Oceanologia (2020) 62, 45—55

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ORIGINAL RESEARCH ARTICLE

Evaluation of morphodynamics of Miani Hor, a coastal lagoon of Lasbela, Balochistan, Pakistan

Naeem Ahmed Syed [a,*], Tahira Siddiqa [a], Niamatullah Sohoo [b]

[a] *Nusrat Jahan College, Rabwah, Chenab Nagar, Chinniot, Pakistan*
[b] *National Institute of Oceanography, Clifton, Karachi, Pakistan*

Received 11 January 2019; accepted 29 July 2019
Available online 17 August 2019

KEYWORDS
Coastal water body;
Lagoon;
Tidal constituents;
Inlet dynamics

Summary In compliance to the estuarine areas having access to the sea and riverine water, Miani Hor, a coastal water body in Lasbela, Pakistan could be categorized as a lagoon due to its shallowness, elongation to the coast, connectivity with the adjacent Sonmiani Bay and occasional receiving of rainwater. In the present paper, Miani Hor was studied to understand its dynamics, and to compare it with the categories of lagoons as proposed by Kjerfve (1986). The result of the field data of water quality and water movement as well as satellite imagery of different years show that this is a tide-dominated lagoon with a single inlet, and it was formed in the last glaciation period. Its only inlet is stable and remains open even during the period of high energy waves offshore Sonmiani Bay that generate strong littoral drift. The data suggest that unlike choked lagoons, as proposed by Kjerfve (1986) for classification of the single-inlet lagoons with limited tidal influence, Miani Hor has a small (0.08) ratio of the channel cross-sectional area to the lagoon surface area. The lagoon channel filters out high energy waves but allows strong tidal signals to penetrate the lagoon. The paper suggests that Kjerfve (1986) classification requires modification by incorporating another class "relaxed lagoons" for the single inlet tide-dominated lagoons.

* Corresponding author at: Department of Earth Sciences, Nusrat Jahan College, Dar-Ul-Rehmat Wasti, Chenab Nagar, Chiniot, Pakistan. Tel.: +92 (47) 6213405.
E-mail addresses: dr.naeem@njc.edu.pk, nasyed.phd@gmail.com (N.A. Syed), sohoonu_gwd@hotmail.com (N. Sohoo).
Peer review under the responsibility of Institute of Oceanology of the Polish Academy of Sciences.

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https://doi.org/10.1016/j.oceano.2019.07.002

1. Introduction

Coasts with a connection to the river and seawater are described as estuarine areas (Pritchard, 1952). The term estuary is further expanded and classified as (a) coastal plain/drowned river valley estuaries, (b) fjord estuaries, (c) bar-built estuaries, and (d) tectonically formed estuaries (Cameron and Pritchard, 1963). Based on detailed surveys, Kjerfve (1986) argues that Cameron and Pritchard (1963) definition is insufficient to cover some particular type of coastal water bodies. Kjerfve (1986) redefined them as (1) estuary — an inland river valley; (2) coastal lagoon — separated from the ocean by a barrier, connected to the sea by one or more restricted inlets; (3) fjord — a glacially scoured inland marine area; (4) bay — a coastal indentation; (5) tidal river — an inland river valley, subject to tidal sea-level variations; and (6) strait — an inland marine waterway, connecting two oceans or seas. The extended definition covers the coastal lagoons describing them as a water body with shallow depths, elongated parallel to the coast (Barnes, 1980; Colombo, 1977; Kennish and Paerl, 2010; Kjerfve, 1994). Lagoons covering 15% of the World's coastline are identified by three prominent features: (i) the presence of an isolating barrier beach, spit or chain of barrier islands; (ii) the retention of all or most of the water mass within the system during periods of low tide in the adjacent sea; and (iii) the persistence of natural water exchange between the lagoon and the parent sea by percolation through and/or overtopping of the barrier, through inlet/outflow channels, etc. permitting the lagoon water to remain saline or brackish (Barnes, 1980).

Pakistan in its 990 km long coastline, contains many coastal water bodies such as; Indus deltaic creeks system, occasional freshwater Hub River, Miani Hor, Kalmat Khor and Dasht River (Snead, 1993). The water bodies, along the Pakistan coast, have diversified physiographic features and could be categorized as estuaries with varying degree of freshwater mixing conditions. Miani Hor (Fig. 1) is one of such coastal water bodies in Pakistan that facilitates mixing the seawater and freshwater, however, it is least known and studied. Snead (1966) was the first who identified and described it geographically and mentioned that it is 65 km long meandering channel with varying width, connected to the Arabian Sea by a single inlet. In recent years, Qureshi (2005) and Rasool et al. (2002) explained its importance to marine life due to the presence of flourishing mangrove forest, but none of them ever discussed its hydrodynamical behavior. Therefore, this study was aimed to understand the characteristics of Miani Hor coastal water body following Cameron and Pritchard (1963) and Kjerfve (1986) criteria and classification for lagoons.

The results of the study suggest that Miani Hor is an estuary in adherence to Cameron and Pritchard (1963). Further to this, it follows the description of the coastal lagoon as provided by Barnes (1980), Colombo (1977), and Kennish and Paerl (2010). As and when there is rain in the catchment areas of Porali and Windar rivers, the rainwater is drained into Miani Hor and mixes with seawater within the lagoon. Its single inlet allows the tidal wave to move in but filter out the high energy waves. The tidal signal within the lagoon is so strong that the impact makes lagoon uncomparable with the three classes proposed for lagoons. The results of the study demonstrate that Miani Hor lagoon with a single inlet is influenced substantially by long-period tidal waves as against the choked lagoons. The lack of Miani Hor similarity with the three classes suggests the need to expand the number of lagoon classes to encompass tidally influenced single-inlet lagoons. Although this study is based on limited data that was collected with different objectives, the results obtained will set the future course of investigations based on planned data type and selection of observation sites.

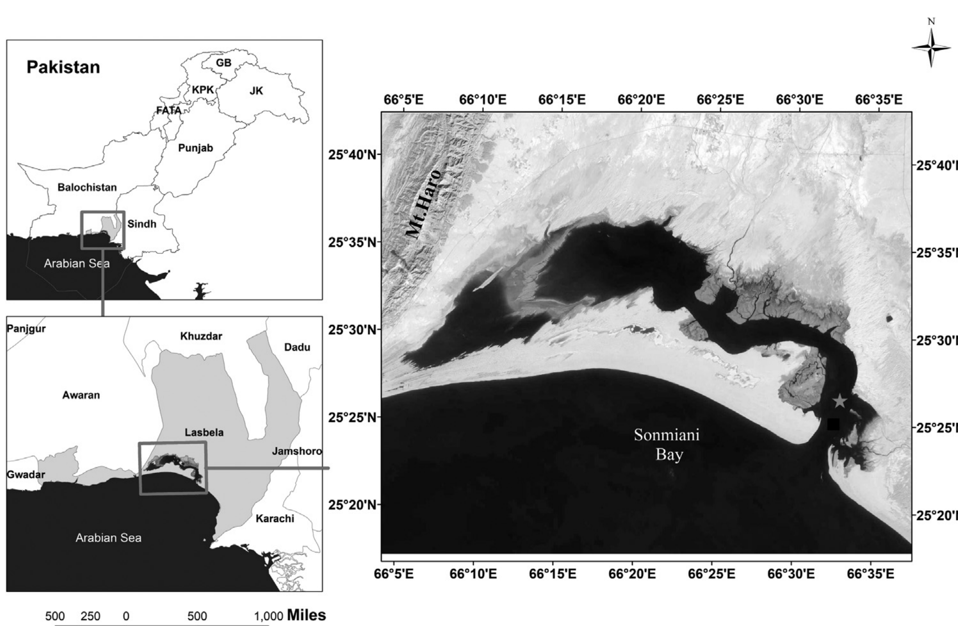

Figure 1 Location map of Miani Hor lagoon in Lasbela district, Balochistan, Pakistan. The data collection site is indicated with a star. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

2. Material and methods

The hydrodynamic characteristics of Miani Hor lagoon were studied using archived data that was recorded during October and November 2017 with different objectives. The data of lagoon water quality and water movement, along with the meteorological data, were used in this study. The vertical and horizontal variation of lagoon water was recorded for 29 days without any break. Aanderaa-made single-point SeaGuard RCM Doppler Current Meter was equipped with Wave and Tide Recording WTR sensor to measure wave and tide with the silicon pressure sensor. The SeaGuard RCM was moored at a depth of 6 m from surface of the water at the location marked with a star in Fig. 1. The instrument was retrieved, and data were downloaded and processed accordingly. One-time water properties within the same period and location were measured using Valeport made MIDAS CTD Profiler.

Offshore Sonmiani Bay hindcasted data by NOAA CFSR model was downloaded from metoceanview.com and used for drawing marine wind condition by plotting wind-rose diagrams. The Climate Forecast System Reanalysis (CFSR) model is developed by NOAA's National Centers for Environmental Prediction (NCEP). The global, high-resolution model was designed and executed as a coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of these coupled domains over the 32 years of record from January 1979 to March 2011. It has been extended as an operational real-time product (NCDC, NOAA).

The study was substantiated with the earlier processed SPOT XS imagery for 3rd September 2005 level 2A by Naeem et al. (2014) to ascertain the littoral drift pattern along the seaward coast of Miani Hor. The shoreline change was determined using the Landsat 8 OLI/TIRS C1 Level 1 imagery for November: 2013, 2014, 2015, 2016 and 2017 with the respective dates: 22, 25, 28, 30 and 17, processed on ERDAS IMAGINE and computed the surface area of the lagoon by controlling the tidal level at image acquisition time. The purpose of regulating the imagery acquisition time was to ascertain the extent of coverage of water in the lagoon with tidal level (Table 1). The Operational Land Imager (OLI) onboard Landsat 8 satellite provides two new spectral bands: a deep blue visible channel (band 1) specifically designed for water resources and coastal zone investigation, and infrared channel (band 9) for the detection of cirrus clouds (https://lta.cr.usgs.gov, 2015). ESRI ArcGIS software was used for image classification and thematic mapping, whereas Matlab for the computation of tidal constituents, calculation of residual levels from the collected water level data by using Codiga (2011) codes and performing spectral analysis functions written by Torrence and Compo (1998).

The maximum combined nonharmonic water levels: Mean High Water Spring (MHWS), Mean Low Water Spring (MHWS), Mean High Water Neap (MHWN), and Mean Low Water Neap (MLWN), along with residual water levels, were determined from computed harmonic tidal constituents as proposed by Pugh (1987). The Form Factor r was also determined using Eq. (1) taken from Pugh (1987) by incorporating the amplitudes of K_1, O_1, M_2, and S_2 tidal constituents:

$$r = \frac{K_1 + O_1}{M_2 + S_2}. \quad (1)$$

The lagoon inlet stability proposed by O'Brien (1969) was computed using the formula:

$$A = xP^n, \quad (2)$$

where x and n are empirical constants. O'Brien (1969) concluded after surveying many lagoons that there might be a relationship between the entrance area and tidal prism and proposed the use of the following values $x = 4.69 \times 10^{-4}$ and $n = 0.85$. Based on his experience, he suggested that for the inlets without jetties good results could be obtained by incorporating $x = 2 \times 10^{-5}$ and $n = 1$. Therefore, the selection of appropriate value for empirical constants depends upon the volume of the tidal prism of the lagoon.

3. Observation and results

3.1. Description of the area

Geographically, Miani Hor lagoon (Fig. 1) is located in between 25°22′26.4″N to 25°37′40.8″N and 066°4′33.6″E to 066°35′45.6″E. It is approximately 95 km west of Karachi in the Lasbela district, Balochistan province of Pakistan (Naeem et al., 2014; Quraishee, 1988; Snead, 1966). The Lasbela is geographically well documented by Snead (1966) and described as an area of the alluvial plain of Porali and other small seasonal rainwater rivers. The analysis of imagery shows that Miani Hor lagoon is 64.73 km long, meandering channel varying in width, covering an average surface area of 401.87 km^2. It is connected with the Arabian Sea through a single, 5.3 km wide inlet that allows seawater to penetrate the lagoon during the rising tide period. The values obtained are similar to Snead (1966) but slightly higher than the values previously reported by Naeem et al. (2014) due to the use of a different approach.

Table 1 Dimensions of Miani Hor lagoon and inlet computed from Landsat 8 imagery.

Image date	Lagoon		Inlet		Tidal stage at imagery acquisition time
	Area [km^2]	Length [km]	Width [km]	Cross-sectional area [m^2]	
11/22/2013	407.25	64.62	5.18	41,440	Falling slack, 1.3 m
11/25/2014	422.5	64.63	5.22	41,760	Rising, 1.5 m
11/28/2015	491.73	64.87	5.26	42,080	Rising, 1.2 m
11/30/2016	349.33	64.85	5.18	41,440	High water slack, 2.4 m
11/17/2017	338.552	64.7	4.81	38,480	Rising, 1.7 m
Mean	401.87	64.73	5.13	41,040	

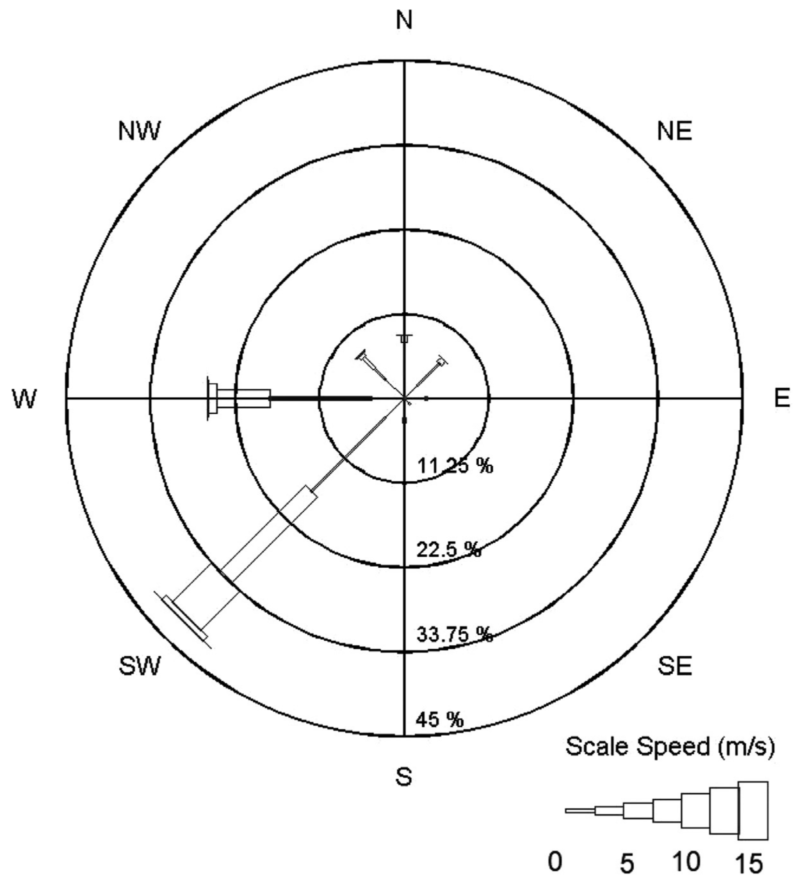

Figure 2 The wind-rose diagram with the percentage of occurrence of wind velocity and direction in the vicinity of Miani Hor (drawn from CFSR modeled data).

Miani Hor lagoon is barricaded from the open sea by two spits. The Adi Spit is situated west of the inlet, it extends to the southern tip of the Haro Mountain range. The Sonmiani Spit, a relatively shorter one, lies east of the inlet (Fig. 1). Porali and Windar rivers were the primary sources of sediment-laden freshwater supply to Miani Hor making it estuarine lagoon. The Windar River used to drain in the area before it ceased to exist, whereas the Porali River and its tributaries still contribute to Miani Hor during rainy seasons diluting the seawater.

3.2. Wind condition

Wind condition for the year 2017, at the coastal belt of the Sonmiani Bay, is hindcasted by the Climate Forecast System (CFS) model. The result of the model (Fig. 2) indicates that prevailing winds blow from west and southwest direction with velocities reaching to 17 m/s. Whereas, during the winter season, the wind stress is not active as compared to summer season but still has a considerable impact on the coastal areas in stabilizing the coast.

Table 2 Summary of wave condition recorded within Miani Hor in 2017.

	Significant wave height [m]	Wave period [s]
Maximum	0.367	7.876
Minimum	0.014	3.215

3.3. Wave condition within Miani Hor

Wave data was recorded by the moored instrument within Miani Hor during October and November 2017, the pre-winter monsoon period with variable offshore winds. The data indicate that waves are negligible within Miani Hor. The maximum height of significant wave recorded during the period is 0.4 m, which is relatively small. The summary of recorded wave data is given in Table 2.

3.4. Tidal level variation

Hourly water level data, recorded at the mooring site, is plotted as time series along with the predicted tide and residual water levels in Fig. 3. The tidal constituents computed from the recorded data, after converting to GMT, are given in Table 3. The values in the table represent the amplitudes and phases of the tidal constituents from true North used to predict the tidal water levels. The maximum-combined nonharmonic water levels computed from tidal constituent amplitudes are given in Table 4.

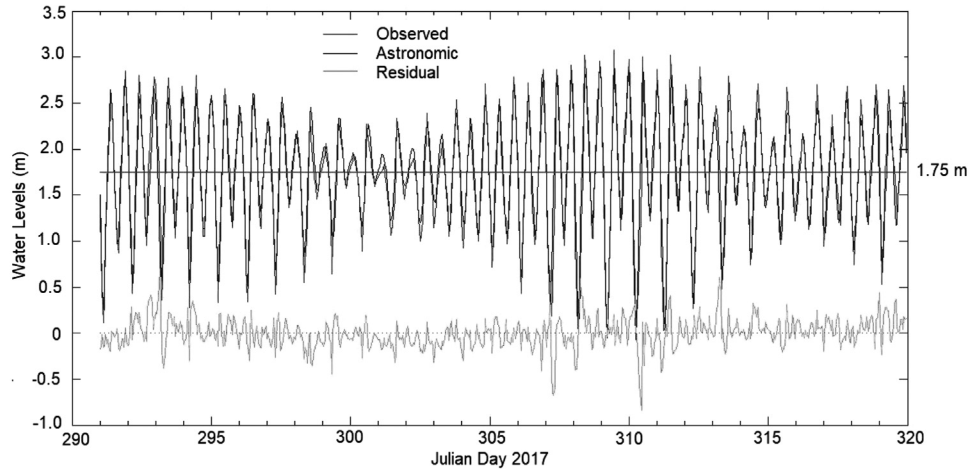

Figure 3 Time series plot of water levels as observed, predicted and residual for the recording period at recording site in Miani Hor.

Table 3 Some of the major tidal constituents computed from 29 days of hourly recorded data.

Constituent	Amplitude [m]	Phase [degrees]
Z0	1.75	
Diurnal		
K1	0.240	148
O1	0.123	188
OO1	0.034	283
J1	0.066	152
Q1	0.051	220
2Q1	0.028	265
NO1	0.047	126
UPS1	0.033	181
Semidiurnal		
M2	0.670	168
S2	0.253	178
N2	0.134	162
Overturn		
M4	0.031	159
M6	0.040	142
MK3	0.097	155
S4	0.001	124
MN4	0.019	47.9
MSF	0.051	35.2
M3	0.015	94.6
M8	0.004	103
MS4	0.015	198
MO3	0.109	206
2MS6	0.050	144
3MK7	0.019	95.3
SK3	0.017	279
2MN6	0.017	141
2SM6	0.011	163
ETA2	0.011	184
2SK5	0.003	332
2MK5	0.002	263

Table 4 Nonharmonic engineering levels at Miani Hor.

Mean water	Level [m]
MHWS	2.673
MLWS	0.827
MHWN	2.167
MLWN	1.333
ISLW	0.464

3.5. Tidal current variation

The seawater velocity data within the lagoon, recorded at a depth of 6 m at the mooring site, reveals that maximum ebb velocity is 0.86 m/s, which is higher than the flood velocity. The water current plotted as current rose diagram (Fig. 4) prominently indicates that Miani Hor is under the influence of tidal flow. The direction and magnitude of the seawater change with the change of tidal stage from ebb to flood or vice versa. The plotted current rose diagram (Fig. 4) further indicates that the dominant flow of lagoon water is in the alignment with the lagoon channel.

3.6. Lagoon water quality

The water quality was determined from temperature and salinity recorded at the mooring site and showed that temperature and salinity are almost mixed from the surface to bottom with relatively higher values at the surface and lower near the bottom (Fig. 5). The plotted profiles depict the average water column temperature of 29.56°C and salinity of 38.19 PSU.

4. Discussion

4.1. Characteristic of Miani Hor

Similarly to the majority of the coastal lagoons of the World, Miani Hor was also formed as a result of past million years

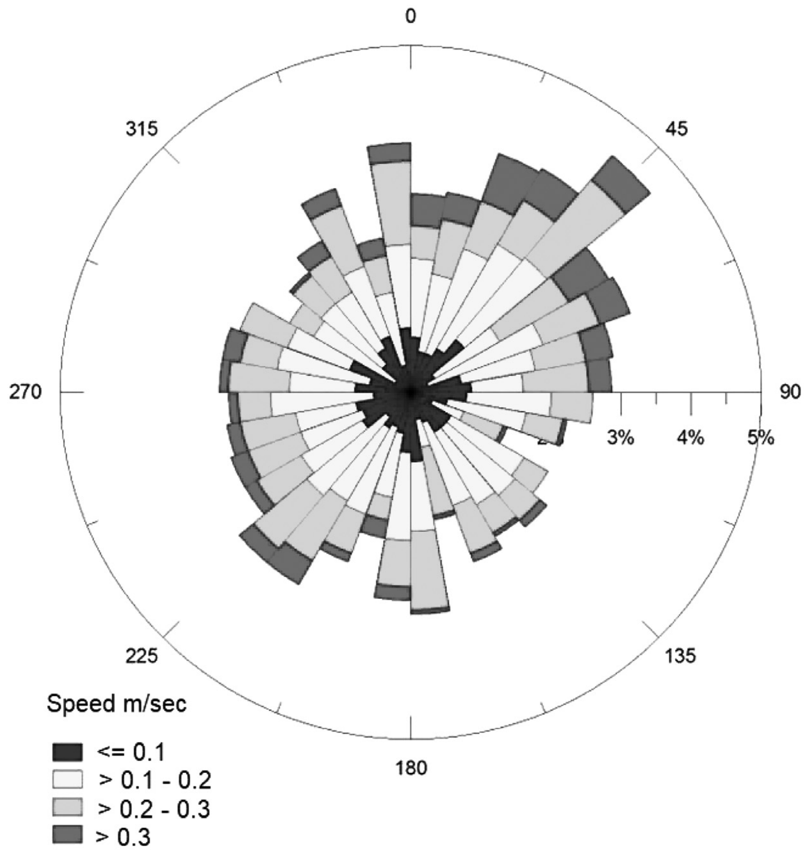

Figure 4 The current-rose-plot of hourly recorded sea water current data from 6 m water depth from the surface.

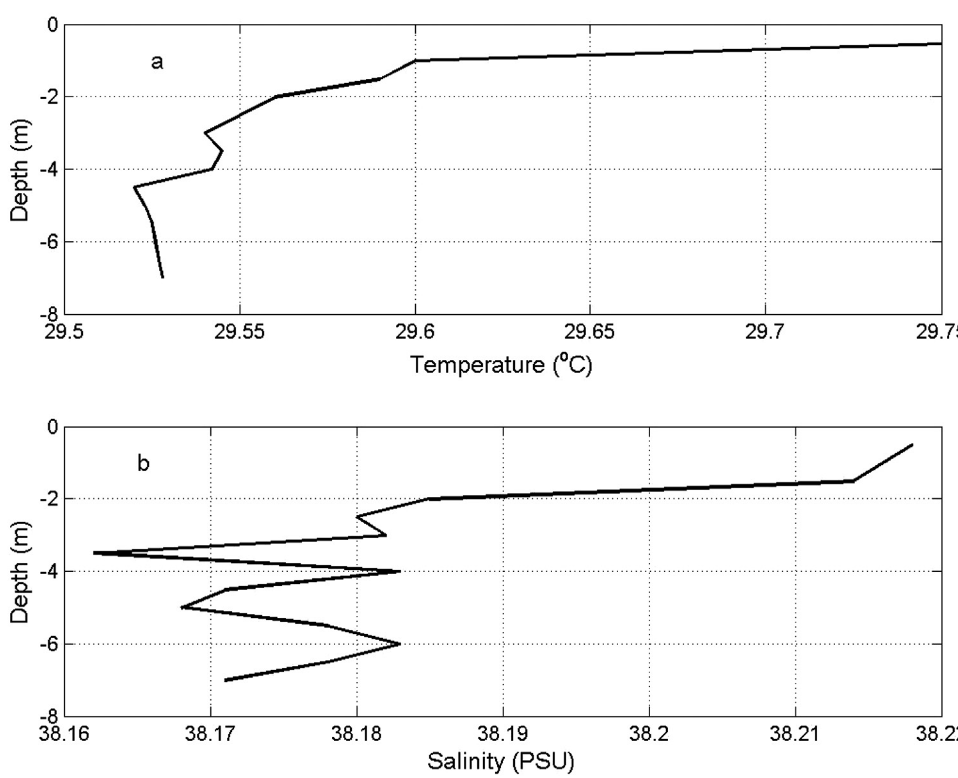

Figure 5 Temperature profile (a) and salinity profile (b) recorded at instrument mooring site in Miani Hor.

alternating filling and erosion in the Lasbela valley, that accompanied the four major glacial stages. Every deglaciation stage caused alluvial deposition in the Lasbela plain, while during the glacial phase, shallow Sonmiani Bay was exposed and supplied voluminous amount of fine material to the coast. The accretion of the accessive amount of sediments on the beach developed series of recurved spits across the shoreline of Sonmiani Bay by the action of strong southwest winds and seawater currents preventing the encroachment of the sea forming Miani Hor lagoon (Snead, 1966). The development of crescent bar and deposition of sediments at the coast made Miani Hor a shallow inland marine water body, oriented parallely to the coast. The crescent-shaped coast was bifurcated into Adi, and Sonmiani spits by a 5 km wide channel. Phleger (1969) described such configured water bodies as coastal lagoons. The elongated configuration of the lagoon is the sign of an easterly drift of sediment. Blue arrows indicate this phenomenon in Fig. 6. The lagoon channel remains open in all seasons due to the flushing of sediment-laden water out of the lagoon through the inlet and because the converged sediments are transported from both sides of barrier spits and are being pushed offshore into the deeper areas of Sonmiani Bay.

The southeasterly summer winds get large fetch area that helps to develop high energy waves all along the Pakistan coast. The average significant waves along the Karachi coast have been reported as 2.5 m, with 80% of them above 1.0 m (Rizvi et al., 1993). However, during winter, mild winds coming from land to sea generate only low energy waves.

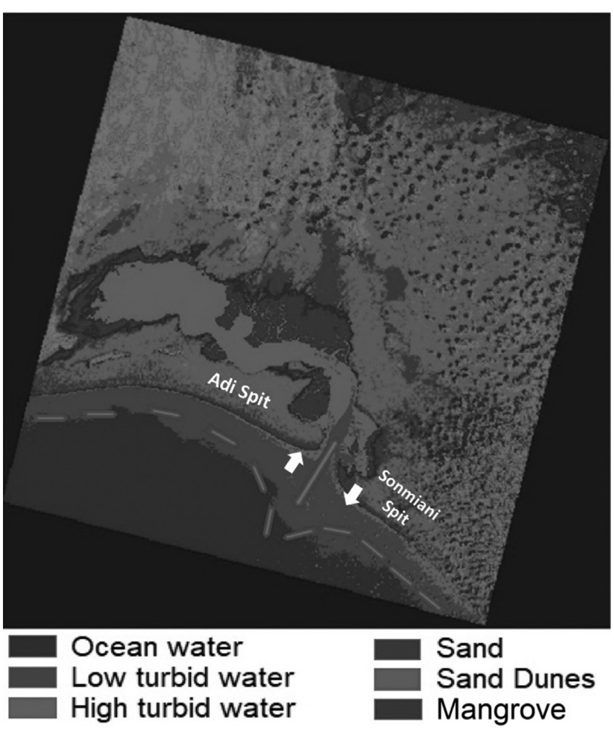

Figure 6 Classification of Spot XS imagery of 3rd September 2005 showing the alongshore, onshore—offshore sediment plume movement with blue arrows, whereas two white arrows indicate the downdrift offset inlet. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The yearlong wave data partially reported by Rizvi et al. (1993) is rearranged and presented as the wave-rose diagram in Fig. 7. The diagram indicates the dominant incoming waves striking the coast from southwest and south. As Sonmiani Bay is not far from Karachi, therefore, the Karachi approaching deep water waves are comparable. The high energy waves, developed during summer, drive the coastal sediments west to east along the Adi Spit and east to west along the Sonmiani Spit (Fig. 6) accumulating in front of the lagoon inlet. Unlike the open sea wave condition, waves within the lagoon are insignificant. The waves condition recorded within the lagoon during 2017 (Table 2 and Fig. 4) shows that within the lagoon the waves are entirely filtered out by the narrow lagoon inlet. The low energy waves within the lagoon are a locally generated waves due to the limited fetch (Naeem et al., 2014).

The analysis of water level data indicates that tidal behavior within Miani Hor lagoon is similar to the other coastal areas of Pakistan. The form factor, a parameter widely used to describe the tide (Pugh, 1987) was computed as 0.393 which suggests that tide within Miani Hor lagoon is significantly mixed but mainly behave as a semidiurnal tide. The presence of tidal wave within Miani Hor is further verified with the spectral analysis of water level data. The results of the spectral analysis plotted in Fig. 8 indicates the presence of strong diurnal, semidiurnal, and third-diurnal tidal signals.

The rise and fall of the tide in the adjacent sea fluctuate the water level within the lagoon and hence, the surface area. The comparison of satellite imagery with the tidal stage at imagery acquisition time (Table 1) shows that on 30th November 2016 (Fig. 9D) it was high tide in the vicinity of lagoon inlet and water was spread over an area of 349.33 km^2. The image further depicts that while it was high-water near the lagoon inlet, there was a low-water condition at the far end of the lagoon. Similarly, the acquisition time of 28th November 2015 imagery (Fig. 9C) coincided with the low tide near the inlet, but water spread over an area of 491.73 km^2 in the lagoon. The extensive coverage of the lagoon seawater area indicates the extent of tidal crust up to the tail of lagoon. The analysis of imagery further reveals that high-water condition at the far end of the lagoon forces the water to spread over the Adi Spit from the southern bank and to move eastward through low lying areas of the spit, flooding the two-third of the spit length. It is, therefore, inferred that by the time tidal crust reaches the far end of the lagoon, the lagoon inlet is at the low tidal stage. The gentle banks of the lagoon surrounded by numerous mangrove-covered mudflats become exposed during low tide (Fig. 9D).

With the fluctuation of the tidal prism, the perimeter of the lagoon and inlet width also varies. The variation in the computed surface area determined from different years of imagery (Table 1) is the indication of tidal water level fluctuation. The surface area of the lagoon reported by Qureshi (2005), Rasool et al. (2002) and Snead (1966) was based on instantaneous measurements. The difference in reported values suggests that a systematic approach is required to determine the surface area of the lagoon and inlet at local chart datum.

Miani Hor lagoon, although relatively widespread at the upper half, changes further down into a narrow distinguishable meandering channel with an average depth of 8 m. The peculiar geometry of the lagoon could be explained as the combination of sediment deposits of Porali and Windar rivers

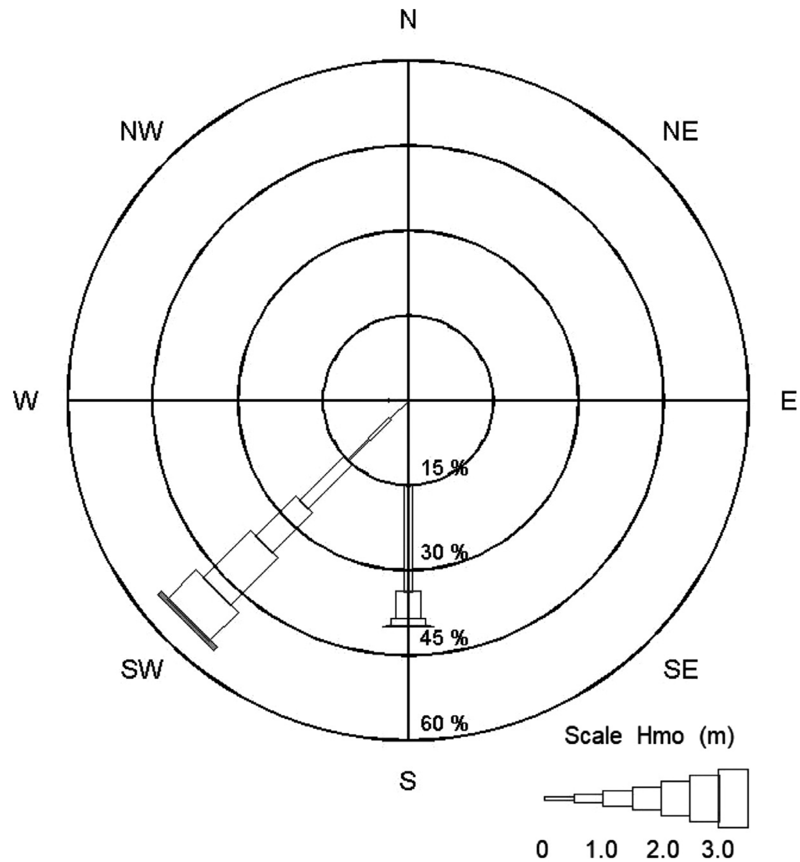

Figure 7 The wave-rose-diagram made from yearlong wave data for offshore Karachi (modified from Rizvi et al., 1993).

into the northern part of the lagoon and migration of the sand bar of the Adi Spit. The lagoon sediments confirm this inference as they are composed of silty clay with few sandy patches (Snead, 1966). The continuous filling of the lagoon forces the main channel to migrate southward. The constant migration of dry sand from Adi Spit pushes the main channel to the northeast (Snead, 1966). The Windar River used to drain at the eastern corner of the lagoon forming the significant size of the delta. However, since the last 150 years, with the upstream usage of Windar water, the delta is devoid

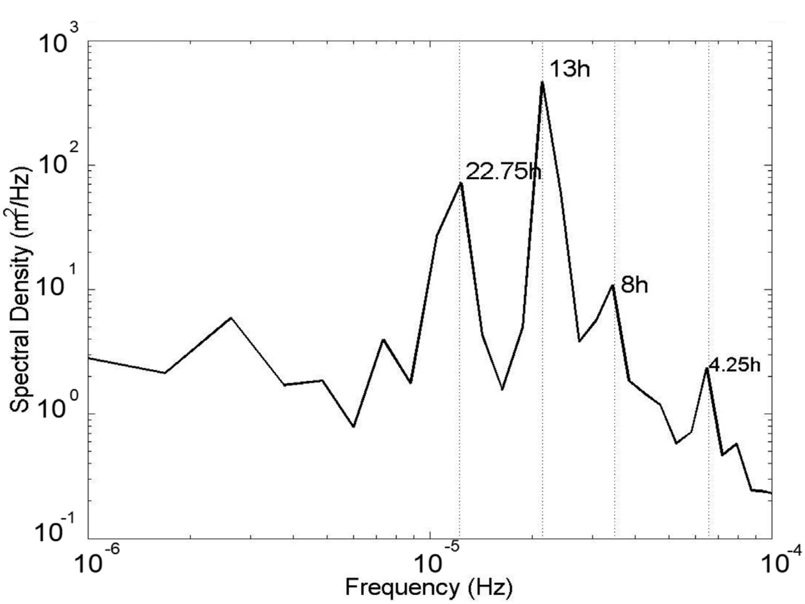

Figure 8 The plot of spectral analysis of observed water levels. The dominant tidal constituent signals are marked in the plot.

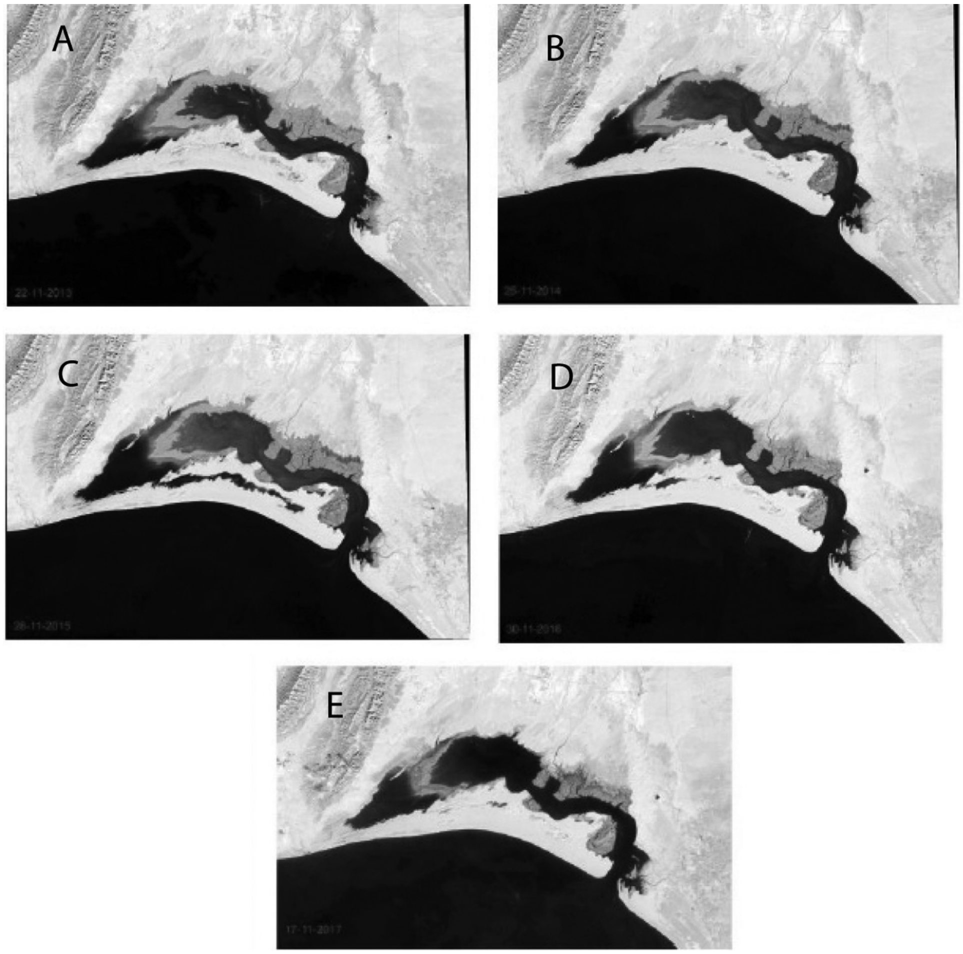

Figure 9 Landsat 8 temporal imagery: (A) 2013, (B) 2014, (C) 2015, (D) 2016, and (E) 2017.

of sediment-laden water. The unavailability of sediment is eroding the northern side of the Adi Spit to balance the sediment budget (Fig. 9B and C). The continuous erosion of Adi Spit and habitable land in the north bank of the lagoon had forced the local communities to retreat and move their houses to a more secure place. This situation has further been intensified by the construction of ill-designed nonfunctional fish landing jetty (Naeem et al., 2014) and two incomplete protection groins.

The data of tidal variation used in this study is the only available data for this study area to understand the tidal behavior within the lagoon. Unfortunately, data collected from a single point is not sufficient to cover the entire lagoon length. Therefore, to know the lagoon dynamics, spatially selected sites all along the lagoon need to be established for simultaneous recording of tidal data.

4.2. Inlet dynamics

Miani Hor lagoon inlet depth profiles show that the eastern side of the inlet is deeper ($\sim$10 m) than the western side ($\sim$6 m) (Snead, 1966) which is indicative of the forceful flow of water on the eastern bank of the inlet. The different inlet cross-sectional areas (38,480—42,080 m^2), and widths (4.81—5.26 km) are obtained from the analysis of the Landsat 8 imagery from 2013 to 2017 (Table 1) during different tidal stages. Morphologically, inlets are grouped into four classes: (1) overlapped inlet, overlapped by downdrift, (2a) significantly offset updrift side, (2b) significantly offset downdrift side and (3) negligible offset (Galvin, 1971). The analysis of satellite imagery shows that Miani Hor inlet is offset to downdrift (highlighted in Fig. 6 with white arrows) and is comparable to the 2b class. The Adi Spit, west of the inlet is offset northward, whereas, the Sonmiani Spit extends offshore (see Fig. 6). The longshore sediment movement is interrupted by the strong ebb currents jetting out of Miani Hor lagoon inlet. Therefore, the formation of type 2b tidal inlet is the result of steady littoral drift and tidal flow that maintain the opening of the channel (Galvin, 1971).

The stability of the inlet is determined from Eq. (2) by incorporating the tidal prism; 7.42×10^8 m^3 the volume of water that enters within the lagoon during high tide. The cross-sectional area of inlet is taken as 43,810 m^2 while empirical constants $x = 4.18 \times 10^{-4}$ and $n = 0.85$ were used (O'Brien, 1969). The resultant cross-sectional area is higher than the area measured from imagery (Table 4). O'Brien (1969) suggested that the empirical constants of Eq. (2) $x = 2 \times 10^{-5}$ and $n = 1$ could be used for inlets without jetties, and lagoons having their tidal prism in between 3.3×10^7 and 1.3×10^{10} m^3. The tidal prism of

Miani Hor is within the range, however, we used empirical constants; $x = 5.59 \times 10^{-5}$ and $n = 1$ to get the measured cross-sectional area (41,478 m^2). The nature of the inlet is the prime parameter that controls the lagoon function and it is the deterministic parameter along with the ratio of the channel cross-sectional area to surface area, that categorizes the lagoon as one of the three classes: choked, restricted or leaky (Kjerfve, 1986).

In accordance with the explanation provided by O'Brien (1969) for the stability of inlet, the dispersion of sediment plum, traced in Fig. 6 by blue arrows, is indicative of coastal sediment-laden water movement toward the lagoon-channel, accumulating the sediment as a result of tide and wave action. Whereas, the ebb and flood of tidal currents that rush through the inlet are responsible for sweeping accumulated bar, built as a result of sediment deposition, away from the channel and keeping it there even during summer monsoon high-energy wave climate. The phenomenon of a littoral drift is comparable to the stabilized inlets as described by O'Brien (1969). It is, therefore, inferred that the tidal inlet of Miani Hor lagoon is stable due to the equilibrium condition. In the absence of significant wave action during the winter monsoon, sediments flushed from lagoon develop into a bar in the Sonmiani Bay that is wiped out in summer.

Salinity values recorded in this study (Fig. 5b) are almost the same as reported by Naeem et al. (2014) but higher than the open sea salinities published by Ali and Naeem (1999) and Rizvi et al. (1993). The difference in salinities in the adjacent sea and lagoon waters indicates that the lagoon behaves as a negative estuary during the dry season and a positive estuary during the rainy season. During the dry season, the water evaporates from the lagoon leaving behind high salinity water. However, some traces of lower salinity at the subsurface layer are indicative of occasional freshwater input from the Porali River. Continuous contribution of freshwater into the lagoon on geologic time scale is further substantiated by the presence of healthy mangrove forest (Fig. 6) within Miani Hor, particularly, in the vicinity of the Porali River mouth and lagoon inlet (Naeem et al., 2014; Qureshi, 2005; Rasool et al., 2002; Saima and Usman, 2006; Snead, 1966). *Rhizophora mucronata* is a dominant species among other two, *Aviciennia marina* and *Ceriops tagal* varieties of mangroves, which are also present in Miani Hor lagoon (Qureshi, 2005; Snead, 1966).

Results of the analysis and the presence of healthy mangrove forest suggest that Miani Hor is a well-established lagoon in accordance with all three identifying features described by Barnes (1989). However, even though it has a single inlet and small ratio of channel cross-sectional area compared to the lagoon surface area, its dynamics are not in agreement with Kjerfve's (1986) choked lagoon classification scheme. Unlike the choked lagoons, Miani Hor lagoon is under the strong influence of tidal dynamics.

The results of the study suggest that Kjerfve (1986) classification of lagoons should be expanded to another class — relaxed lagoon, to encompass the single inlet lagoons with strong tidal influence. The proposed new classification of lagoons could be grouped as:

1. Choked lagoons — with a single inlet and limited tidal influence confined to the entrance.
2. Relaxed lagoons — with a single inlet and strong tidal influence.
3. Restricted lagoons — with two or more inlets and located on low/medium wave energy coasts with low tidal ranges.
4. Leaky lagoons — connected with the ocean by wide tidal passes that transmit oceanic effects with minimum resistance.

5. Conclusion

Miani Hor lagoon is located in the Lasbela district of Balochistan, Pakistan, and connected to the sea with the single inlet. It was formed as a result of the past million years of alternate filling and erosion in the Lasbela valley that accompanied the four major glacial stages. During the glacial stages, the shallow continental shelf of Arabian Sea was exposed at Sonmiani Bay which became a voluminous source of fine material for the formation of series of recurved spits by the southwest winds action. Formation of spits created barrier separating Miani Hor lagoon from Sonmiani Bay. Analysis of water level data collected for this study suggests that the lagoon is under the strong influence of tidal action. The form factor computed from the harmonic tidal constituents is 0.393, characterizing it as mixed but mainly semidiurnal tide. Miani Hor lagoon is a shallow inland marine water body, oriented parallely to the coast, separated from the Arabian Sea by a barrier but connected to the sea by an inlet. The characteristics mentioned by Phleger (1969) describe Miani Hor as a well established coastal lagoon.

The surface area of the lagoon changes prominently twice a day between high and low tides, that enter the lagoon from single inlet connecting it with the sea. The rise and fall of the tide in the adjacent sea causes horizontal flow of water into and out of the channel that in turn causes fluctuation of water level of the lagoon and hence the volume of water. Miani Hor lagoon inlet is more closely comparable with the Galvin (1971) 2b class due to significant offset in the downdrift of the inlet. Wave condition within the lagoon and adjacent sea indicate that offshore deepwater waves do not penetrate the lagoon due to the single narrow inlet. Strong tidal currents cause most of the erosion and accretion within and out of the lagoon. The sediments used in this process are either being eroded by the inundation of seawater to Adi Spit from lagoon side, or erosion of Windar delta and its vicinity.

Miani Hor lagoon was compared with Kjerfve (1986) classification, which is based on the number of inlets and tidal influence. The scheme of classification categorized lagoons into choked, restricted, and leaky groups. However, Miani Hor lagoon characteristics suggest that it cannot be ultimately compared with the mentioned classes. Unlike the lagoons with single inlet classified as choked lagoons, Miani Hor, even though it is connected with the sea by a single inlet and has a small ratio (0.08) of inlet cross-sectional area to the lagoon surface area, is strongly influenced by the tide but not wind-generated gravity waves. The results of the study based on limited data suggest that recognized classification of lagoons is incomplete and should be expanded to include single inlet lagoons with strong tidal effects. This study proposes the inclusion of another class — relaxed lagoon, for the tide-dominated single inlet lagoons.

Acknowledgments

Authors acknowledge the National Institute of Oceanography, Karachi for the facility provided during visits to the study area and for giving access to the archived data, Dr. Mirza Naseer Ahmad of Nusrat Jahan College Rabwah for encouraging and facilitating the study. Authors are also in debt of anonymous reviewers for their constructive comments that significantly improved this paper.

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