a)} \quad (9)$$

where BLSTR = Qs (m^3/s) is the volume rate of longshore sediment transport, θ_b is the angle between crest and the coast normal at the initial breaking point, m_b is the coast slope from the initial breakerline to the coastline, ρ_s sediment density is 2650 kg/m^3, ρ water density is 1025 kg/m^3 and the porosity index is 0.4.

Initially, coefficients for all sediment transport formulas, including all coefficients of α_1, α_2, α_3, α_4 and α5 and also C related to the CERC, Kamphuis and Kamphuis-MilHomens formulas were gathered totally in view of Equation 20. All these coefficients are presented in summary in Table 1.

The experimental coefficient k for the CERC formula is 0.39 based on the initial breaking wave height parameter. Furthermore, g is acceleration due to gravity, y_b is the breaker index, H_b/h_b in which h_b is the depth at the break point. C_f is a coefficient of friction that is 0.005 according Bayram formula (Mil-Homens, 2013) and ε is coefficient of sediment material transport that has been estimated in this formula.

In this study, the coefficient and exponents of Equation 9 are optimized with twelve different metaheuristic algorithms, using a range of different optimization methods and a new dataset.

Data and data analysis methods

The extensive Bayram data set is very relevant and should not be ignored, but the data suffer from being inhomogeneous in terms of data-derivation techniques. Therefore, this study investigated whether our understanding of the accuracy improves by using a more homogeneous field dataset, i.e. data based on BLSTR field data derived according to similar methodologies. It is our hypothesis that a more homogeneous dataset could lead to improved accuracy and/or converging views.

The Iranian Ports and Maritime Organization (PMO, 2021) partly collected (through field observations) and partly constructed (through calibrated and validated numerical modelling) a more homogeneous dataset in the context of Integrated Coastal Zone Management Plans evaluating engineering interventions for 12 different ports in Iran (Figure 1, Figure 2 and Table 2). Comprehensive field measurements were conducted in four provinces both along uninterrupted stretches of the provincial coast and in the direct vicinity of 12 ports in these provinces, of which four are in the southern part of the Caspian Sea and eight in the Persian Gulf. The data include not only the relevant parameters in the BLSTR formulae such as grain size, mean beach slope, average wave period, mean wave height and dominant wave angle at the breaking point, but also detailed information

Table 1. Coefficients and exponents of BLSTR formulas (modified and extended after Fernandez et al., 2015).

Equation	C	a_1	a_2	a_3	a_4	a_5
CERC	$k/16\rho_s(\frac{g}{\gamma_b})^{1/2}$	2.5	0	0	0	1
Kamphuis	2.27	2	1.5	0.75	-0.25	0.6
Kamphuis-Mil Homens	$0.15\,\rho^a{}_s$	2.8	0.89	0.86	-0.69	0.5

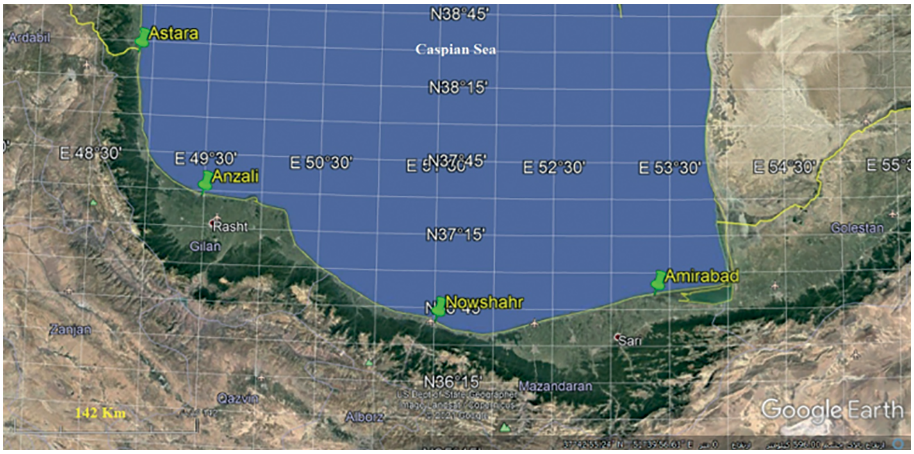

Figure 1. Locations and dominant wave directions at the initial breaking point of 4 PMO managed Iranian ports in the Caspian Sea.

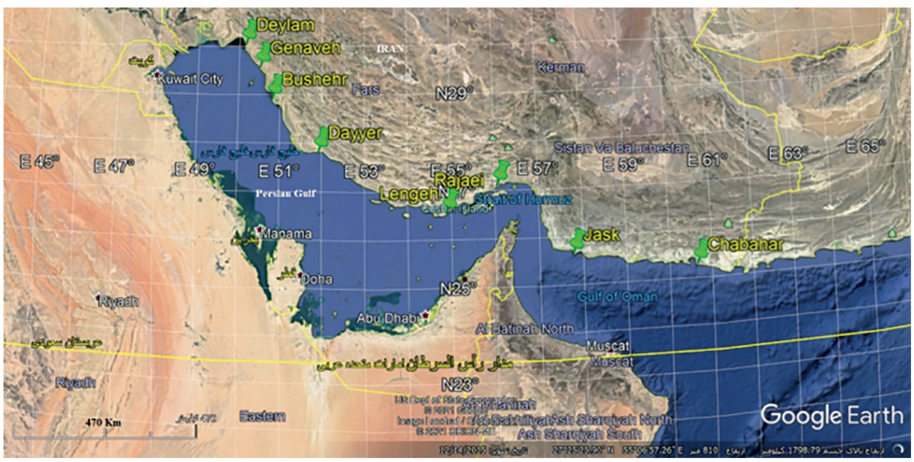

Figure 2. Locations and dominant wave directions at the initial breaking point of 8 PMO managed Iranian ports in the Persian Gulf.

on incident and cross-shore wave heights, periods, frequency of occurrence (see Figures 3, 4), longshore flows, cross-shore bed profiles and bottom roughness information. The collected detailed information justifies the use of a cross-shore resolving longshore wave, flow and sediment transport model for calibration. The state-of-the-art numerical model LITPACK (Deigaard et al., 1986) was applied. The calibration procedure was based on comprehensive modelling for the large coastal stretches in the four provinces where the ports are located. While for all variables default values were adopted, the only variables in the calibration were bed roughness and incident wave energy. (Mahmoodi et al., 2020). After calibration on the uninterrupted coastal stretches in the provinces, the LITPACK model was validated primarily based on satellite-based temporal areal changes on the updrift side of the ports (Jafari et all., 2016), without changing the model parameters.

The total number of data after analysis and normalization consists of more than 2000 items, describing detailed information on BLSTRs as a function of the relevant process parameters. These data are considered first to form an alternative, more homogenous basis for optimization other than the Bayram dataset and second an opportunity to explore meta-heuristic optimization algorithms as alternative, very efficient algorithms relative to the traditional optimizations. This allows using a wide range of such algorithms that should shed new light on the variability of the powers of the process parameters.

Meta-heuristic algorithms are a group of algorithms used to solve optimization challenges. In the field of computer sciences, artificial intelligence and

Table 2. Field data of different sites for longshore transport at different parts of the coast of Iran, after data analysis for sensitivity.

Province	Ports	D50 (mm)	mb (%)	Tp (s)	Hs,b (m)	dominant waves direction	θbr	~Qs m³/ year (litpack model)	~Qs m³/ year (field data)
Gilan	Astara	0.1 to 0.2	0.9	4.6	0.51	NorthWest	50	98627	95000
Gilan	Anzali	0.1 to 0.3	0.8	4.8	0.73	NorthWest	10	57800	59000
Mazandaran	Nowshahr	0.1 to 0.3	0.8	4.9	0.64	North	350	58700	55000
Mazandaran	Amirabad	0.1 to 0.2	0.2	4.6	0.53	NorthEast	335	55276	57000
Boushehr	Deylam	0.5	0.16	3.0	0.50	South East	245	22124	25000
Boushehr	Ganaveh	0.35	0.15	3.6	0.47	South West	265	19810	20000
Boushehr	Boushehr	0.3	0.15	4.0	0.51	South East to North East	265	33784	30000
Boushehr	Deyer	0.15	0.1	3.6	0.37	South West to NorthEast	235	19100	21000
Hormozgan	Lengeh	0.2 to 0.7	0.2	3.2	0.21	Sou-thwEst-East	135	3000	3491
Hormozgan	Shahid Rajaee	0.01to 0.02	0.5-1	3.6	0.10	South East	150	3343	3000
Hormozgan	Jask	0.2	0.13	3.7	0.63	South West	150	83307	85000
Sistan &Balouchestan	Chabahar	0.0625 to 2	0.47	4.7	1.01	South	176	31000	35000

optimization problems, these algorithms are a way to achieve optimization that classical solutions are slow to solve, or even more serious an approximate solution to problems that classical ways cannot find exact answers to. Most complex problems require evaluating a myriad of possible modes to determine an exact answer. Meta-heuristic algorithms play an effective role in resolving such issues by using methods that require less evaluation and provide answers within acceptable time limits. Meta-heuristic algorithms are general algorithmic frameworks that can provide specific solutions to the optimization problem. These algorithms belong to the class of various approximate optimization algorithms having solutions to exit from local optimal points and have the capability to be applied to an extensive spectrum of problems. Meta-heuristic algorithms use large-scale problems to provide satisfactory solutions within a reasonable amount of time. The common goal of all meta-heuristic algorithms is to solve difficult optimization problems (Dreo et al., 2006).

Meta-heuristic methods have the following common features. They are commonly applied to solve hybrid problems but can also be used in continuous problems. They are usually inspired by the concepts of biology, animal behavior and physics. One of the common drawbacks of these methods is the difficulty of setting and matching the parameters. Different criteria can be used to classify meta-heuristic algorithms, i.e. answer-based and population-based. Answer-based algorithms change a response during the search process, while population-based algorithms consider a population of responses during a search. Many meta-heuristic algorithms are inspired by nature. Some meta-heuristic algorithms lack memory, meaning that these types of algorithms do not use the information obtained during the search, while some search algorithms do. They use memory storing the information obtained during the search. Exact and possible: a definitive meta-heuristic algorithm solves the problem using definite decisions. However, in some meta-heuristic algorithms, a series of possible rules are used during the search.

In total, 12 meta-heuristic algorithms were explored that are among the most important ones inspired by the behavior of nature (Yang, X.S, 2010). Using the 12 meta-heuristic algorithms, an optimization of the BLSTR coefficients and exponents was conducted for all field data (Gholami et al., 2021). The coefficients and optimal capacities were extracted

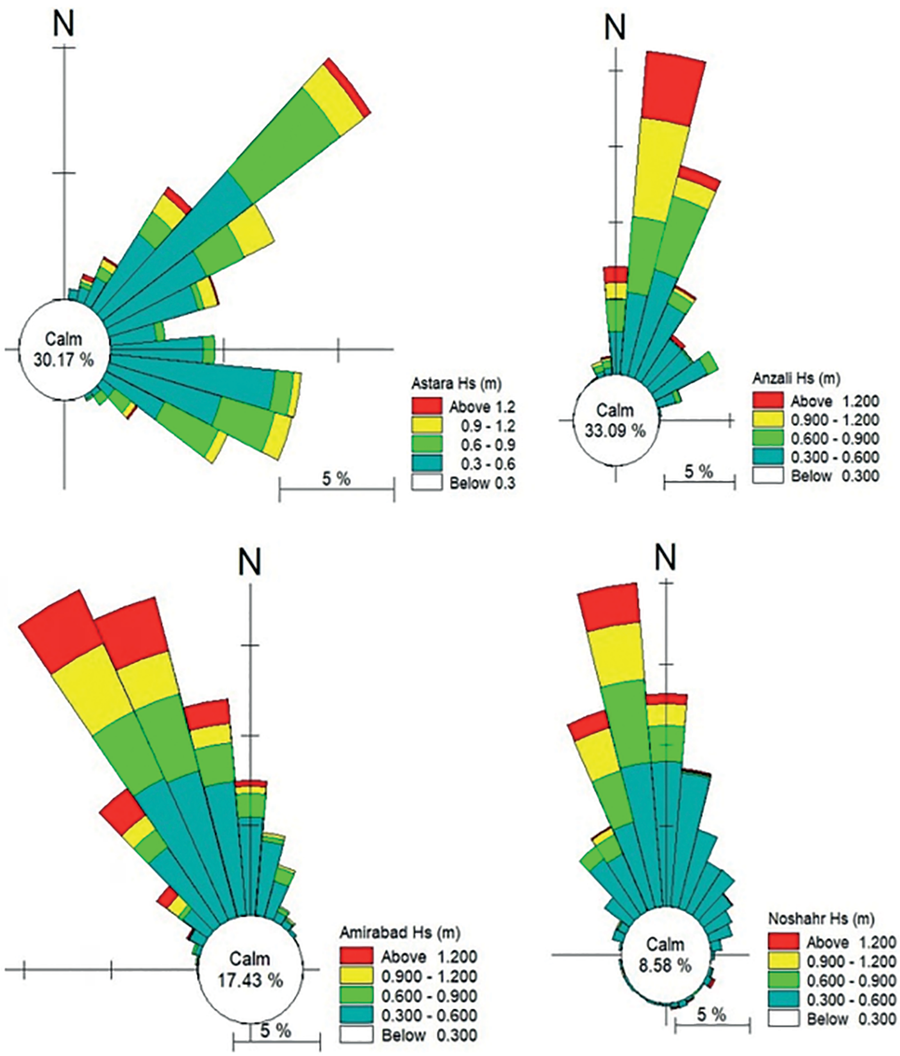

Figure 3. Dominant wave directions at the initial breaking point of 4 Iranian ports in Caspian Sea.

using meta-heuristic algorithms in MATLAB space for the data as summarized in Table 2.

From a more profound evaluation of the results, it is concluded that three algorithms, i.e. Ant Colony (ACO), Bath (BAT) and Whale (WOA), performed best. Although the results for all algorithms were close, these algorithms showed a fast convergence between the calculated and observed values, which is a good indicator of their optimization reliability. For reasons of conciseness only the results for the selected three algorithms are presented. These algorithms use swarm intelligence as a relatively new approach to problem solving that takes inspiration from the social behaviors of insects and of other animals.

Ant colony optimization (ACO) is a population-based meta-heuristic that can be used to find approximate solutions to difficult optimization problems (Dorigo et al, 2006). Ant colony optimization takes inspiration from the foraging behavior of some ant species. These ants deposit pheromone on the ground in order to mark some favorable path that should be followed by other members of the colony. Ant colony optimization exploits a similar mechanism for solving optimization problems.

The bat optimization algorithm (BAT) is a novel meta-heuristic optimization algorithm introduced by Yang (2010). The algorithm is inspired by the echolocation behavior of bats, which guides the bats'

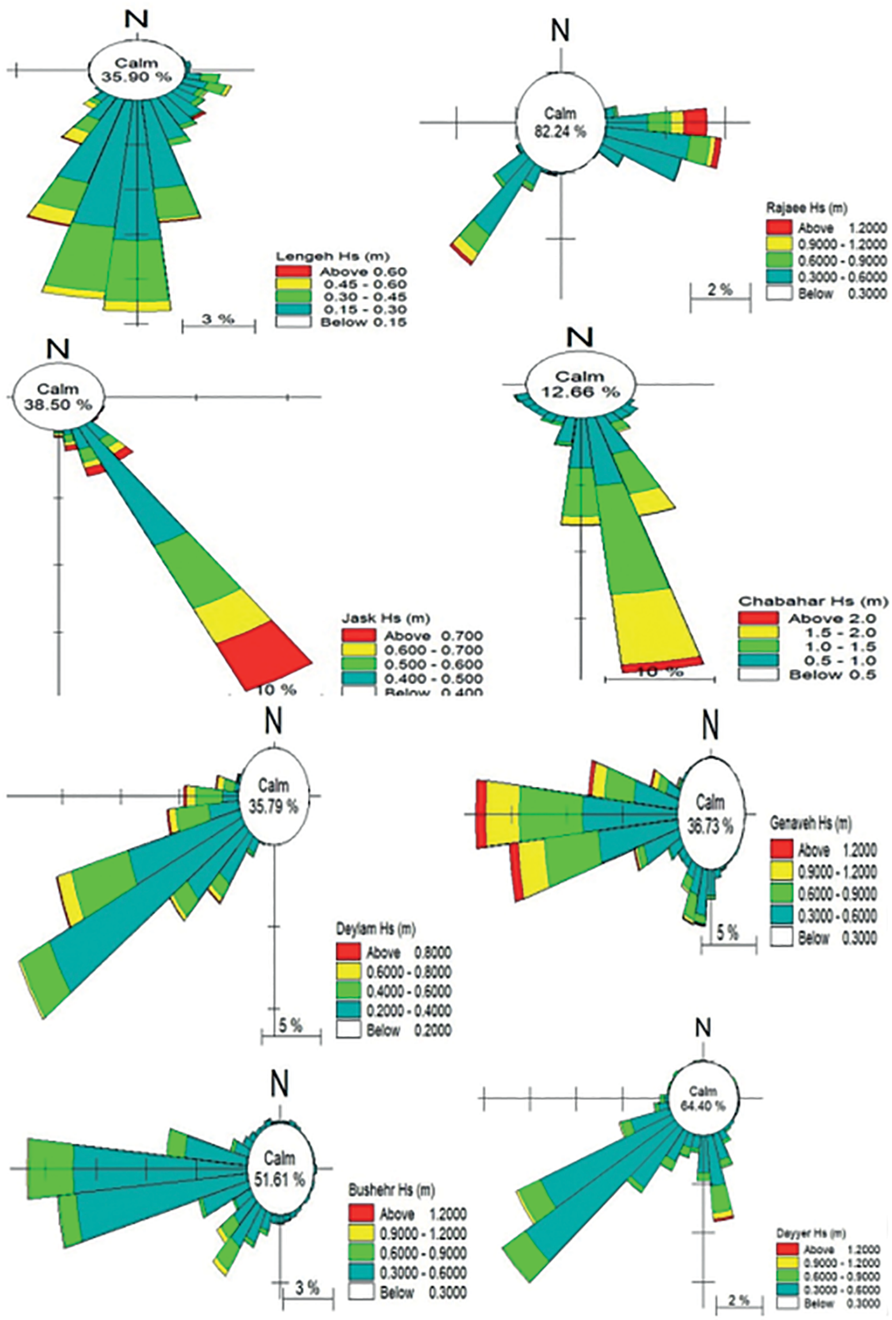

Figure 4. Dominant wave directions at the initial breaking point of 8 Iranian ports in Persian Gulf.

movements during their flight and hunting even in complete darkness. This algorithm carries out the search process using artificial bats as search agents mimicking the natural pulse loudness and emission rate of real bats. (Fattahi et al., 2007).

The whale optimization algorithm (WOA) is a biological heuristic algorithm presented by Mirjalili and Lewis (2016). WOA is a swarm intelligence optimization algorithm inspired by the unique humpback hunting method. Because of this unique optimization mechanism, WOA has a good global search capability. Therefore, the new algorithm has been widely proposed by the engineering community.

Table 3 lists some of the properties that characterize these three algorithms.

RESULTS

The meta-heuristic optimization results for the three selected algorithms are presented in Table 4 and compared to the Kamphuis and Kamphuis-MilHomens optimizations of Eq. 9. As a first observation it is promising to conclude that there is only moderate quantitative variation between these results mutually.

In order to check whether one of the algorithms performs better, the RMSE for these three algorithms was derived for the dataset of Manzadaran Province, considered to be one of the most homogeneous due to the monodirectionality of the alongshore sediment transport.

$$RMSE = \sqrt{\frac{\Sigma_{i=}^{n} \left(\log\left(Qp.i\right) - \log\left(Qm.i\right)^{2}\right.}{n}} \quad (10)$$

The RMSE value is a commonly used error measure. The sum of squares gives more weight to higher error values, and consequently higher error variances. The bias provides insight on any systematic offset of the data. Because logarithmic values (base 10) are considered in both statistical measures, the values indicate errors in terms of magnitude order, e.g., an RMSE value of 1 would mean that the predicted values are roughly, on average, 10 times larger or smaller than the measured ones. Logarithmic values were chosen because the data range extends through several orders of magnitude (Mil-Homens, 2013).

The three algorithms, i.e., Ant Colony (ACO), Bath (BAT) and Whale (WOA), performed very similar with an RMSE of 0.012, 0.011 and 0.010 respectively, which does not imply a significant difference between the algorithms. These low values indicate that the dataset is very homogeneous in methodology and leads to two important conclusions. First, a more homogeneous dataset leads to more reliable, quantitative results for BLSTR formulations. Second, different combinations of values for the coefficients and the exponents in Equation 20 can lead to similar results for a homogeneous dataset.

DISCUSSION

During recent decades, different formulas have been developed to estimate BLSTR through calibration on regionally different and therefore often non-homogeneous datasets. Equations that have shown

Table 3. Properties of the 3 selected meta-algorithms.

Name of Algorithm	Abbreviation	Use to solve optimization problems	Inspired by nature	Population based	Answer based	Focus on local search areas	Guidance searches to different areas for answers	Used to solve Hybrid problems	Used to solve continuous problems	Has reciprocal relationship and repetition	High flexibility in solving problems
Ant Colony Optimization	ACO	√	√	×	√	√	×	×	√	√	√
Bath	BAT	×	√	×	√	√	×	×	√	√	√
Whale Optimization	WOA	×	√	×	√	√	×	×	√	√	√

Table 4. Coefficients and exponents of Equation 12 for Kamphuis, Kamphuis-Milhomens using the Bayram data-set and for the 3 selected meta-heuristic algorithms) using the field data of table 2.

Method/approach	a_1	a_2	a_3	a_4	a_s	c
Kamphuis	2.0	1.50	0.75	-0.25	0.60	*2.27*
Kamphuis-Mil-Homens	*2.8*	*0.89*	*0.86*	*-0.69*	*0.50*	$0.15\,\rho_s^{a}$
Ant Colony (ACO)	2.8	0.61	0.73	-0.57	0.40	*2.22*
Bath (Bat)	2.7	0.11	0.55	-0.48	0.66	*2.18*
Whale (WOA)	2.2	0.79	0.69	-0.55	0.51	*2.21*

the best capability to predict BSLRT are the formulas of CERC, Kamphuis and Kamphuis-MilHomens. In the present study, the same process parameters as used in the Kamphuis and Kamphuis-MilHomens formulas are accepted. However, two innovations are introduced here. Firstly, the coefficients and exponents of the different formulations are optimized with twelve meta-heuristic algorithms, using a range of different optimization methods. Secondly, the optimization is not based on existing data from literature but on a unique, new and rather homogeneous Iranian dataset acquired for port design and port management purposes. Using meta-heuristic algorithms, a first optimization of the BLSTR coefficients and exponents was conducted for the whole Iranian field dataset. An evaluation of the results on the basis of two criteria concludes that three algorithms, i.e. Ant Colony (ACO), Bath (BAT) and Whale (WOA), performed best. These algorithms showed both a fast convergence between the calculated and observed values and are close to the quantitative values of the coefficients and exponents of the most recent formulation and optimization of Kamphuis-MilHomens. The three mentioned algorithms performed very similar with an RMSE of 0.012, 0.011 and 0.010 respectively. These low values indicate that the dataset is very homogeneous and leads to two important conclusions. First, a more homogeneous dataset leads to more reliable, quantitative results for BLSTR formulations. Second, different combinations of values for the coefficients and the exponents can lead to similar results for a homogeneous dataset.

The results lead to the conclusion that independently from the results by Mil-Homens (2016) derived from the Bayram dataset, the present study confirms these findings based on a totally different dataset and optimization methodology. Specifically, the weaker impact of wave period and the stronger impact of the median grain diameter are in accordance with each other. The latter finding provides a stronger support for the mutual cancellation of the impact of slope and grain diameter in BLSTR, lending explanatory and converging support to the CERC formula once beach slope and grain size are not known.

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AUTHOR CONTRIBUTIONS

Z.G.: Conceptualization; Investigation; Software; Formal Analysis; Writing – original draft; Writing – review & editing;

K.L.: Methodology; Software; Formal Analysis; Investigation; Writing – review & editing;

A.A.B.: Supervision, Formal Analysis; Writing – review & editing;

A.H.J.: Supervision, Formal Analysis; Writing – review & editing.

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