A NEW FORMULATION FOR ASSESSING COASTAL EROSION AND MORPHOLOGY CHANGE IN THE SAND-MUD BEACH AREA

MARDIHA BINTI MOKHTAR

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In profound tribute to the most motivating figure on this remarkable Ph.D. expedition, my beloved late mother, Hjh. Mah Bte. Hussain (22/4/1947 – 22/7/2023). May Allah forgive her for all her sins and grant her the highest rank of Jannah insya-Allah… Al- Fatihah

and

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ABSTRACT

Coastal erosion prediction in mixed sediment environments, encompassing cohesive (mud) and non-cohesive (sand) components, poses a critical challenge in coastal engineering projects. This research aims to address the issue by achieving four main objectives. Profiles of shoreline and elevation changes were produced using UAV photogrammetry techniques. The data was processed by the Pix4D and Global Mapper application tools, offering valuable insights into coastal dynamics at Pantai Punggor, Batu Pahat, Johor, which is known for erosion. The results revealed that Zone C exhibits accretion of 0.726 m, while Zone D experiences the highest erosion rate (-12.073 m). Volume changes indicated an increase in Zone A, while Zone D showed the most significant erosion. The research achieved Objective 1 by producing shoreline and elevation change profiles. Sediment analyses in Objective 2 revealed poor sediment characteristics in Zone D that contributed to significant changes in its shoreline evolution. Objective 3 assessed the coastal erosion using Dean numbers (N). Zone D had the highest erosion (N = 8.879), and Zone A had the lowest accretion (N = 0.138). However, there was a limitation in the Dean equation as data from the mid tide (MT) and low tide (LT) levels, consisting of sand-mud sediment, exceeded the range for sandy beaches. Objective 4 was achieved by developing a new formulation for erosion and accretion assessment, namely the N_{Mf} equation, derived from physical tests. The N_{Mf} values ranged from 1.06 in Zone A (accretion) to 3.73 in Zone D (erosion). A confirmation test validated the N_{Mf} equation, aligning with the observed pattern. The uniqueness of the novel equation overcame the limitations, providing a reliable tool for evaluating sand-mud sediment erosion. In conclusion, even though coastal evolution can influence erosion and accretion areas, there is a lack of studies on this type of sand-mud coast, and the erosion mechanism is still not clearly understood. This research fills in the gaps by offering sedimentary analyses, including sand-mud sediment, which will aid in the development of better knowledge of how coastal morphology changes occur.

ABSTRAK

Ramalan hakisan pantai dalam persekitaran campuran sedimen, merangkumi komponen berjeleket (lumpur) dan tidak berjeleket (pasir), merupakan cabaran kritikal dalam projek kejuruteraan pantai. Penyelidikan ini bertujuan untuk menangani isu ini dengan mencapai empat objektif utama. Profil perubahan garis dan aras pantai dihasilkan menggunakan teknik fotogrametri UAV. Data diproses oleh aplikasi Pix4D dan Global Mapper, menawarkan maklumat mengenai dinamik pantai di Pantai Punggor, Batu Pahat, Johor yang terkenal dengan hakisan. Keputusan menunjukkan bahawa Zon C mengalami penambakan 0.726 m, manakala Zon D mengalami kadar hakisan tertinggi (-12.073 m). Objektif 1 tercapai dengan penghasilan profil perubahan garis pantai dan arasnya. Analisis sedimen di dalam Objetif 2 mendedahkan ciri-ciri sedimen yang lemah di Zon D menyumbang kepada perubahan ketara dalam evolusi garis pantai. Objektif 3 menilai hakisan pantai menggunakan formulasi Dean (N). Zon D mempunyai hakisan tertinggi (N = 8.879), dan Zon A mempunyai penambakan paling rendah (N = 0.138). Walau bagaimanapun, terdapat had dalam formulasi Dean apabila data dari aras air pasang pertengahan (MT) dan air surut rendah (LT), yang terdiri daripada sedimen pasir-lumpur, melebihi julat untuk pantai berpasir. Objektif 4 dicapai dengan membangunkan formulasi baru untuk penilaian hakisan dan penambakan, iaitu persamaan N_{Mf}, yang diperoleh dari ujian fizikal sedimen. Nilai N_{Mf} berkisar dari 1.06 di Zon A (penambakan) hingga 3.73 di Zon D (hakisan). Ujian validasi mengesahkan persamaan N_{Mf}, selari dengan pemerhatian. Keunikan formulasi baru ini mengatasi hadnya, menyediakan kaedah penilaian hakisan sedimen pasir-lumpur. Kesimpulannya, walaupun evolusi pantai boleh mempengaruhi kawasan hakisan dan penambakan, terdapat kekurangan kajian berkaitan jenis pantai pasir-lumpur ini, dan mekanisme hakisan masih belum difahami dengan jelas. Penyelidikan ini mengisi jurang kekosongan dengan menawarkan analisis sedimen, termasuk sedimen pasir-lumpur, yang akan membantu dalam pembangunan pengetahuan yang lebih baik tentang bagaimana perubahan morfologi pantai berlaku.

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LIST OF SYMBOLS/ABBREVIATIONS/TERMINOLOGIES

Cc	-	Coefficient of Curvature
C_f	-	friction coefficient (dimensionless),
C_p	-	clay percentage
Cu	-	Uniformity Coefficient
D	-	grain diameter
D_{50}	-	median diameter of sediment
E	-	Erosion
E_0	-	erodibility parameter
g	-	acceleration of gravity
G_s	-	Specific gravity
$H_{s,b}$	-	significant breaker height (m)
H_o	-	offshore significant wave height
K	-	dimensionless coefficient
m	-	slope of the sea bottom
n	-	power function of the sediment composition
N	-	Dean Number
N_{Mf}	-	N number for Mardiha Formulation
p	-	sediment porosity
Q	-	longshore sediment transport
S_u	-	Undrained shear strength
R^2	-	Coefficient of determination
T	-	wave period
T_p	-	peak wave period (s)
V_s	-	Settling velocity
W	-	surf zone width (m),
w	-	sediment fall velocity
α	-	constant value

α_b	-	wave incidence angle at the breaker (degrees)
β	-	coefficient value
γ_b	-	breaker parameter
μ	-	dynamic viscosity of water
ρ_a	-	sea water density
ρ_s	-	sediment density
ρ_w	-	density of water
τ	-	shear stress
τ_b	-	average bed shear stress
τ_c	-	critical shear stress
τ_d	-	bottom shear stress
τ_y	-	vane shear strength
ANOVA	-	Analysis of Variance
ASETS	-	Automated Sediment Erosion Testing System
DEM		Digital Elevation Model
DHI	-	Danish Hydraulic Institute
DID	-	Department of Irrigation and Drainage
DOE	-	Department of Environment
DOF	-	Department of Fisheries
DOM	-	digital orthomosaic
DSAS	-	Digital Shoreline Analysis System
DSM	-	Digital Surface Model
DTM	-	Digital Terrain Models
ECMWF	-	European Centre for Medium-Range Weather Forecasts
EPR	-	End Point Rate (EPR), (LRR)
FM	-	Flow Model
GCP	-	Ground Control Points
GEBCO	-	General Bathymetric Chart of Oceans
GIS	-	Geographic Information System
GNSS	-	Global Navigation Satellite System
GPS	-	Global Positioning System
GSD	-	Ground Sample Distance

HT	-	High Tide
HYCOM	-	Hybrid Coordinate Ocean Model
IMU	-	Inertial Measurement Unit
ISMP	-	Integrated Shoreline Management Plan
LiDAR	-	Light Detection and Ranging
LOI	-	Loss On Ignition
LRR	-	Least Regression Rate
LSTR	-	Longshore sediment transport rate
LT	-	Low Tide
LULC	-	Land-use/Land cover
MATLAB	-	matrix laboratory
MC	-	Moisture Content
MLR	-	Multiple Linear Regression
MT	-	Mid Tide
NCES	-	National Coastal Erosion Study
NDVI	-	Normalized Difference Vegetation Index
NDWI	-	Normalized Difference Water Index
NEM	-	Northeast Monsoon
NRE	-	Natural Resources and Environment
NSM	-	Net Shoreline Movement
PI	-	Plasticity Index
PPK	-	Post Processed Kinematic
PVC	-	polyvinyl chloride
RMK	-	Malaysia Plan
RMSE	-	Root Mean Square Error
RTK	-	Real-Time Kinematic
SfM	-	Structure from Motion
SLR	-	Single Linear Regression Model (SLR)
SPSS	-	Statistical Package for the Social Sciences
SSC	-	Suspended Sediment Concentration
SW	-	Spectral Wave
SWH	-	Significant wave height
SWM	-	Southwest Monsoon

TCPD	-	Town and Country Planning Department
UAS	-	Unmanned Aerial Systems
UAV	-	Unmanned Aerial Vehicle
UMT	-	Universiti Malaysia Terengganu
USCS	-	Unified Soil Classification System
USGS	-	U.S. Geological Survey
VST	-	Vane Shear Test
WAVERYS	-	Global Ocean Waves Reanalysis
WLR	-	Weighted Least Square Regression

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CHAPTER 1

INTRODUCTION

1.1 Research background

Coastal or beach morphology addresses the evolution of coastal features, such as sediment (sand and silt-clay) and their interaction with hydrodynamics, which is an important subject in coastal studies. The soil sample is the earliest part of soil testing and the foundation for information derived from laboratory analyses, soil test interpretations, and recommendations. Beach topography, its geometric properties, and estimates of eroded and deposited sand volumes will be the early significant output of the study that will lead to the identification of erosion areas and sediment characteristics.

Coastal erosion is defined as sediment loss with the wearing away and transportation of sediments. It is related to the inland displacement of the sea/land contact point (i.e., the mean sea level) where the shoreline is being pushed inland due to the effects of wind, current, and wave (Prasad & Kumar, 2014; Mörner & Finkl, 2019). Shoreline change analysis and coastal erosion prediction are significant for integrated coastal zone management and development plans in the coastal area, as well as for coping with the phenomena of sea level rise and climate change.

Mentaschi *et al.* (2018) conducted an evaluation of coastal morphodynamics over 32 years (1984–2015) based on satellite observations and found that eroded land is twice the gained land. Their results exposed that anthropogenic factors are projecting drivers of global coastal morphological change trends. Coastal morphology modifies flood hazard; future flood risk depends on changing shoreline position, and a very substantial role is played by beach morphology through its impact on the delivery of wave energy to the base of the cliff (Earlie *et al*., 2018; Pollard *et al*., 2018).

Previous studies (Liu *et al*., 2013; Tamassoki *et al*., 2014; Aryastana *et al.,* 2018) primarily relied on historical data from satellite or airborne sensors to map coastal morphology in terms of land cover and three-dimensional structure. Both satellite and airborne sensors face their own unique challenges when it comes to mapping coastal morphology. However, in the context of the previous studies discussed, the use of satellite data appears to be the most challenging method for mapping coastal morphology. The availability of satellite data is subject to specific acquisition schedules and limited spatial coverage, which may not align perfectly with the needs of studying coastal morphology. Additionally, satellite data may not always provide up-to-date information, especially in rapidly changing coastal environments where timely data is crucial. The high costs associated with satellite data can limit the extent and frequency of data collection, potentially leading to outdated or incomplete information. Resolution limitations pose another challenge for satellite data. While satellite imagery can provide valuable insights into coastal morphology, the resolution of satellite sensors may not be sufficient to capture fine-scale details. Airborne sensors, on the other hand, offer advantages such as higher resolution and more flexible acquisition schedules. However, airborne data collection has its own challenges, including cost considerations and logistical constraints associated with deploying and operating airborne platforms. Therefore, while both satellite and airborne sensors face challenges, the use of satellite data appears to be the most challenging method for mapping coastal morphology in the previous studies mentioned.

Malaysia is a maritime nation, which is made up of 13 states of Peninsular Malaysia (referred to as West Malaysia), Sabah and Sarawak (referred to as East Malaysia), and the Federal Territories of land-locked Kuala Lumpur and the island of Labuan. The coasts of Malaysia experience enormous and numerous environmental and ecological problems due to massive development. Shoreline erosion has changed the coastal morphology, with extensive development of microcliffs and shelly beaches. The main factors influencing beach morphodynamics and coastal erosion in Malaysia are wave climate, topography, and sediments (Sa & Boon, 2010; Yanalagaran & Ramli, 2018; Ehsan *et al*.,2019). The main government departments with a sectoral interest in coastal issues are the Department of Irrigation and Drainage (DID), the

Department of Environment (DOE), the Town and Country Planning Department (TCPD), and the Department of Fisheries (DOF) (Asmawi *et al*., 2015).

The National Coastal Erosion Study (NCES) was completed in 1986, and the study findings revealed that out of the country's total coastline of 4,809 km, about 29% or 1,380 km faced erosion problems. In order to tackle this problem, the Government established the Coastal Engineering Technical Centre within the DID in 1987 to implement the Coastal Erosion Control Program for the whole country. Realizing the increasing trends of coastal erosion and conflicts, the Government of Malaysia through the DID planned the Integrated Shoreline Management Plan (ISMP). The objectives of ISMP are as follows: 1) Appraisal and selection of coastal development management strategies, 2) Appraisal and selection of defense options for the coastline, and 3) Formulation of specific guidelines and policies for development activities/ proposals in the coastal area. The status of ISMP implementation for West Johor was completed in 2012. Coastal protection structures had been implemented in West Johor Coast, such as rock revetment, soft rock structure, gabions wall, Labuan Blocks, geotubes, *bakau/nibong* stakes, seawalls, and spun piles (DID, 2005; Ainee *et al*., 2014; Mokhtar *et al*., 2020; DID, 2019).

In the current literature, several initiatives have been done by the government for mitigation and preparedness for coastal erosion. However, the government through DID needs to establish a continuously effective coastal erosion management and monitoring system, which can then be used to guide the stakeholders concerned to balance environmental and economic needs. As stated in the ISMP report (DID, 2005), the main issue encountered in the use of coastal protection structures is that they require regular maintenance at least twice a year after the passing of each monsoon.

Cohesive sediment exhibits distinctly different physicochemical characteristics from non-cohesive sediment. Pure cohesive and non-cohesive sediments have been widely investigated in the literature, while mixed cohesive and non-cohesive sediments are less commonly understood. Therefore, the erodibilities of cohesive and non-cohesive sediments have been researched separately over the past few decades (Ledden *et al*., 2004; Le Hir *et al*. 2008; Le Hir *et al*., 2011; Perera *et al*. 2020). This segregated research has significant implications for accurately determining erosion. Hence, it is essential to subject the sediment to geotechnical testing to ascertain its properties before conducting further erosion analysis.

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APPENDIX G

VITA

Born in Kedah, Malaysia, the author's educational journey began at Sekolah Menengah Kebangsaan Jitra, Kedah, Malaysia, where she completed her secondary education. Her passion for engineering led her to pursue her education and obtained a B.Eng. (Hons) in Civil Engineering from Universiti Tun Hussein Onn Malaysia (UTHM), Johor in 2007. Her quest for knowledge continued, and in 2008, she embarked on a new academic pursuit at the same university, where she earned her M. Eng. in Civil Engineering (Geotechnic) in 2011. Armed with expertise in her field, she began her professional journey as an engineer at the Public Works Department (JKR) Kuala Lumpur in 2013. However, her passion for sharing knowledge led her to embrace a new role as a lecturer at the Civil Engineering Department, Centre of Diploma Studies, Universiti Tun Hussein Onn Malaysia, Johor, in 2014. Despite her busy schedule, the author was determined to excel academically. In 2020, she embarked on a Ph.D. program in Coastal Engineering under Faculty of Civil Engineering and Built at UTHM, fueling her dedication to research and innovation. Throughout her Ph.D. journey, she actively participated in five international conferences, namely the International Conference on Applied Science and Technology (ICAST2020), International Conference on Applied Science and Technology (ICAST2021), International Symposium on Science, Technology, and Engineering (ISSTE 2022), World Sustainable Construction Conference (WSCC2022), and 3rd International Conference on Computing, Information Science, and Engineering (ICISE2023). Her commitment to advancing knowledge is evident through her impressive publications. As the main author, she published five Scopus Journal papers and co-authored four papers during her Ph.D. program. Recognized for her expertise, she currently holds a membership in the Malaysia Board of Technologists (MBOT) as a Professional Technologist and serves as a Senior Lecturer at UTHM. Through her exceptional academic and professional journey, the Author continues to make significant contributions to the field of engineering and education, inspiring future generations and leaving a lasting impact in her field.