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Classification of tidal inlets along the central east coast of India

N. Amaranatha Reddy^{a*}, M. Vikas^b, Subba Rao^c, Jaya Kumar Seelam^d

^a Research scholar, National Institute of Technology, Surathkal, Karnataka, India, amarmtech@gmail.com

^b Post Graduate student, National Institute of Technology, Surathkal, Karnataka, India, kbl9dad@gmail.com

^c Professor, National Institute of Technology, Surathkal, Karnataka, India, surakrec@gmail.com

^d Principal Scientist, Ocean Engineering, CSIR- National Institute of Oceanography, Goa, India, jay@nio.org

Abstract

Coastal inlets are the openings along the coastline that provide a linkage between the open ocean and the hinterland water bodies. These coastal inlets are varied in nature depending on many influencing parameters such as tide, wind, river flow and waves. Amongst these parameters, the tides are the most regular while waves and freshwater flow are more seasonal. The tidal inlets have to be examined and studied to understand the nearshore coastal processes. The inlet remains stable (i.e. open) as long as the alongshore sediment bypasses the tidal inlet. Classification of coastal systems in a broader view is necessary for the management of tidal inlets. There are several methods to classify tidal inlets based on different perspectives namely geo-morphological, hydrodynamic etc. In the present study, tidal inlet classification is carried out considering the hydrodynamics and morphodynamics along the Andhra Pradesh coast, considering the classification method as in Hayes (1984) and Thuy (2013). The Hayes (1984) classification considers only the tidal range and significant wave height, whereas Thuy (2013) considers discharge due to tide (\sim Tidal prism /tide duration) and wave ($\sim\sqrt{gH^3}$). A total of 108 tidal inlets along Andhra Pradesh coast on the east coast of India are classified considering annual mean wave height (H_s) as well as seasonal wave heights. This paper presents the methods used and results of the coastal classification along the central east coast of India.

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* Corresponding author. Tel.: +91 8686151727
E-mail address: amarmtech@gmail.com

1. Introduction

Tidal inlets are defined as short, narrow passages between two sandy barrier islands and connect the ocean (or sea) to a bay. Tidal inlets provide the access between the ocean and a bay by both nature and human interventions. Hence these barrier islands are migrating either landwards or seawards depending upon the strength morphological drivers such as tide, waves and river flow. The major tidal inlet functions are natural flushing in the form of flow of currents into and out of the bay through an inlet there by maintaining good water quality, migration of fish, fish larvae, and other sea life through the inlet channel. Closure of tidal inlets causes significant threat to the fisherman communities as well as the flooding of the upstream region. Therefore stability of an inlet plays a major role along any coastline in regulating the water exchange.

2. Study area

The study region selected is Andhra Pradesh coast along central east coast of India. The study area is located in a tropical monsoon region and is characterized as a micro-tidal (tidal range 0-2m), wave dominated coastal environment. The tropical monsoon climatic conditions are more responsible for morphology controlling factors of the tidal inlets which are highly dynamic and variable in nature. Majorly the Andhra Pradesh coast has its influence on tidal inlet morphology through seasonal variation of river flow and wave climate. Andhra Pradesh is having a long coastline of 974 km starting from Nuralrevu village near Ichapuram in Odisha to Therunattam village in the southern tip of the coastal plain of Andhra Pradesh. There are nine coastal districts along Andhra coast (Figure 1). A total of 106 inlets are identified along the coastline of Andhra Pradesh. Inlets with width less than 5m is not considered in the present study and the names given to the inlets are based on the nearest visible place around the inlet on Google Earth ®. The oceanographic climate in this region is divided into North-East monsoon (October-January), South-West monsoon (June -September) and Fair Weather season (February -May). The tides in this region are semi-diurnal. The study region on east coast of India is prone to cyclonic storms every year with an average of about 5 cyclones per annum

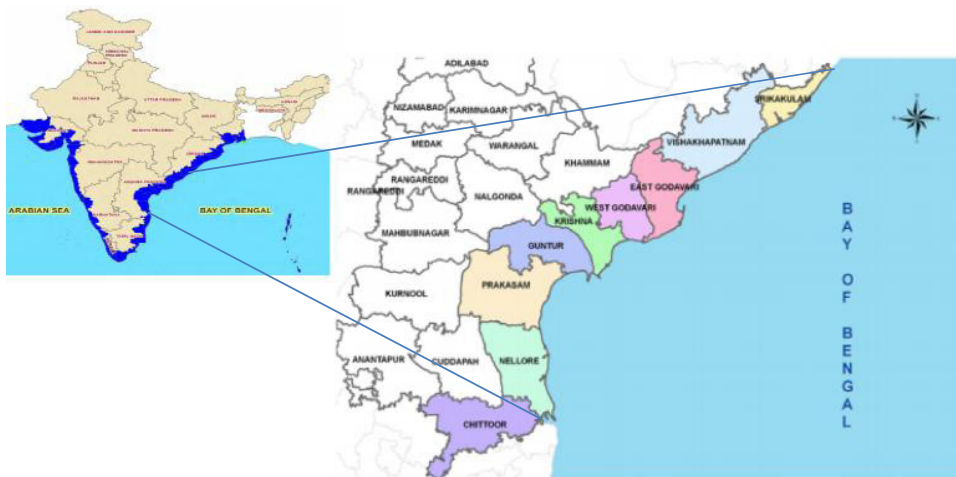


Figure 1. Location map

3. Methods and Methodology

Tidal entrances constitute an important dynamic boundary condition with respect to the coastal regime due to their role as interfaces for exchange between seawater and embayed water. Generalized morphodynamic

relationships applicable to the entrances serve as useful tools for characterizing the physical state and the dynamic behavior of entrances.

3.1 Input parameters:

Tidal range (R_{10}) is defined as the vertical difference between the high tide and the consecutive low tide. The tidal range is obtained by simulating the tidal variation along the coast using MIKE21 flow model (FM). The results obtained are cross-checked with the tidal stream flow in hydrographic charts, published by the National Hydrographic office, Dehra Dun, India.

Lagoon area or the bay area (A_b) for the identified inlets is calculated from the high-resolution data obtained from Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) from U.S. Geological Survey Department. This data consists of various high-definition images of different bands and these are overlaid and the final image is obtained by ArcMap 10.1. From the composed image, the lagoon or bay area is calculated by creating new shape files in ArcMap 10.1 and further verifying the same by MIKE21 and area calculation tool from draftlogic. Note that the calculation bay area has been restricted approximately to 15 Km for some inlets whose extent is very large and those which are less than 10 Km, have been fully considered.

Tidal prism (P) is defined as the amount of water necessary to fill up the basin between ebb tidal water level and flood tidal water level and is calculated by multiplying the tidal range times the basin area and subtracting the volume of sandy shoals.

Significant wave height (H_s) is defined as the average height of the highest one-third waves in a wave spectrum. The Significant wave height data is obtained from the MIKE21 spectral wave model simulated for the year 2010. The average significant wave height data is extracted by giving latitudes and longitudes as the input at 10m water depth along the respective inlets.

Flood discharge is collected at the gauge stations from Water Resources Information System (India-WRIS) for 36 tidal inlets which are located close to the tidal inlet entrance by assuming that there are no losses in between.

Peak or mean tidal discharge

Peak or mean tidal discharge in m^3/s , Q_{tide} is calculated using the relation below. (Vu, 2013)

$$Q_{tide} = \frac{P\pi}{T}$$

Where,

P- Tidal Prism in m^3

T- Tidal period, T= 12 hrs 25 min for semi-diurnal tides = 44712 s

3.2 Inlet classification:

There are several number of tidal inlet classifications available in the literature based on geomorphological and hydrological behaviour around the inlets, wave climate and energy potential, e.g., Hayes et al. (1979), de Vriend et al. (1999), Heap et al. (2001), Ray et al. (2001), Vu (2013). The variation of the inlet dimensions and locations for all the tidal inlets over a period of about 15 years is carried from the Google Earth® images. The morphology of the inlets was studied using remote sensing satellite images. Firstly the geomorphological classification as per de Vriend (1999) was carried out (Figure 2).

Hayes (1979) and Davis and Hayes (1984) characterized inlet plan form morphology according to the relative strength of tide and waves, as depicted in Figure 3, with tidal range serving as a surrogate for tidal prism (volume of water entering or leaving an inlet in the corresponding half tidal cycle) or tidal current (which moves the sediment) and also the Hayes' classification is concerned not only with the morphologic behaviour of a tidal inlet, but also with the frequency of occurrence and number of inlets along a barrier coastline.

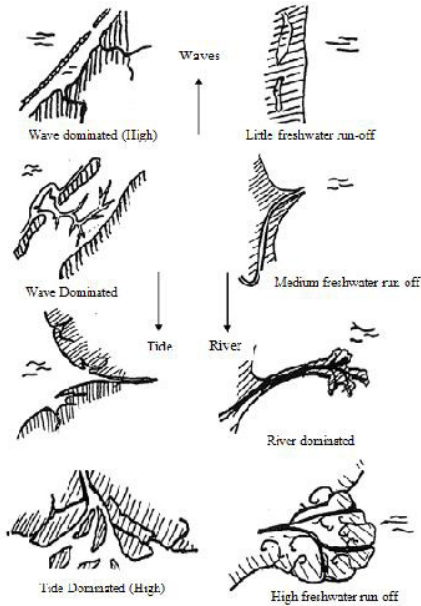


Figure 2: Classification of inlet shapes based on influence of waves, tide and river flow (de Vriend et. al, 1999)

Table 1: Classification of Coastal systems based on dimensionless parameters (Vu, 2013)

No.	Criteria	Type of dominance
1	$\frac{Q_{tide}}{\sqrt{gH^5}} < 75$	Wave dominated coast
2	$\frac{Q_{tide}}{\sqrt{gH^5}} > 75$	Tide dominated coast
3	$\frac{Q_f}{\sqrt{gH^5}} \approx 2$	River dominated coast

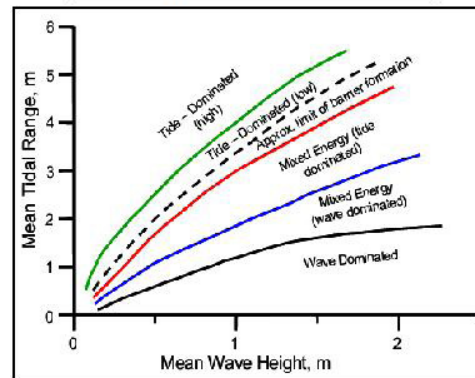


Figure 3: Hydrodynamic based classification of tidal inlet morphology (Hayes 1979)

The classification introduced by Vu (2013) is based on dimensionless parameters which represent the relative strength of the three main forcing agents, viz., tide, river flow and waves (Table 1). The non-dimensional parameters $\frac{Q_{tide}}{\sqrt{gH^5}}$ and $\frac{Q_f}{\sqrt{gH^5}}$ are introduced in which tidal forcing is quantified in terms of the peak tidal discharge and wave forcing represented in terms of sediment transport capacity. Another method of classification based on dimensionless parameters Vu (2013) is modified and the parameter mean wave period (T) is included for the classification. Modified Vu (2013) method considered wave period (T) in addition to the wave height (H) in the dimensionless parameters $\frac{Q_{tide}}{\sqrt{gH^5}}$ and $\frac{Q_f}{\sqrt{gH^5}}$ by the runup scale $\sqrt{HL_0} = \sqrt{H \frac{gT^2}{4\pi}}$ which leads to new dimensionless parameters viz. $\frac{Q_{tide}}{(g^{1.75}H^{1.25}T^{2.5})}$ and $\frac{Q_f}{(g^{1.75}H^{1.25}T^{2.5})}$ respectively. The values set for each of the dominance criteria is shown in Table. 2.

Table 2. Classification criteria used for modified non-dimensional method (modified Vu method)

$\frac{Q_f}{(g^{1.75}H^{1.25}T^{2.5})}$	$\frac{Q_{tide}}{(g^{1.75}H^{1.25}T^{2.5})}$ non-d	Type of Dominance
< 0.045	< 0.0001	Wave Dominated (ICOLLs)
< 0.045	> 0.0001	Wave Dominated
> 0.045	< 0.0001	Tide Dominated
> 0.045	> 0.0001	River Dominated

4. Results

4.1 Geomorphological classification:

The classification method given by de Vriend et al. (1999) is used to classify the inlets. Mostly the Andhra Pradesh coastline is subjected to wave dominance environment because of high wave activity along east coast compared to the west coast. Seasonal closure of tidal inlets is observed in almost 25% of the inlets because of high wave activity during summer season. The details of the inlet names and the type of classification observed are shown in Table. 3.

4.2 Hydrological classification:

As mentioned above in section 3.2, the tidal inlets are classified by Hayes (1979) classification is used to identify geomorphic inlet type by mean tide range and mean average significant wave height (Figure 4). In this classification method there are three limiting states viz., Tide Dominated (TD), Wave Dominated (WD) and Mixed Energy (ME). Tidal inlet classification is carried out for the seasonal variation of wave height in North East monsoon, South West monsoon and Fair weather season. It is observed that the type of dominance over some inlets varies seasonally. This is because of the variation in wave height during different seasons. The Andhra Pradesh coast on the East coast is comparatively less prone to monsoons and more exposed to cyclones. Thus, all the inlets are almost equally influenced by cyclones and hence they represent as a group (Figure 5).

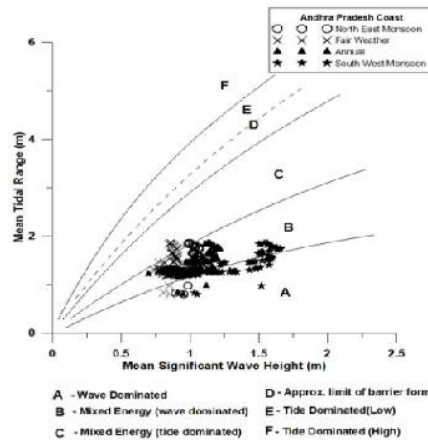


Figure 4: Classification based on Hayes (1979) for all seasons along Andhra Pradesh coast

4.3 Dimensionless classification:

Morphological classification method is considered to be more accurate method because of their field measurements and visual observations. Only three forcing parameters viz., tide, waves and fresh water flow were considered in this classification. Due to inadequate data, among 108 inlets only 7 inlets were considered for the classification using non-dimensional parameters (Figure 5). This classification system did not show a good agreement with morphological classification system. The type of dominance is also not clearly seen.

4.4 Non-dimensional classification including time period:

Including the wave period along with the main driving agents such as tide, waves and river flow, the modified non-dimensional classification method is applied to the 7 inlets. Using the new criteria set for the modified classification method, the 7 inlets considered showed good agreement with the morphological classification (Figure 6).

Table 3. Classification of inlets based on Geomorphology

Inlet ID	Name	Classification
1	Karimanal	WD
2	Shar	Closed
3	Chinnathota	WD
4	Nalagamula	Closed
5	Konduru	WD
6	Swanamukhi river	WD
7	Kothapatnam	WD
8	Srinivasa	Closed
9	Gunnampadia-2	Closed
10	Gunnampadia-1	Closed
11	Gopalapuram-2	Closed
12	Gopalapuram-1	WD
13	Nelaturu	WD
14	Pathapalem	WD
15	Koruturu	Closed
16	Ramudupalem	WD
17	Utukuru	Mixed Energy
18	Ramathirtham	Closed
19	Isakapalle	WD
20	Juvvaladinne	WD
21	Ramayapatnam-2	Closed
22	Ramayapatnam-1	WD
23	Karedu	WD
24	Pakala	Closed
25	Anantavaram-2	WD
26	Anantavaram-1	WD
27	Peddapattapalam	Closed
28	Motumala	WD

29	Chintayigari palem	WD
30	Kanuparthi	WD
31	Peddaganjam	WD
32	Pallepalem	WD
33	Pullaripalem-3	Closed
34	Pullaripalem-2	Closed
35	Pullaripalem-1	Closed
36	Katari palem	WD
Inlet ID	Name	Classification
37	Krupa nagar	WD
38	Pandurangapuram	WD
39	E. Gollallem	WD
40	Gokarnamatam	WD
41	Dindiadavala	WD
42	Haripuram	WD
43	LVD	Mixed Energy
44	Elachetladibba	Mixed Energy
45	RKP	WD
46	Ramakrishnapuram2	Closed
47	Ramakrishnapuram1	Closed
48	Palakayatippa	Mixed Energy
49	Machilipatnam	WD
50	Polatitippa	Mixed Energy
51	Chilikalapudi	WD
52	Kara agraham	Mixed Energy
53	Gokavaram	WD
54	Tallapalem	WD
55	Kanuru	Mixed Energy
56	Kruthivennu	WD
57	Peda gollapalem	WD
58	Chinna gollapalem	WD
59	Marritippa	WD
60	Odalaravu	Mixed Energy
61	Komaragiri patanam	Mixed Energy
62	Gachakayala pora	WD
63	Kothapalem	Mixed Energy
64	Gadimoga	WD
65	Sasikanth nagar	Mixed Energy
66	Nemam	WD
67	Mulapeta-2	WD

68	Mulapeta-1	WD
69	Pentakota	WD
70	Rajanagaram	WD
71	Boyapadu	Closed
72	Dhandawaka	Closed
73	Bangarammapalem	WD
Inlet ID	Name	Classification
74	Pudimadaka	WD
75	Chippada	Closed
76	Dosuru	Closed
77	Cheepurupalle	WD
78	Peddapalem	WD
79	Vishaka port	WD
80	MVP sector	WD
81	Musalayypalem	Mixed Energy
82	Pedda rushikonda	WD
83	Kummaripalem	WD
84	Kancheru	WD
85	Konada	Mixed Energy
86	Kollaya valasa-2	Closed
87	Kollaya valasa-1	Closed
88	Pathiwada	WD
89	Chintapalli	WD
90	NJR puram	WD
91	Tekkai	Closed
92	Kuppili	WD
93	Bontala koduru	WD
94	Vastavalasa	WD
95	Seepanapeta	WD
96	Kalingapatanam	Mixed Energy
97	Siddibeharakothuru	WD
98	Malagam	Closed
99	Devunalthada	WD
100	Vajrapukothuru	WD
101	Metturu	Closed
102	Pithali	Closed
103	Uppalam	WD
104	Borivenka	WD
105	Pukkalapalyam	Closed
106	Donkuru	WD

[WD=Wave dominated]

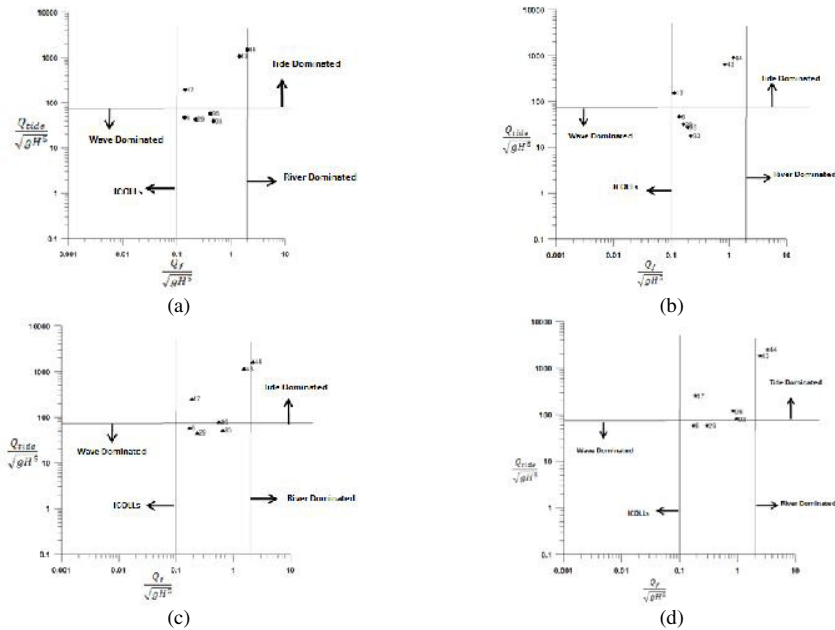


Figure 5. Classification based on dimensionless parameters for (a) annual wave heights (b) for South West Monsoon wave heights (c) North East Monsoon waves and (d) for Fair Weather waves

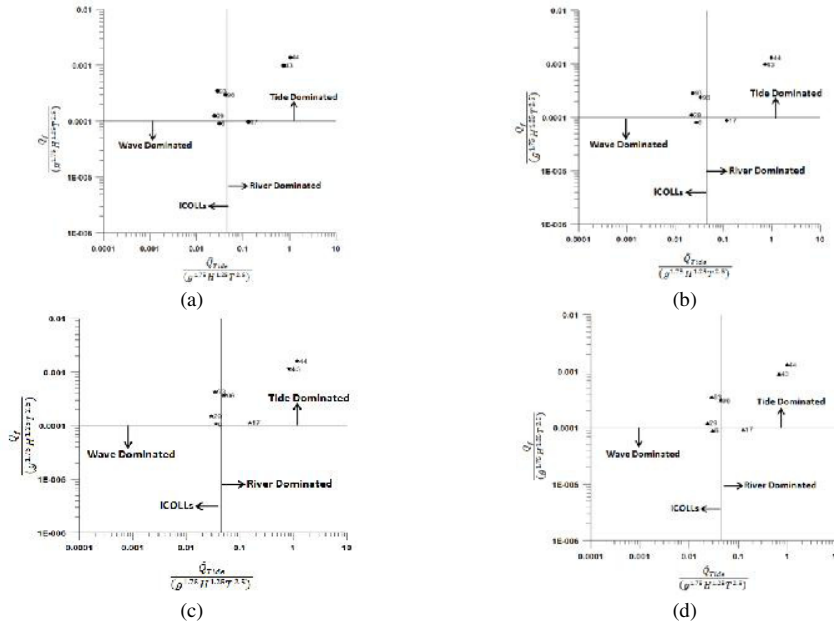


Figure 6. Classification based on dimensionless parameters including wave period for (a) annual and (b) South West Monsoon wave heights (c) North East Monsoon and (d) Fair Weather wave heights including wave period

5. Conclusions

A total of 108 tidal inlets are classified along the Andhra Pradesh coastline using different coastal classification systems such as morphological, hydrodynamic, dimensionless classification with/ without wave period. Inlets were considered in present study only if width of inlet is greater than 5m and labelled as nearest visible place on Google

Erath. The present study on dynamics of tidal inlets is to gain a better understanding of their hydrodynamic and morphodynamic responses under the main forces namely tide, wave and fresh water flow. These three parameters are the most responsible for shaping of any inlet. The non-dimensional classification which represents the relative strength of tide, waves and river flow along the wave period into consideration gives better agreement along the Andhra Pradesh coastline (Table 4).

Table 4. Tidal inlet classification methods by different methods

Inlet ID	Name of inlet	Classification methods			
		Geomorphological	Hayes	Vu	Modified-Vu
6	Swanamukhi River	WD (ICOLL)	ME (WD)	WD	WD (ICOLL)
17	Utukuru	RD	ME (WD)	TD	RD
29	Chintayigari palem	WD	WD	WD	WD
43	LVD	ME	ME (WD)	TD	TD
44	Elachetladibba	ME	ME (WD)	TD	TD
93	Bontala koduru	WD	ME (WD)	WD	WD
96	Kalingapatanam	ME	ME (WD)	WD	WD

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