Landscape and Urban Planning 174 (2018) 24–32

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Research Paper

Sustainable coastal zone planning based on historical coastline changes: A model from case study in Tainan, Taiwan

Yi Chang*, Ka-wai Chu, Laurence Zsu-Hsin Chuang

Institute of Ocean Technology and Marine Affairs, National Cheng Kung University (NCKU), Taiwan

ARTICLE INFO

Keywords:
Coastal management
Erosion
Lagoon
Satellite imagery
Taiwan

ABSTRACT

Coastal regions are threatened by natural processes, such as erosion driven by storm surge and the effect of jetties, as well as by human behavior. This study outlines a management framework based on an analysis of a case study dataset of long-term coastal change in southwestern Taiwan. Specifically, the coastal structure of Taiwan's largest lagoon, Cigu, was analyzed over a 300-year-long period. A series of satellite-derived images between 1974 and 2015 were assessed. The dataset was integrated with a geographic information system (GIS). The results revealed that human activities, including the construction of hard structures along the coastline and along an upstream reservoir, altered the balance of sediment transmission and resulted in the retreat and erosion of barrier sandbars along the coast. A lagoon evolution model revealed that the Cigu Lagoon may disappear in the future. Furthermore, the coastline will continue to retreat because harbor dykes and offshore breakwaters stop sediment transportation to the downdrift. Soft erosion mitigation is suggested as an immediate approach. However, recovering the sediment budget from reservoirs and dykes could be a long-term solution. In principle, the best coastal environmental protection plan from the national involves delaying urbanization and preserving unexploited coastal wetlands.

1. Introduction

Over the past 100 years, coastal erosion has emerged as a worldwide problem in both natural ecosystems and human communities (Anthony et al., 2009; Valiela, 1995). For instance, many sandy beaches around the world are in recession and approximately 86% of the barrier islands and beaches of the Eastern United States have suffered erosion during the 20th century (Zhang, Douglas, & Leatherman, 2004). Coastal erosion has also been documented along the Chinese coastline (Cai, Su, Liu, Li, & Lei, 2009), around many islands in Indonesia (Farhan & Lim, 2011), and along the western coast of Taiwan (Hsu, Lin, & Tseng, 2007; Yang, Wu, Hwung, Liou, & Shugana, 2010). Changes in the coastline length and elevation can lead to seawater intrusion and flooding. Without a protective coastal buffer, seawater can migrate into estuaries and rivers, reducing their drainage capacity (Allan & Komar, 2006; Komar, 2010). Therefore, urban planning for disaster prevention is a crucial concern for the socio-economic development of littoral/coastal cities. Since the early 1990s, the notion of sustainable coastal development has garnered growing acceptance around the world (Farhan & Lim, 2011).

Coastal zone management mechanisms aim to ensure the sustainability of resources and the environment. Preserving a fixed coastline requires engineering approaches. Strategies include the use of hard structures (e.g., seawalls), soft techniques (e.g., sand nourishment/replenishment), and legislative coastal management acts (French, 2001). Although structures such as dykes can reduce wave energy at the shoreline (Leonard, Dixon, & Pilkey, 1990), they lack the capacity to slow coastal erosion over the longer-term (Yang et al., 2010). Komar (2010) surmised that coastal erosion in eastern New Zealand is primarily due to artificial barriers. They cause sediment to be displaced in greater quantities than they are replenished by local rivers. Sustainable coastal plans and polices typically prohibit development in coastal areas where (coastline) retreat rates are high. A plan against coastal erosion has been implemented in China (Cai et al., 2009) to provide a conceptual framework; it included scientific understanding of coastal erosion, prevention measures, a management system, and protection of the coast based on legislation.

In the worldwide case studies mentioned above, coastal protection plans and conceptual designs were mainly discussed, but an algorithmic framework has not provided. Therefore, we sorted out three principles from Cai et al. (2009) and to develop, diagnose and propose a framework for coastal zone planning. The original concepts of coastal erosion protection in Cai et al. (2009) included basic research of coastal erosion, proper prevention measures, and promoting legislation to protect

* Corresponding author.
E-mail address: yichang@mail.ncku.edu.tw (Y. Chang).

https://doi.org/10.1016/j.landurbplan.2018.02.012
Received 5 May 2017; Received in revised form 24 February 2018; Accepted 28 February 2018

coastal resources. Understand coastline evolution trends as the first step before a coastal plan has been suggested for determining appropriate prevention measures within the coastal zone plan from a local or national level. The objectives of this study were as follows: (1) to understand the process of coastal change using scientific mapping with historical photographs and satellite images; (2) to propose appropriate strategies from earlier measures; and (3) present a framework of sustainable coastal planning.

2. Materials and methods

2.1. Maps and satellite data acquisition

We compiled 18th and 19th century cartographic maps of Tainan City from library references to supplement aerial and satellite images of the coastal area. This database allowed for visualization and quantification of changes in the areas and shapes of sandbars and other natural barriers in the Cigu Lagoon. Aerial photos taken by the United States Army in 1947 and by the Taiwanese air force in 1974 were also included with spatial resolutions of 0.95 m and 0.3 m, respectively (Chiang & Tseng, 2016). A cartographic map with scale of 1/100,000, published by the Taiwanese government in 1987, was obtained. These cartographic maps and aerial photos were archived and coordinated by the Center for GIS, at the Research Center for Humanities and Social Sciences (RCHSS), within the Academia Sinica of Taiwan. Academia Sinica also provided the georeferenced features through a public website (http://gissrv4.sinica.edu.tw/gis/twhgis/). The center for GIS digitized graphic maps and aerial photos provide latitude and longitude based on geographic features or landscapes that exist even today. For example, temples and crossroads existed before the 19th century and still stand today could be used as control points for coordination of the geo-referencing function in the GIS software ArcGIS 10 (http://www.esri.com/arcgis/about-arcgis). Two types of satellite-derived images with Transverse Mercator projection were purchased from the Center for Space and Remote Sensing Research at the National Central University of Taiwan. One set was from the satellite SPOT-3 launched by France in 1993, and the other set was from the Taiwanese satellite Formosa-2 (FS2) launched in 2004. Images from SPOT-3 were taken between 1996 and 2004 and had a spatial resolution of 20 m, whereas the images from FS2 had a spatial resolution of 2 m and were taken between 2005 and 2015. All of the maps and images were projected into a TWD97 coordinate system and integrated into a GIS dataset with a particular emphasis on the positions of the coastline, sandbars, and barrier islands.

2.2. Coastline change analysis

Long-term coastal evolution was examined through the digital processing of satellite images and spatial change calculations. The coastline was extracted from each image along the high-water mark at the wet/dry sand boundary on the beaches or on the edge of rock cliffs (Hapke, Himmelstoss, Kratzmann, List, & Thieler, 2011). Furthermore, coastline changes were investigated using Digital Shoreline Analysis System (DSAS Version 4.3, Thieler, Himmelstoss, Zichichi, & Ergul, 2009). DSAS enables the classification of coastal erosion in coastal zones. This approach calculates the erosion rate and considers bias and uncertainty values for each feature type through a statistical analysis. A linear regression rate (LRR) with a 90% confidence interval was considered to be an index of the coastline change in a given period. Features, photos, and maps starting from 1987 were used to calculate the LRR to examine trends over a 40-year-long period from 1974 to 2015. The uncertainty of the spatial references in multi-satellite images (Smith & Zalliro, 1990) was considered in the LRR estimations.

2.3. History of coastal protection

In the 1990s, the government of Taiwan began to realize the significance of coastline retreat when critical erosion occurred (Lin, 2014; NCKU/HOE R&D Foundation, 2015). The evolution of sandbars negatively impacted the lagoon hydrology and ecosystems (Lin, Cheng, & Huang, 2013) that it supported (the socioeconomic foundation of the surrounding villages). Since then, the government has continuously supported systematic research and construction projects for the Cigu Lagoon. Completed coastal protection plans were archived from technical reports released by both central and local governments (Ho, Liu, Wang, & Tseng, 2013; Lin, 1996, 2014; NCKU/HOE R&D Foundation, 2006, 2015). These reports provide scientific data to inform the protection framework for coastal planning.

2.4. The study area

In Taiwan, urban growth in the coastal zone has been hindered by coastal disasters. Storm surges, caused by tropical cyclones during the summer, have plagued residents for many years. Tainan City is one of the frequently flooded regions impacted due to a large area of human-induced coastline change. Since the 1970s, more than 2800 ha of nature tidal flats in the lagoon have been constructed as fishponds. These have been determined to reduce the ability for flood retention (Lin et al., 2013). We chose Tainan City for our case study not only for the unique landscape of the Cigu Lagoon but also due to the frequent flood disasters in the nearby villages. The study area has 2 fishing harbors constructed to the north lagoon, and the Tsengwen Reservoir was completed in the upstream in 1973 (Fig. 1). These construction projects changed the balance of sediment transport along the coast; the sand barriers eroded and gradually migrated landward. Reduced sediment deposition in Taiwan is due to poorly planned coastal construction, such as breakwaters and upstream reservoirs (Chiau, 1998). Torrential freshwater discharge, storm surges, and human interference have all compromised the coastal sediment budgets. Human interference includes aquaculture, urbanization, and other anthropogenic impacts (Kuo, Lin, & Shao, 2001; Turner et al., 2007). These are major causes for concern (Chiau, 2006) not only for the natural environment but also for human communities. We need an environmentally sustainable planning framework for socio-economic development. A planning framework helps to resolve the conflict between coastal exploitation and shoreline protection.

3. Results

3.1. Coastal evolution of Tainan City since the 18th century

Historical imagery data of Tainan City for over 300 years were compiled and analyzed in our project (Fig. 2). The first hand-drawn

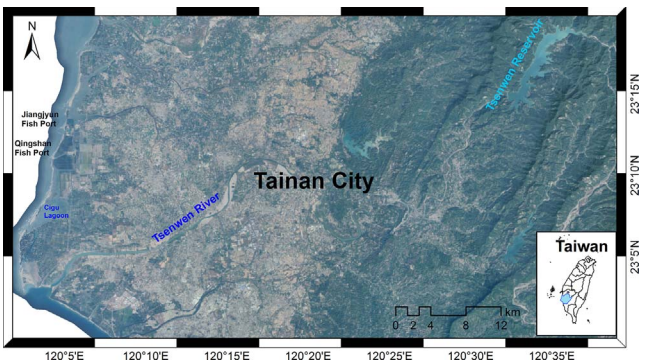

Fig. 1. Map of study area based on composite images from the Formosa-2 satellite derived in 2015.