A review and meta-analysis of remote sensing data, GIS methods, materials and indices used for monitoring the coastline evolution over the last twenty years

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ABSTRACT

The current review study focuses on a statistical analysis (Meta-analysis) of the most common methods, materials, software, and indices used by researchers over the last twenty years to evaluate and quantify the shoreline evolution. Furthermore, this review targets to highlight some critical points through studied literature such as a) the low rate of high-resolution satellite images usage in a subject where the accuracy is prerequisite, b) the effort to derive information from Landsat images in order to take advantage of the 50-years archive and the freely availability c) the impulse of the UAV during the last 5 years as an alternative low cost but high accurate source of data d) the fact that only 50% of the coastal erosion studies are funded. One hundred thirty-eight papers and articles have been analyzed in detail by the authors and all the key points (methods, materials, software, and indices) were sorted for further statistical analysis. This study is not intended to criticize neither the methods nor the results being mentioned in the previous studies but to give the opportunity to the researchers (especially the new ones) to have an overall view of the subject for the last 20 years with just a glimpse.

Introduction

About the shoreline

There are plenty of shoreline definitions along the time among researchers (Alesheikh et al., 2004; E Bird, 2008; Coastal Engineering Research Center (CERC), 1984; Niedermeier et al., 2005; Pajak & Leatherman, 2002). A conventional definition for the term “shoreline” is the physical border between land and sea (Dolan et al., 1980). The term “shoreline” is considered synonymous with the term “coastline” and there is no difference in this review study. During the last decades, the remote sensing science in combination with several Geographic Information System (GIS) applications has taken a various place in geo-surveys such as the coastline evolution analysis. Many studies tried to analyze and find the best approach to this subject based on several algorithms and computations (table 1–4). Automatic classification algorithms were also used and applied on aerial photos (A.C. Teodoro et al., 2009) or on IKONOS-2 satellite data (A. Teodoro et al., 2011) to identify coastal features and coastal patterns. The coastline is a dynamic environment where human structures and activities took place near or along it. So, it is important to have a reliable tool to enumerate, estimate and even, if so, to predict the shoreline movement landward or seaward. For this reason, many numeric methods, factors and algorithms have been established and applied the last two decades on a variety of data types such as aerial photos, satellite images, or Optical and RADAR data, Topographic maps and recently Unmanned Aerial Vehicle (UAV) images. The structure of the coastal environment and the pressures it is under are the first things that someone should understand in order to study its development. As coastline is a dynamic environment and it’s profile can very easily change from coast to coast continually, there is not one and only indicator which can match to all types of coasts. Indicators that measure the evolution and change of the coastline should be accurate and describe the timeless evolution of the area as well as the natural processes that have taken place. In figure 1 the allocation of diverse studies areas all over the world is presented. At these areas, shoreline evolution mapping was performed using remote sensing data/technologies as described in 138 studies published in the last 20 years (table 1–4).

Material and datasets

Materials

This research is based on a methodological recoding of several critical points that have been used by several authors (Table 1–4) in the last 20 years (2000–2019) for shoreline monitoring such as a) periods of interest, b) type of data that have been acquired c) shoreline spatial extraction methods, indicators, techniques and models, d) software and e) erosion/accretion estimation methods and algorithms.
Several types of data have been used by researchers such as Topo-sheets, aerial photos, satellite images, RADAR data and UAV’s images were identified, recorded and categorized by the Authors.

The beginning of the coastline evolution mapping is inextricably linked with the use of topographic maps (Gil et al., 2019; Hoque et al., 2019; Hashmi & Sajid, 2018; Carolina et al., 2018; Kaliraj et al., 2017; Ayadi et al., 2016; Ganasri & Ramesh, 2016; Prasita, 2015; Shenbagaraj et al., 2014; Kumaravel et al., 2013; John & Scott, 2010; Xuejie & Damen, 2010; Aliakbar et al., 2010; Appeaning 2009; Aris et al., 2008; Peter & Kaminsky George, 2003; Charles et al., 2003). Moreover, toposheets were the most reliable data utilized as base maps for satellite images georeferencing (Yulianto et al., 2019; Fatima et al., 2018; Joevivek & Saravanan Sakthivel, 2018; Vandebroek et al., 2017; Bharathvaj 2015; Louati et al., 2015; Joevivek & Saravanan Sakthivel, 2013; Sharma & Acharya, 2010; Nageswara Rao et al., 2008; Adel & Ryutaro, 2007).

Analogue topographic maps were the primary source of information in studies developed before the decade of 70’s as in most cases there wasn’t any other available data. This type of source is not necessary nowadays as well as digital information is available to researchers. Nevertheless, there are recent studies where such type of data is used for shoreline mapping. For instance, Kaliraj et al. (2017) used topographical maps, Landsat ETM+ and IKONOS data for mapping a coast in Kanyakumari district of India. Moreover, there are many other studies that combined topographic maps with remote sensing data. Ganasri and Ramesh (2016) used Toposheets and IRS LISS-3 satellite images and tried to assess the soil erosion by the RUSLE model in India. Dawson and Smithers (John & Scott, 2010) used historic survey maps and topographic survey datasets to reconstruct a shoreline history for Raine Island in Great Barrier Reef, Australia. Xuejie and Damen (2010) used topographical, nautical
and Landsat data to study a river’s estuary shoreline change in China. Another fundamental element in diachronic studies for investigating the movement of the coastline is aerial photographs and orthophotographs (Valderrama-Landeros & Flores-de-santiago, 2019; Pantanahiran, 2019; Fatima et al., 2018; Carolina et al., 2018; Burningham & French, 2017; Anand et al., 2016; Ayadi et al., 2016; Saci et al., 2016; Paravolidakis et al., 2016; Vassilakis et al., 2016; Ford Murray & Kench Paul, 2015; Andredaki et al., 2014; Vassilakis & Papadopoulou-Vrynioti, 2014; Thomas & Hildegard, 2014; Del Río et al., 2013; Antonello et al., 2013; Luca et al., 2013; Murray, 2013; Kim et al., 2013; Da Guia Albuquerque et al., 2013; Annibale Guariglia et al., 2009; Addo, 2009; Faik et al., 2008; Thampanya et al., 2006; Fromard et al., 2004; Schwarzer et al., 2003; Charles et al., 2003).

Some indicative studies which have used aerial photographs and orthophotographs data for shoreline mapping are referred below. Anand et al. (2016) used aerial photographs to investigate the range of the shoreline and erosion changes along a coast of Mauritius. Del Río et al. (2013) in the South-Atlantic coast of Spain used aerial photographs and orthophotographs in order to investigate the shoreline evolution in conjunction with the diverse morphological and dynamic factors controlling the beach development. Schwarzer et al.

### Table 1. Researchers’ whose interest about time interval (n) of shoreline monitoring was n ≤ 10 years.

| Researchers | Place | Period of study | Years interval | Number of Citations |
|-------------|-------|-----------------|----------------|---------------------|
| Chao Chen et al. (Chen Chao Chen et al., 2019) | Yangtze River | 2017 | 1 | 6 |
| Gutina et al. (Gutina Feyisa et al., 2014) | Copenhagen, Denmark, Switzerland, Addis Ababa, Ethiopia, South Africa, New Zealand | 2009–2010 | 1 | No data |
| Ganasi and Ramesh (2016) | Nethravathi/India | 2009 | 1 | 17 |
| Aiello et al. (Antonello et al., 2015) | Italy, CATENA | 2001 | 1 | 77 |
| Papakonstantinou et al. (2015) | Lesvos Island, Eressos beach Greece | 2015 | 1 | 3 |
| Chikhradze et al. (Nino et al., 2015) | Portugal | 2015 | 1 | No data |
| Sekovski et al. (Ivan et al., 2014) | Ravenna Province Italy | 2011 | 1 | 82 |
| Nikolopoulos et al. (Nikolopoulos Konstantinos & George, 2017) | Rio, Patras, Greece | 2018 | 1 | 79 |
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used aerial photographs to investigate the coastal evolution on a ten-year scale in the Pomeranian Bight in the Southernmost part of the Baltic Sea. Furthermore, many studies that have been carried out the last 20 years have combined aerial photographs and orthophotos with remote sensing data. Nikolakopoulos et al. (2019) reported the usage of remote sensing data as an origin of information for the coastline evolution in Lefkada island, Greece. The present study refers to the last twenty years of shoreline movement investigation, it is necessary to document the satellite evolution for this period. Until the twentieth-century, remote sensing was only based on aerial photography using analog mechanical or optical equipment (Cracknell Arthur, 2018). The biggest achievement in remote sensing research development was undoubtedly the usage of satellites. The Landsat program starts in 1972 and over the years there was a succession of Landsat’s missions, equipped with new sensors with better imagery resolution until the most recent, Landsat 8, that was launched in 2013. As the time passed and technology evolved, parallel to the Landsat satellites series many other satellites came to the foreground which could be discerned in three main categories: high, medium and low imagery resolution.

Due to the bibliometric studies, we found many studies that have used high resolution (0.5–5 m) satellites images. For instance, IKONOS-2 imagery has been used by Pantanahiran et al. (2019), Kaliraj et al. (2017), Vassilakis et al. (2016), and Maglione et al. (2015); Ford (Murray, 2013); In-Ho et al. (Kim et al., 2013); Teodoro (Teodoro & Gonçalves, 2012); Marfai et al. (Aris et al., 2008); Di et al. (2003). Worldview-2 has been used by Pantanahiran et al. (2019); Vassilidakis et al. (Vasilis et al., 2018); Vassilakis et al. (2016); Maglione et al. (2015); Ford and Kench (Ford Murray & Kench Paul, 2015); Sekovski et al. (Ivan et al., 2014); Mann & Westphal (Thomas & Hildegard, 2014). QuickBird has been used by Almonacid-Caballer et al. (Jaime et al., 2016); Andredaki et al. (2014); Mann and Westphal (Thomas & Hildegard, 2014); Da Guia Albuquerque et al. (2013); Ford (Murray, 2013) and Faik et al. (2008). RapidEye has been used by Duarte et al. (2018). Corona has been used by Annibale et al. (Annibale Guariglia et al., 2009) and Bulent et al. (2004) and Pleiades has been used by Pantanahiran et al. (2019). Some indicative relative studies which have used high-resolution data are presented in the next paragraph.

Pantanahiran et al. (2019) used a combination of high-resolution satellite (IKONOS, Quick Bird, Worldview-
Table 3. Researchers’ whose interest about time interval (n) of shoreline monitoring was 30 < n ≤ 70 years.

| Researchers | Place | Period of study | Years interval | Number of Citations |
|-------------|-------|-----------------|----------------|---------------------|
| Thampanya et al. (2006) | Southern Thailand | 1966–1997 | 31 | No data |
| Cenci et al. (2017) | Portugal (Ovar) Italy (Magra and Serchio) | 1980–2011 | 31 | 17 |
| Selsi et al. (2008) | Trabzon, Turkey | 1973–2005 | 32 | No data |
| Joeivek et al. (2018) | Tamil Nadu, India | 1973–2006 | 33 | 2 |
| Joeivek et al. (2013) | Manavai and Vijayapathi, Southern Tip of India | 1973–2006 | 33 | 1 |
| Al-Asmar and Herehe (2011) | Nile Delta | 1973–2006 | 34 | No data |
| Ratna et al. (2018) | Central Java Province, Indonesia | 1988–2017 | 35 | No data |
| Ratna & Wietseks (2019) | Sayung, Indonesia | 1988–2017 | 35 | 2 |
| Liu et al. (2013) | Qinghuigou River, China | 1973–2009 | 36 | 4 |
| Natesan et al. (2015) | Tamil Nadu, India | 1978–2014 | 36 | 0 |
| Pardo-Pascual et al. (2012) | port of Burriana, Spain | 1984–2010 | 36 | No data |
| Fatima et al. (2018) | Morocco | 1981–2017 | 36 | 134 |
| Pritam & Prasenjit (2010) | Bhitarakanya, India | 1973–2009 | 36 | No data |
| Xuejie et Damen (2010) | China | 1966–2003 | 37 | No data |
| Kuleli et al. (2011) | Ramsar Turkey | 1972–2005 | 37 | 21 |
| Bulent et al. (2004) | Istanbul | 1963–2000 | 37 | 14 |
| Hashmi et al. (2018) | Sindh Pakistan | 1973–2011 | 38 | 2 |
| Jana and Bhattacharya (2013) | India | 1972–2010 | 38 | 14 |
| Wenyu and Gong (2016) | Florida | 1984–2013 | 39 | No data |
| Cui & Li (2011) | Yellow River delta, China | 1976–2015 | 39 | 143 |
| Davson & Scott (2010) | Great Barrier Reef, Australia | 1967–2007 | 40 | 15 |
| Salghuna & Bharathvaj (2015) | Coramandal Coast, India | 1972–2013 | 41 | 27 |
| Fajar et al. (2019) | Pekalongan, Indonesia | 1978–2017 | 41 | 24 |
| Kumaravel et al. (2013) | Tamilnadu, South India | 1971–2012 | 41 | 53 |
| Louati et al. (2015) | Medjerda delta Tunisia | 1972–2013 | 41 | No data |
| Al-Amin Hoque et al. (2019) | Bangladesh | 1974–2016 | 42 | No data |
| Zed et al. (2018) | El-Arish Egypt | 1972–2016 | 44 | 104 |
| Landeros de & de-Santiago (2019) | Marismas Nacionales, Mexico | 1970–2015 | 45 | 74 |
| Schwarzer et al. (2003) | Baltic Sea | 1951–1996 | 45 | 3 |
| Anand et al. (2016) | Trou aux Biches—Mont Choisy, Mauritius | 1967–2012 | 45 | 21 |
| Fromard et al. (2004) | French Guiana | 1951–1999 | 48 | 34 |
| Del Rio et al. (2013) | Cadiz, Spain | 1956–2008 | 52 | 14 |
| Annibale et al. (2009) | Basilicata Region (Southern Italy) | 1949–2001 | 52 | 41 |
| Martinez et al. (2018) | Chile | 1964–2017 | 53 | 18 |
| Fletcher et al. (2003) | Khei, West Maui Hawaii | 1949–2002 | 53 | 65 |
| Ayadi et al. (2016) | Bejaia bay (East Algeria) | 1960–2013 | 53 | 74 |
| Kermani et al. (2016) | East Algeria | 1960–2014 | 54 | 6 |
| Andreddak et al. (2014) | Nests River, Greece | 1945–2002 | 57 | 10 |
| Gonçalves et al. (2019) | Fusaro-louor Portugal | 1988–2017 | 57 | 51 |
| Vissellakis Papadopoulosou-Vryniosi (2014). | Evia Island | 1945–2003 | 58 | 15 |
| Shenbagaraj et al. (2014) | Kolachel to Kaylorpattanam Coast, India | 1953–2013 | 60 | 6 |
| Horacio et al. (2019) | Galicia, Spain | 1956–2018 | 62 | 25 |
| Mark A. Davidson et al., (2017) | Perranporth, Cornwall, UK/Narrabeen, NSW, Australia | no data | 63 | 47 |
| Ford (2013) | Marshall Islands | 1945–2012 | 67 | 45 |
| Ford & Kench (2015) | Marshall Islands | 1943–2010 | 67 | 42 |
| Mann & Hildegard (2014) | Papua New Guinea | 1943–2012 | 69 | 5 |
| Bakhour et al. (2017) | Goree Island (Senegal) | 1942–2011 | 69 | 74 |

Table 4. Researchers’ whose interest about time interval (n) of shoreline monitoring was n ≥ 70 years.

| Researchers | Place | Period of study | Years interval | Number of Citations |
|-------------|-------|-----------------|----------------|---------------------|
| Rakesh & Ramkrishna (2019) | Indian Sundarbans | 1945–2017 | 75 | 146 |
| Marafi et al. (2008) | Semarang Indonesia | 1908–2003 | 95 | 42 |
| Kwasi (2009) | Ghana’s Accra | 1904–2002 | 98 | 24 |
| Smith and Cromley (2012) | Connecticut, USA | 1838–1938 | 100 | 15 |
| Cunningham and French (2017) | Suffolk England | 1881–2015 | 135 | 110 |
| Aiello et al. (2013) | Gulf of Taranto, Italy | 1870–2005 | 135 | 20 |
| Ruggiero et al. (2003) | Washington State | 1860–2001 | 141 | 7 |

2 and Pleiades) images to estimate the coastal evolution in Thailand after tsunami of 2004. Duarte et al. (2018) made a short-time study of shoreline movement by RapidEye images in Brazil. Teodoros (Teodoros & Gonçalves, 2012) proposed a novel semi-automatic method to delineate sand from water bodies in Cabedelo area, Portugal, using IKONOS-2 images. Sekovski (Ivan et al., 2014) used high-resolution data from Worldview2 to vectorize the shoreline of Ravenna coast, Italy. Di K. et al. (Di et al., 2003) digitized the shoreline using IKONOS images. Studies that have used medium resolution (5–20 m) satellite imagery such as Sentinel-2 has been used by Cabaza-Rabadan et al. (2019); Konko et al. (Yaow et al., 2018); and Zifeng et al. (2018). Furthermore, SPOT images have been used by Valderrama-
Landeros and Flores-de-santiago (2019); Ayadi et al. (2016); Wei-Wei and Hsien-Kuo (Chen & Chang, 2009); Annibale et al. (Annibale Guariglia et al., 2009); Weicheng (2007); Bulent et al. (2004); El-Asmar & Hereher (El-Asmar & Hereher, 2011); Xuejie and Damen (2010), Shui-sen Chen et al. (2005), and Fromard et al. (2004); Cooley and Barber (Cooley Paul & Barber David, 2003). Rapid-eye has been used by Duarte et al. (2018).

Some indicative relative studies which have used medium-resolution data are presented in the next paragraph.

Cabezas-Rabadán et al. (2019) used Sentinel-2 images to quantify and characterize beach changes on the Valencian coast (Spanish Mediterranean). Zifeng et al. (2018) used Sentinel-2 images in order to try a new automated water index method called MuWI (Multi-Spectral Water Index). An estimation in coastal equilibrium made by Weicheng (2007) using multitemporal Satellite SPOT images. Duarte et al. (2018) used Rapid-eye imagery to evaluate the morphological changes observed in a beach in Brazil. Indian high-resolution satellites, such as IRS 1 C/1D and IRS (Pan) have been used by Mujabar et al. (Sheik & Chandrasekar, 2013) IRS 1 C/1D; Rasuly et al. (Aliakbar et al., 2010), 2002 and Nageswara et al. (Nageswara Rao et al., 2008). Finally, TERRA-ASTER has been used by Dewi, Ratna (2019); Ratna and Wietse (Ratna & Bijker, 2019); Hashmi et al. (Hashmi & Sajid, 2018); Addo et al. (Addo et al., 2011) and Brock et al. (2001).

**Low resolution (>20 m)** satellites such as IRS – LISS-3 has been used by Mitra et al. (2017); Ganasri and Ramesh (2016); Aedla et al. (Antonello et al., 2015) and Kumaravel et al. (2013). Earth Observing-1 images have been used by Nikolakopoulos et al. (Konstantinos et al., 2007) for Image classification procedure using the spectral angle mapper (SAM) algorithm in order to detect underwater springs in the Evvoikos Gulf in central Greece.

**Landsat** series have been used by most of the researchers such as (Valderrama-Valderrama-Landeros & Flores-de-santiago, 2019); Al-Amin (Hoque et al., 2019; Chao Chen Chao Chen et al., 2019; Mohamed et al., 2019; Yan et al., 2019; Yulianto et al., 2019; Ratna, 2019; Ratna & Bijker, 2019; Bera & Maiti, 2019; Karim et al., 2019; Sandeep et al., 2018; Yawo et al., 2018; Behling et al., 2018; Asib et al., 2018; Jeevivek & Saravanan Sakthivel, 2018; Hashmi & Sajid, 2018; Do et al., 2018; Zed Abu et al., 2018; Liu & John, 2018; Ratna et al., 2018; Xu Nan, 2018; Kaliraj et al., 2017; Mitra et al., 2017; Qingxiang Liu et al., 2017; Ratna et al., 2017; Luca et al., 2017; Manjulavani et al., 2017; Wenyu & Gong, 2016; Jaime et al., 2016; Vittal & Akshaya, 2015; Usha et al., 2015; Salghuna & Aravind Bharathvaj, 2015; George et al., 2015; Prasita, 2015; Kankara et al., 2015; Antonello et al., 2015; Arab et al., 2015; Gudina Feyisa et al., 2014; Sedar et al., 2014; Shenbagaraj et al., 2014; Yanxia Liu et al., 2013; Jeevivek & Saravanan Sakthivel, 2013; Jana & Bhattacharya, 2013; Luca et al., 2013; Pardo-Pascual et al., 2012; Bouchahma et al., 2012; El-Asmar & Hereher, 2011; Tuncay et al., 2011; Kawakubo et al., 2011; Addo et al., 2011; Bu-Li Cui; Bu-Li & Xiao-Yan, 2011; Aliakbar et al., 2010; Xuejie & Damen, 2010; Sharma & Acharya, 2010; LGED & Elbeih, 2010; Annibale Guariglia et al., 2009; Aris et al., 2008; Adel & Ryutaro, 2007; Thampanya et al., 2006; Vanderstaete Tony et al., 2006; Shui-sen Chen et al., 2005; Alfredo et al., 2005; Shaghude et al., 2003; Brock et al., 2001).

Studies that emphasized in multitemporal shoreline evolution used all the Landsat series MSS, TM, ETM and OLI. For instance, Landsat images have been used by Fajar (Yulianto et al., 2019) to perform coastal landform mapping, as well as a recording of multitemporal progress in coastal formation for twenty years in Pekalongan, Indonesia. Esmail et al. (Mohammed et al., 2019) used Landsat 5 and 7 images to assess the evolution of shoreline due to the seawall structures existed from a period of 1990 to 2015 in Damietta coast, Egypt. Landsat images have been used by Salghuna and Bharathvaj (Salghuna & Aravind Bharathvaj, 2015) for monitoring the shoreline changes in the Northern part of the Coromandel coast, India. Landsat images have been used by Arab et al. (2015) to estimate the shoreline movement on a delta coast in Tunisia.

Except of the exclusive usage of the Landsat images in multitemporal shoreline evolution studies there were researchers that combined Landsat with other satellite or aerial imagery. It is characteristic that most researchers used a combination of all the types of satellite images that were available, most of them which were free downloaded. Landsat TM, ETM+ and ASTER images have been combined by Addo et al. (2011) for an analysis of shoreline evolution in Ghana. Moreover, Landsat TM, ETM+ combined with IRS-P5 (Cartosat-1) and IRS-P6 (LISS-III & LISSIV) satellite images by Kankara et al. (2015) for monitoring and evaluation multitemporal shoreline changes in a coast in East India, for 22 years (1990–2012). Landsat MSS/Landsat ETM in conjunction with IKONOS images have been used by Marfai et al. (Aris et al., 2008) for the shoreline mapping and coastal dynamic assessment in a coastal area of Semarang, Indonesia. A combination of SPOT-PX/XS, Landsat TM and Corona satellite imagery with aerial data have been made by Annibale et al. (Annibale Guariglia et al., 2009) to map the coastline evolution in Basilicata Region, Southern Italy. Landsat MSS, TM and ETM+ images and a SPOT’ scene, topographical and nautical data have been used by Xuejie and Damen (2010) to study and analyze the shoreline changes of the Pearl River, China.
Furthermore, there were those researchers who used high-resolution satellite data (Worldview-2, Pleiades, QuickBird, IKONOS, etc.) or a combination of them in order to have very high accuracy to their measurements. Pantanahirian (2019) used Pleiades, IKONOS, Quick Bird and WorldView-2 satellite images to measure the coastal changes in Koh Kho Khao island in Thailand after the 2004 tsunami. Mann & Westphal (Thomas & Hildegard, 2014) used QuickBird and WorldView-1/2 images to determine changes in shoreline position in Papua New Guinea islands for 70 years. Sesli et al. (Faik, 2015) used Quickbird satellite image data for Monitoring the changing position of the shoreline at Eastern coast of Trabzon, Turkey.

In the last 20 years, a new low-cost, high-resolution digital image acquisition tool has emerged and is being used by researchers. These are unmanned aerial vehicles (UAV) that are equipped with high-tech instruments that can overcome some of the problems we face with satellites and airplanes (Papakonstantinou et al., 2016).

The coastal surveys due to UAV’s provide a low-cost method for rapid and high-accurate spatial resolution (2–5 cm) data acquisition. Drummond et al. (Christopher et al., 2015) present an overview of the use of UAV’s as an alternate and potentially improved option for mapping, surveying and monitoring the coastal zone.

Over the last 10–15 years the first surveys have been taken place by UAV’s equipped with a variety of expensive sensors and cameras which only few researchers could afford. Nowadays, everyone can get one in low cost and make his own research as well as the home UAV’s are technologically in advanced and can produce high-resolution data at a low cost for a specific area.

UAV’s images for shoreline monitoring used by: Jesús et al. (2019); Nahon et al. (Alphonse et al., 2019) and Goncalves et al. (Gil et al., 2019); Nunziata et al. (Ferdinando et al., 2018); Benqing et al. (Benqing Chen et al., 2018); Nikolakopoulos et al. (Nikolakopoulos Konstantinos & George, 2017); Letortu et al. (Pauline et al., 2018); Casella et al. (2016); Turner et al. (Ian et al., 2016); Papakonstantinou et al. (2016); Chikhradze et al. (Nino et al., 2015); Marcaccio et al. (James et al., 2015); Drummond et al. (Christopher et al., 2015); Elsner et al. (Elsner Paul et al., 2015).

Chikhradze et al. (Nino et al., 2015) used unmanned aerial vehicle (UAV) to produce 2D orthophotos and 3D digital elevation models in order to investigate the geocological state in North-West Portuguese zone. Elsner et al. (Elsner Paul et al., 2015) used unmanned aerial systems to study the evolution in beaches consisted of gravel and sand in England. Nikolakopoulos et al. (Nikolakopoulos Konstantinos et al., 2017) used UAV for mapping the coast in Rio beach in Western Greece.

Apart from the optical satellite data many researchers used Radar data (Mohammad et al., 2018; Ferdinando et al., 2018; Vandebroek et al., 2017; Francesca et al., 2016; Fugara et al., 2011; Hervé et al., 2005; Cooley Paul & Barber David, 2003). Radar scans the Earth’s surface operating at the microwave region of the electromagnetic spectrum and its results depended on the backscattering coefficient on the physical properties of the observed surfaces. SAR images, depending on their intensity and coherence, provide information about the type of surfaces and their dielectric properties as well as the modification of the shape of anthropogenic and natural objects (Ganzorig et al., 2006).

There are a lot of advantages by combining optical and radar images as the electro-magnetic radiation have the characteristic that an object which is invisible in passive sensor image could emerge in the image of the active sensor and this procedure can work inversely (Alessandro et al., 2008; Ganzorig et al., 2006).

Radar data provides information about the shape and structure of a surface and less about its type (Herold et al., 2004; Marghany & Hashim, 2010a). For this reason, radar data are suggested to be used in cases of dealing with natural hazards or when we are interested in data at specific times (Pradhan, 2009; Pradhan & Shafie, 2009). Radar has the advantage that offers potential for coastal monitoring application. It has great penetration capability as it works at microwave frequency which is independent of weather conditions, clouds and sunlight and it can be used day or night. Moreover, radar offers a high spatial resolution imagery and it is an active remote sensing system as it provides its own energy source.

Cooley and Barber (Cooley Paul & Barber David, 2003) used RADARSAT 1 and SPOT 4 images to correlate the rock, sand, and vegetated coast characteristics after classification process in Africa where the vegetation is particularly dense. Taha and Elbeih (LGEd & Elbeih, 2010) fused radar and Landsat images to classify and discern with better accuracy the wetary from nonwatery areas regardless of the cloud cover. Psomiadis et al. (2005) used a combination of Landsat images and a Temporal Differentiate Image (TDI), created by three radar images (SARPRI/ERS-2) in order to investigate the shoreline changes in Sperchios River, Greece. Trebossen et al. (Hervé et al., 2005) used radar images in a study of coastal development and monitoring coastal risks off the coast of French Guiana. AL_Fugara et al. (2011) used RADARSAT-1 images for monitoring coastal evolution of shoreline on Kuala Terengganu of Malaysia. Konko et al. (Yawo et al., 2018) made a combination of optical Landsat (TM and ETM+) and Sentinel satellite
images with and Radar images in order to analyze the coastal erosion in West Africa.

Similar to radar systems are Light Detection And Ranging (LiDAR) instruments which are usually mounted on an airplane platform. The main difference is that LiDAR uses laser light pulses to scan the environment. It works on the short wavelength and so it can detect small objects on the surface. Moreover, it has limited usage in nighttime and cloudy weather while it is quite an expensive technology. Horacio et al. (Jesús et al., 2019) combined LiDAR images with historical air photographs and images obtained by an UAV in order to observe a coastal-valley evolution in Galicia, Spain. Nahon et al. (Alphonse et al., 2019) used a combined photogrammetry technique based on ground and kinematic control points, and mobile laser scanning to construct an accurate 3D model of beach-to-dune transition in Cap Ferret area, SW France. Gonçalves et al. (Gil et al., 2019) used UAS, LiDAR, historical images and orthophotos in conjunction to construct digital surface models and estimate the local shoreline changes for the years 2011 and 2015 in Furadouro beach located in the Northern Portugal. Ruggiero et al. (Peter & Kaminsky George, 2003) used LiDAR data in determining historical and modern shoreline mapping uncertainties and implications for conducting change analyses along the coast of southwest Washington State. Gares et al. (Gares Paul et al., 2006) used LiDAR images to discern the beach’s limits from dune’s and to evaluate the volumetric changes for each area in North Carolina, USA. Almonacid-Caballer et al. (Jaime et al., 2016) used multi-data satellite sets combined with LiDAR data to assess the annual rate of shoreline derived from Landsat (TM, ETM and OLI) imagery and using it as an indicator to estimate the mid-term of beach trend in El Saler, Spain. Burningham and French (2017) used multi-temporal data based on historical map, aerial photos and LiDAR for a period of 1881 to 2015 to determine a shoreline trend analysis in Suffolk coast of England.

**Google Earth (GE)** provides an alternative high resolution freely available satellite imagery. These images have been taken by different time periods and thus are valuable to those who study the land use evolution. But there are some limitations in using Google Earth images as they are not able to obtain image classification as well as original multispectral band data is absent.

As well as the spatial resolution is very high, these data can be used by someone to execute on-screen digitizing of water bodies, hydrographic networks and other geological structures in GIS environment (Malarvizhi et al., 2016). In an older study by Nikolakopoulos and Dimitropoulos (Nikolakopoulos Konstantinos & George, 2017) has been evaluated the usage of Google Earth data for mapping. Accuracy measurements were performed through roads being digitized from GE images and overlapped them to those vectorized from Quickbird. Mörner and Klein (2017), used Google Earth images to observe the beach erosion procedure caused by human action on the Yasawa Islands in Fiji.

Mitra et al. (2017) used GE to check the accuracy of the shoreline detection method by using the LISS III and LANDSAT images to discern land from water. Martínez et al. (Carolina et al., 2018) use GE pro imagery in conjunction with aerial photographs and topographs to delineate the shoreline evaluation from 1964 to 2017 in Valparaiso Bay, central Chile. Fatima et al. (2018) studied the role played in the construction of a new marina in the historical evolution of the coastline in Tangier Bay, Morocco, Strait of Gibraltar, based on a combination of air photos, GE images, in-situ observations and surveys. Shenbagaraj et al. (2014) used Landsat (TM, MSS, ETM and OLI) images, topographic maps and GE images to join a technique named “iso-data classification” to estimate the shoreline movement in India. Prasita (2015) used Landsat Thematic Mapper (TM), GE images and topographical map to determine the shoreline movement in Pamurbaya, Indonesia. Paravolidakis et al. (2016) used aerial images and GE data to apply an algorithm in order to digitize the coastline in Georgioupoli region, located at North West Crete, Greece.

Seneviratnha et al. (2018) conducted a survey using the past and recent Quick Bird data derived from GE to investigate the coastal zone trend in Unawatuna beach of Sri Lanka. Ratna et al. (2018), used GE images to check Sentinel-2, ASTER and Landsat TM imagery accuracy, a combination of them were used to study the shoreline changes in Indonesia.

Global Navigation Satellite Systems (GNSS) or Global Positioning Systems (GPS) can be used to delineate the shoreline position. Such systems are the Real-Time Kinematic (RTK) systems that are being used in field surveys. Despite the great technological evolution that satellites, radar, and UAVs brought in remote sensing field of science, topographic surveys are still a high accurate tool that offer both acquiring shoreline data and deriving shoreline positions. Nevertheless, such surveys are high cost and time-consuming and researchers tried to avoid or replace with others equally accurate as sometimes is impossible to be used for an entire coastal system survey. Ruggiero et al. (Peter & Kaminsky George, 2003) used among other data, GPS-based topographic surveys to extract the shoreline position in an area of Pacific Northwest, Washington State. Aiello et al. (Antonello et al., 2013) used GPS surveys to quantify and analyze the amount of coastal erosion in the Gulf of Taranto, Italy. Vandebroek et al. (2017) used RTK-GPS topographic surveys in order to validate the shoreline position that derived from high-resolution Terra SAR-X satellite data in Sand Motor area,
The semi-automatic shoreline extraction methods

The spatial extraction of the shoreline is the main issue which the researchers must overcome. It is the fundamental element for further estimations such as coastline movement (erosion or accretion), coastal zone management, natural hazards prediction, etc. Data sources such as topographic maps, aerial-photos, ground surveys, satellite imagery with a variety of spatial resolution and more recently UAV’s images have been used for this purpose. At the same time a lot of software has been developed to help with this effort. Through the literature, there are two main methods that have been used for shoreline evolution observation (1) In-situ measurements which could involve topographic survey techniques along the coast and (2) Analysis of shoreline positions through multitemporal data sets coming from aerial and satellite images as well as unmanned aerial vehicles (UAV).

Except for the primary data collection, methods being used for the shoreline extraction by the researchers it is important to be qualified and quantified. The methods in general can be divided in manual and semi-automatic as fully automatic does not exist. Semi-automatic shoreline extraction is the process that uses some mathematical algorithms on satellite images to separate the land from water body. All these calculations have been named by researchers as indices and algorithms for water line extraction and they are carried out through appropriate software such as ArcMap, ENVI, ERDAS Imagine, etc. Manual shoreline extraction is the procedure that someone follows, in order to manually digitize the shoreline. The uncertainty and the risk of this method is quite high, and the accuracy depends on the users experience and the quality of the handling images.

Through the studied literature, the authors found the usage of those two methods for the shoreline procession and digitalization semi-automatic and manual. In semi-automatic category belong: a) the usage of NIR waveband to distinguish sea from the land (Valderrama-Landeros & Flores-de-santiago, 2019; Joevivek & Saravanan Sakthivel, 2013; Yawo et al., 2018), b) edge detection used as a shoreline proxy (Vasilis et al., 2018; Paravolidakis et al., 2016; Murray, 2013; Fugara et al., 2011), c) Supervised Classification used by Shalaby and Tateishi (Adel & Ryutaro, 2007), f) Unsupervised Classification used by Thomanya et al. (2006), g) Natural Breaks (Jenks) used by Andredaki et al. (2014), h) LDA Linear Discriminant Analysis used by Cooley and Barber (Cooley Paul & Barber David, 2003) and i) ISODATA classification technique used by Do et al. (2018); Mitra et al. (2017); Sekovski et al. (Ivan et al., 2014); Shenbagaraj et al. (2014) and Annibale et al. (Annibale Guariglia et al., 2009).

On the other hand, in manual category belong a) the on-screen digitizing (Pantanahiran, 2019; Asib et al., 2018; Senevirathna et al., 2018; Carolina et al., 2018; George et al., 2015; Prasita, 2015; Andredaki et al., 2014; Kim et al., 2013; El-Asmar and Hereher 2011; Tateishi 2007; Hervé et al., 2005; Fromard et al., 2004; Aris et al., 2008; Faik et al., 2008) and b) Differential Global Positioning System (DGPS) field measurements (Addo, 2009; Andredaki et al., 2014; Annibale Guariglia et al., 2009; Antonello et al., 2013; Elsner Paul et al., 2015; Ferdinando et al., 2018; Gil et al., 2019; Da Guia Albuquerque et al., 2013; Hervé et al., 2005; Jaime et al., 2016; Jesús et al., 2019; John & Scott, 2010; Peter & Kaminsky George, 2003; Vandebroek et al., 2017; Vassilakis & Papadopoulou-Vrynioti, 2014).

2.1.4 A summary of indicators, techniques, and models of shoreline movement through studied literature

A shoreline indicator is an element that can represent the “true” shoreline position. In literature there is recorded two main categories of shoreline indicators which have different base. The first based on the discrimination of land and water boundaries by visual observation and the second based on the tidal datum of the area. Worldwide in coastal evolution studies there have been listed 45 coastline indicators by Boak and Turner (Elizabeth & Ian, 2005) while a summary of shoreline indicators was recently represented by Toure et al. (2019). Gens (2010) summarize and record some various techniques to assess the coastline position from a variety of data while the most common models for predicting the coastal erosion and accretion was presented by Prasad and Kumar (2014).

Indices

Many indices which have been used by the researchers to delineate water from land, were found in the studied literature and have been recorded by the authors. The dominant index is the Normalized Difference Water Index (NDWI), introduced by McFeeters (1996), which researchers seem to prefer most and it is calculated using near-infrared (NIR) and short-
wave infrared (SWIR) wavelengths (Behling et al., 2018; Joevivek & Saravanan Sakthivel, 2018; Zed Abu et al., 2018; Yawo et al., 2018; Do et al., 2018; Nan, 2018; Hashmi & Sajid, 2018; Asib et al., 2018; Qingxiang Liu et al., 2017; Al Mansoori & Al-Marzouqi 2016; Maglione et al., 2015; Joevivek & Saravanan Sakthivel, 2013; Tuncay et al., 2011; El-Asmar & Hereher, 2011; Aliakbar et al., 2010; Alfredo et al., 2005). Modified Normalized Difference Water Index (MNDWI) which is like NDWI effectively removes the land noise from built-up, vegetation and soil cover (Xu, 2006), but instead of near infrared (NIR) band MIR band is utilized and used for the enhancement of open water features (Asib et al., 2018; Behling et al., 2018; El-Asmar & Hereher, 2011; Hashmi & Sajid, 2018; Nan, 2018; Qingxiang Liu et al., 2017). Normalized Difference Vegetation Index (NDVI) (Rouse et al., 1974) which measure the difference between near-infrared vegetation reflects and red light vegetation absorbs and it is used where vegetation is present along the coast (Bera & Maiti, 2019; Mitra et al., 2017; Al Mansoori & Al-Marzouqi 2016; Luca et al., 2013; Aliakbar et al., 2010). High Water Line (HWL) (Fenster & Dolan, 1999) which is determined as the intersection of the land with the water surface at an elevation of high water (NOS CO-OPS1 2000), was another index researchers used as a shoreline proxy (Addo, 2009; Addo et al., 2011; Del Rio et al., 2013; Kankara et al., 2015; Peter & Kaminsky George, 2003; Robertson et al., 2004). Automatic Water Extraction Index (AWEI) introduced by Gudina et al. (Gudina Feyisa et al., 2014), used for digitizing water bodies mainly from Landsat images improving the classification accuracy in areas where shadow and dark surfaces exist (Gudina Feyisa et al., 2014; Wenyu & Gong, 2016).

Except of the widely used indices that were mentioned before, there were some other used by researchers individually such as: Average High-Water Line (AHWL) which is defined as the proxy of the coastline between two large uneven tides, has been used by Ruggiero et al. (Peter & Kaminsky George, 2003), Land Surface Water Index (LSWI) which uses the shortwave infrared (SWIR) and the NIR regions of the electromagnetic spectrum, has been used by Rakesh and Ramkrishna (Bera & Maiti, 2019), High Tide Line (HTL) which is the maximum height reached by a rising tide (NOS CO-OPS1 2000), has been used by Martinez et al. (2018), Seaward Dune Vegetation Line (SwDVL) which is defined as the line separating the dune area which is mainly covered by dense and stable vegetation, from the seaward area that is mainly occupied by scattered vegetation (Thomas Tony et al., 2011), Instantaneous Water Line (IWL) which is the position of the beach–sea boundary at an instant in time and Stable Dune Vegetation Line (StDVL) which is defined as the line dividing the seaward, scattered vegetation from the beach area without vegetation (Elizabeth & Ian, 2005) have been used by Cenci et al. (Luca et al., 2017), Low Water Level (LWL) which is defined as the intersection of the land with the water surface at an elevation of low water (NOS CO-OPS1 2000) has been used by Fletcher et al. (Charles et al., 2003) and Mean Low Water (MLW) which is the average of all the low water heights observed over a period has been used by Burningham and French (2017).

Algorithms/equations
In order to delineate the water body from land surface, it was found that researchers tried diverse algorithms and equations on their studies. Most of them used in studies are presented in the next paragraph.

Histogram analysis has been used by Nassar et al. (Karim et al., 2019); Modava et al. (Mohammad et al., 2018); Kumaravel et al. (2013), Vassilikas et al. (2016), Vassilikas and Papadopoulou-Vrynioti (2014), and Fugara et al. (2011); Cui and Li (Bu-Li & Xiao-Yan, 2011); Chen and Chang (2009); Marfai et al. (Aris et al., 2008); Shaghude et al. (2003). Structure from Motion (SfM) has been used by (Alphonse et al., 2019; Benqing Chen et al., 2018; Christopher et al., 2015; Elsner Paul et al., 2015; Ian et al., 2016; James et al., 2015; Nino et al., 2015; Papakonstantinou et al., 2016; Pauline et al., 2018). FCM (fuzzy c-means) has been used by (Patna and Wetske (Patna & Bijker, 2019); Patna et al. (2018); Patna et al. (2017)). K-means algorithm used by Paravolidakis et al. (Vasilis et al., 2018); Vandebroek et al. (2017); Paravolidakis et al. (2016). Otsu method has been used by Patna (2019) and Qingxiang et al. (Qingxiang Liu et al., 2017). Wet/Dry line has been used by Sekovski et al. (Ivan et al., 2014). Tasseled Cap Transformation (TCT) has been used by Chen Chao et al. (2019) and Rasuly et al. (Aliakbar et al., 2010). Monte Carlo prediction model has been used by Davidson et al. (Davidson Mark et al., 2017) and Davidson et al. (2010). Radiometric approach method has been used by Bruno et al. (Francesca et al., 2016). Super resolution method used by Qingxiang et al. (Qingxiang Liu et al., 2017). Band Combination method has been used by Cabezas-Rabadán et al. (2019); Mitra et al. (2017); Salghuna and Bharathvaj (Salghuna & Aravind Bharathvaj, 2015); Gormus et al. (Sedar et al., 2014); Geosci et al. (Arab et al., 2015); Yanxia et al. (Yanxia Liu et al., 2013); Cui and Li (Bu-Li & Xiao-Yan, 2011); Xuejie and Damen (2010); Sharma and Prasenjit (Sharma & Acharya, 2010); Shui-sen Chen et al. (2005). ISODER clustering algorithm has been used by Kawakubo et al. (2011). Software/extensions used
We found that lots of researchers liked to use several software depending on the type of images they had to analyze. ArcMap and its versions, through the time,
concentrated the interest of researchers’ majority. This software is a well working GIS software equipped with many geospatial tools, such as the DSAS software (Digital Shoreline Analysis System, an add-in to Esri ArcGIS desktop) which is in widely usage for shoreline movement measurements among the scientific community (Al-Amin Hoque et al., 2019; Mohammed et al., 2019; Ratna & Bijker, 2019; Bera & Maiti, 2019; Jesús et al., 2019; Pantanaharir, 2019; Gonzalves Gil et al., 2019; Karim et al., 2019; Ratna, 2019; Valderrama-Landeros & Flores-de-santiago, 2019; Yawo et al., 2018; Bening Chen et al., 2018; Sandeep et al., 2018; Carolina et al., 2018; Romariz Duarte et al., 2018; Hashmi & Sajid, 2018; Fatima et al., 2018; Joeivek & Saravanam Sakthivel, 2018; Abu Zed Abu et al., 2018; Do et al., 2018; Kaliraj et al., 2017; Bakhoom et al., 2017; Manjulavani et al., 2017; Luca et al., 2017; Vassilikis et al., 2016; Anand et al., 2016; Saci et al., 2016; Ayadi et al., 2016; Antonello et al., 2015; Nino et al., 2015; Vittal & Akshaya, 2015; Ford Murray & Kench Paul, 2015; James et al., 2015; Kankara et al., 2015; Usha et al., 2015; Salghuna & Aravind Bharathvaj, 2015; George et al., 2015; Prasita, 2015; Jaime et al., 2016; Sakthivel et al., 2014; Andreadaki et al., 2014; Ivan et al., 2014; Vassilikas & Papadopoulou-Vrynioti, 2014; Thomas & Hildegard, 2014; Arab et al., 2015; Shenbagaraj et al., 2014; Joeivek & Saravanam Sakthivel, 2013; Da Guia Albuquerque et al., 2013; Kumaravel et al., 2013; Del Río et al., 2013; Antonello et al., 2013; Murray et al., 2013; Luca et al., 2013; Smith & Cromley, 2012; Yanxia Liu et al., 2013; Jana & Bhattacharya, 2013; Sheik & Chandrasekar, 2013; Bu-Li & Xiao-Yan, 2011; El-Asmar & Hereher, 2011; Addo et al., 2011; Tuncay et al., 2011; Aliakbar et al., 2010; Sharma & Acharya, 2010; Addo, 2009; Faik et al., 2008; Nageswara Rao et al., 2008; Alfredo et al., 2005).

Especially, Digital Shoreline Analysis System (DSAS) has a dominant position among tools that researchers used to measure the shoreline movement (Valderrama-Landeros & Flores-de-santiago, 2019; Bera & Maiti, 2019; Karim et al., 2019; Mohammed et al., 2019; Gil et al., 2019; Ratna, 2019; Yawo et al., 2018; Duarte et al., 2018; Fatima et al., 2018; Carolina et al., 2018; Do et al., 2018; Hashmi & Sajid, 2018; Manjulavani et al., 2017; Burningham & French, 2017; Luca et al., 2017; Bakhoom et al., 2017; Anand et al., 2016; Vassilikas et al., 2016; Ayadi et al., 2016; Saci et al., 2016; Vittal & Akshaya, 2015; Raju et al., 2015; Usha et al., 2015; Salghuna & Aravind Bharathvaj, 2015; Kankara et al., 2015; Jaime et al., 2016; Ford Murray & Kench Paul, 2015; Vassilikas & Papadopoulou-Vrynioti, 2014; Ivan et al., 2014; Thomas & Hildegard, 2014; Arab et al., 2015; Da Guia Albuquerque et al., 2013; Luca et al., 2013; Liu, et al. 2013; Del Río et al., 2013; Antonello et al., 2013; Jana & Bhattacharya, 2013; Murray, 2013; Smith & Cromley, 2012; Tuncay et al., 2011; Addo et al., 2011; Sharma & Acharya, 2010; Addo, 2009).

Digital Shoreline Analysis System (DSAS) is suitable for distance measurements using the Shoreline Change Envelope (SCE). Moreover, statistical indices such as End Point Rate (EPR), Least Regression Rate (LRR) and Weighted Least Squares Regression (WLSR) can be calculated. Furthermore, supplemental statistics for Least and Weighted regression such as Confidence Interval (LCI/WCI), Standard Error (LSE/WSE), R-squared (LR2/WR2) is available.

ERDAS Imagine is the second most popular software among researchers (Aliakbar et al., 2010; Anand et al., 2016; Antonello et al., 2013; Ayadi et al., 2016; Bu-Li & Xiao-Yan, 2011; El-Asmar & Hereher, 2011; Hashmi & Sajid, 2018; Jana & Bhattacharya, 2013; Kaliraj et al., 2017; Kankara et al., 2015; Kumaravel et al., 2013; LGEd & Elbeih, 2010; Manjulavani et al., 2017; Mitra et al., 2017; Raju et al., 2015; Sadi et al., 2016; Sandeep et al., 2018; Sheik & Chandrasekar, 2013; Shenbagaraj et al., 2014; Thampanya et al., 2006; Usha et al., 2015; Vittal & Akshaya, 2015; Xuejie & Damen, 2010).

ENVI software has been used by Al-Amin Hoque et al. (2019); Esmail et al. (Mohammed et al., 2019); Nassar et al. (Karim et al., 2019); Joeivek et al. (Joeivek & Saravanam Sakthivel, 2018); Abu Zed et al. (Zed Abu et al., 2018); Duarte et al. (2018); Cenci et al. (Luca et al., 2017); Salghuna & Bharathvaj (Salghuna & Aravind Bharathvaj, 2015); Petropoulos et al. (George et al., 2015); Aiello et al. (Antonello et al., 2015); Gundia et al. (Gudina Feyisa et al., 2014); Sekovski et al. (Ivan et al., 2014); Joeivek et al. (Joeivek & Saravanam Sakthivel, 2013); Addo et al. (2011); Kawakubo et al. (2011); Taha & Elbeih (LGEd & Elbeih, 2010); Wang et al. (Zifeng et al., 2018).

Agisoft PhotoScan has been used by Gonzalves et al. (Gil et al., 2019); Nahon et al. (Alphonse et al., 2019); Horacio et al. (Jesús et al., 2019); Letortur et al. (Pauline et al., 2018); Nikolakopoulos et al. (Nikolakopoulos Konstantinos & George, 2017); Papakonstantinou et al. (2016); Casella et al. (2016); Chikhradze et al. (Nino et al., 2015); and Elsner et al. (Elsner Paul et al., 2015).

QGIS has been used by Chikhradze et al. (Nino et al., 2015). MapInfo has been used by Fromard et al. (2004). IDRISI Selva has been used by Geosci et al. (Arab et al., 2015); Shalaby and Tateishi (Adel & Ryutaro, 2007). GIS MGE has been used by Chen et al. (Shui-sen Chen et al., 2005). SAGA-GIS has been used by Nahon, et al. (Alphonse et al., 2019). Microsoft Excel has been used by Sandeep et al. (2018) and Thampanya et al. (Thampanya et al., 2006). SPSS has been used by Cui & Li (Bu-Li & Xiao-Yan, 2011) and Thampanya et al. Thampanya et al. (2006). AUTOCAD has been used by In-Ho et al. (Kim et al., 2013) and Sesli et al. (Faik et al., 2008).

PG-STTENER v.4.2 has been used by Kim et al.
Erosion/accretion methods and algorithms

Many researchers have dealt with the use of various models and algorithms to calculate erosion/accretion numerically and in addition comparing results tried to estimate the future coastal behavior. RUSLE model has been used by Ganasi and Ramesh (2016), while RUSLE and UPSED models have been used by Aiello et al. (Antonello et al., 2015). Volumetric Changes in beaches’ sand studied by Horacio et al. (Jesú et al., 2019); Kaliraj et al. (2017); Sakthivel et al. (2014); Gares et al. (Gares Paul et al., 2006). CVI (coastal vulnerability index) is another significant feature that researchers used (Hoque et al., 2019; Jana & Bhattacharya, 2013; Joevivek & Saravanam Sakthivel, 2013; Mujabar & Chandrasekar, 2013; Nageswara Rao et al., 2008; Ratna et al., 2018). Tracer stick method has been used by Schwarzer et al. (2003). Beach width (BW) has been used by Cabezaz-Rabadán et al. (2019) while AEHR (Annual Erosion Hazard Rate) has been used by Fletcher et al. (Charles et al., 2003).

Methods

Meta-analysis

We gathered hundreds of published articles that reported methods of shoreline monitoring and proposed indices and methodologies. This broad spectrum of studies included a variety of data such as aerial photos, different sensor types, GPS and topsheets, satellite, UAV’s and radar images. For each article, we registered the high spot of the study and the index that being used for monitoring the shoreline position determination. Finally, all the collected features were sorted and classified in a Microsoft Excel Sheet and statistical charts were created to make it easier to draw relevant conclusions (figure 2).

Furthermore, this meta-analysis targets to highlight both, some shortcomings in the literature and the good practices that have mainly been used regarding the subject.

Year of publication

More than seventy percent (70%) of the studies were published during 2013–2019 (figure 3). This can be directly combined with the fact that researchers over the last decade had the ability to use instruments and data for their studies with improved accuracy (i.e. GNSS techniques, GPS and satellites with 0.01 m and 0.5 m spatial resolution, respectively). Furthermore, from figure 3 we can realize that there has been a strong upward trend in the study of the
phenomenon of coastal erosion in the last 20 years (blue line), a fact that proves the existence of the problem and reveals the real concern of the scientific community.

At the same time, in figure 4 we can see that the growth trend in the number of studies in the last two decades can be combined with the concern of the governments and several institutes which have funded the relevant studies. The rate 47.83% of “no funded” is a critical point which being occurred during this study and indicates that one in two studies of coastal erosion issue is being proceeded by researchers without financial support and this should be changed in the next years in order to improve the quality of the results as well as free of charge low-resolution data were used frequently and so the results based on them are limited.

**Periods of interest**

We distinguished four categories of periods (n in years) which researches work on; a) \( n \leq 10 \), b) \( 10 < n \leq 30 \), c) \( 30 < n \leq 70 \) and d) \( n > 70 \) and we found an equal distribution between the first three classes as figure 5 shows.

From the diagram above it is obvious that researches are concerned equally for the 10 or less years (a & c period interval). Particularly for the (a)
period we can assume that is happened probably due to the fact that new and accurate data of these years are available as mentioned before. Moreover, the (c) period (30 < n ≤ 70) seems to be in great interest probably due to the fact that many researchers have tried to combine many types of available data due to the time. Furthermore, the (b) period (10 < n ≤ 30) is in great demand as it represents a sort-term period which is most peoples’ concern.

Finally, the (d) period should include historical data, i.e. old maps and aerial photos which are in low accuracy and their scope is most for the study of the diachronic evolution of an area.

Materials

Through literature we found and recorded many types of data that were used in researches such as Topo-sheets, aerial photos, satellite, RADAR and UAV’s images (figure 6).

As we can observe from figure 6 the majority of the researchers used mainly three data sets, Landsat satellite, aerial photos and topo-sheets. The specific data sets present two main advantages: Low cost or no cost at all and extensive historical archives that refers for many decades in the past. Moreover, Landsat series (MSS, TM, ETM+, OLI) were the unique continuous mission for nearly 50 years. The rise in the use of UAV imagery is noticeable and proves that researchers have found in UAV’s a low cost but also accurate survey method. Moreover, high-resolution satellite images such as Worldview1/2, QuickBird and Pleiades are not in great demand per study because of their high cost of acquisition and the small extend per scene.

On the other hand, if we sum up all the types of satellites (table 5) and classify them into three types a)
Table 5. Data sources classified by spatial resolution a) High resolution, b) Medium resolution and c) Low resolution.

| High resolution (< 5 m)                       | Medium resolution (5–20 m)       | Low resolution (>20 m)              |
|-----------------------------------------------|----------------------------------|-------------------------------------|
| UAV’s | SAR (synthetic aperture radar)/RADARSAT-1 | LISS-2 | Landsat 30m                   |
| Corona | Google Earth | LIDAR (light detection and ranging) | QUICKBIRD |
| Pleiades | QuickBird | WORLDVIEW2 | KONOS |
| RapidEye | SPOT (1/2/3/4) | COSMO-SkyMed | TERRA – ASTER |
| SENTINEL 1 | TERRA – MOS | SENTINEL 2 | IRS – PACE |
| IRS – LISS | Earth Observing-1 | LANDSAT series | LISS | LISS |

High resolution, b) Medium resolution and c) Low resolution, we could note that the above conclusion is overturned (figure 7). As it can be observed in figure 7 in 62 studies high–resolution data was used while low–resolution data was used in 71 studies. This difference of nine studies represents only a 5.5% difference between the high– and low–resolution data in total. This small difference in frequency of use between the freely available low-resolution data such as Landsat and the high-cost data like Worldview could be explained if we took into consideration that always there is a need for validation of the results. Thus, many researchers execute their studies using free of charge low and medium-resolution satellite images. However, the same researchers prefer to use high-resolution images which are more accurate for the verification of the results.

Software statistical analysis

The meta-analysis of the studies also examined the software that were used for the shoreline evolution (figure 8). It is proved that in most of the studies there was not only one software used for the analysis but a combination of them. As it can be observed in figure 8, ArcMap software and its tools (in different versions) has a dominant part in coastal researches (40%). Furthermore, it is assumed that the specific software is widely used mainly thanks to the add-on software (DSAS) which many researchers used to estimate various statistical rates of shoreline movement.

At the same time, ERDAS Imagine, ENVI and Agisoft Photoscan follow the researcher’s preferences. Furthermore, in figure 8 there are two fields which are noticeable, “no data” and “other”. The “no data” field includes studies where no type or name of a software exists but only the expression “GIS software” and the “other” field which includes a variety of software which appeared one, two or three times in the texts being studied (figure 9). Finally, we have chosen to categorize the software for UAV’s data processing separately (figure 10) as they are modern research tools that continuously being developed and moreover they appeared from 2015 onwards in papers that were studied. It is expected in the years to follow that this type of software will be multiplied and improved.

Indices

As has been mentioned in paragraph 2.1.4 of the current paper, Boak and Turner (Elizabeth & Ian, 2005) listed 45 various shoreline indices that have been used worldwide in coastal monitoring studies while a summary of shoreline indicators was recently represented by Seynabou Toure et al. (2019). Some of these indicators which have been used from the researchers in order to delineate land from water are presented in figure 11.

It is obvious that the NDWI index was the most popular among researchers at a rate of 37.21% while the NDVI, MNDWI and HWL rates ranging between 11.63% and 13.95%. It should be noticed that independently from the fact that some indices seems to be more favorable between the researchers, every index has advantages and drawbacks and moreover the final choice is
Figure 8. Most common software used in shoreline analysis.

Figure 9. Software with low-frequency appearance in shoreline studies.

Figure 10. Most used software for UAV's data processing.
depended on many factors (i.e. available data, equipment, etc.). It is characteristic that the AWEI index has been used only in two studies as we can notice in figure 11. Nevertheless, as has been referred by (Gudina Feyisa et al., 2014) although there are not many studies about the usage of this index, it is very accurate especially when applied in areas where under deep shadow caused by the terrain.

**Shoreline extraction methods**

In order to delineate the water body from the land surface, except of the traditional manual shoreline extraction which includes field surveys and on-screen digitizing, researchers have tried some automatic classification methods. Such algorithms and equations are presented in figures 12 and 13. It is quite obvious that there is a lot of procedures available for the separation between land and water. These procedures have been called semi-automatic as fully automatic does not exist since now. Furthermore, semi-automatic and manual methods were compared (figure 14) and seems to be equally distributed in the published studies.

**Digital shoreline analysis system (DSAS) rates**

The DSAS is a plug-in to the ArcMap software developed by the United States Geological Survey (USGS) and it is being used for calculating the shoreline change rates. Figure 15 presents the usage of different DSAS rates from the researchers in the studied literature.

The EPR (End Point Rate), LRR (Linear Regression Rate) and NSM (Net Shoreline Movement) seems to be the most popular with a rate of 36%, 24% and 18.67%, respectively. The net shoreline movement (NSM) calculates the total distance between the newest and the oldest shorelines. The EPR is the NSM rate divided by the time elapsed and the LRR determines a rate-of-change statistic by fitting a least square regression to all shorelines at a specific transect (Himmelstoss et al., 2018).

**Erosion/accretion methods and algorithms**

The final and most interesting part of our research were the tools that have been developed up to now in order to compute the erosion or accretion rate (figure 16). We found that among the tools being used to compute the erosion or accretion rate, coastal vulnerability index (CVI) and volumetric technics of the amount of the sand being lost are the most common tools among researches and being appeared at a rate of 40% and 26.67%, respectively. These methods require the acquisition of several type of data such as topsheets, aerial or remote sensing images, ground control points, etc., and thus it is very complex procedure.

**Citations**

A list of the most referenced publications by articles referred in coastal erosion/accretion field using remote sensing is presented in table 6. The article that received the highest number of citations was “Management of Coastal Erosion Using Remote Sensing and GIS Techniques”, with a total of 471 citations in Scopus published in the International Journal of Ocean and Climate Systems in 2014.
Conclusions

One hundred thirty-eight studies from the literature reporting remote sensing data, GIS methods, materials and indices used worldwide to estimate the shoreline evolution, have been analyzed. Our aim was to define the usage of such techniques and methods and finally through the meta-analysis to highlight the most dominant indicators, software and methods followed by researchers the last 20-years relative to the coastal erosion/accretion subject. Furthermore this review targets to emerged some critical points through studied literature such as a) the low rate of high-resolution satellite images usage in a subject where the accuracy is prerequisite b) the necessity of the Landsat images being improved as they are the only ones related to the distant past and freely available, c) the usage of the new generation of UAV’s since 2015 as an alternative low-cost source for very high accurate imagery d) the fact that 50% of the studies for coastal erosion is being proceeded without financial

Figure 12. Methods used to determine the shoreline.

![Shoreline Extraction Methods](image)

Figure 13. Algorithms and equations used by researchers to delineate the shoreline position.

![Semi-automatic/ Manual Shoreline extraction](image)

Figure 14. Semi-automatic and manual methods.

Conclusions

One hundred thirty-eight studies from the literature reporting remote sensing data, GIS methods, materials and indices used worldwide to estimate the shoreline
support and thus the scientists are obliged to use only freely available data.

Applying the methodology of meta-analysis we have found that there has been a strong upward trend in the study of the phenomenon of coastal erosion in the last twenty years and there are three interesting periods which seems to be equally distributed at a rate of 33%: a) below the 10 years, b) 10 to 30 years and c) 30 to 70 years, while for a period of more than 70 years there seems to be little interest since it is quite difficult to retrieve the necessary historical data. Furthermore, the usage of Landsat satellite images dominates among researchers at a rate of up to 40% while high-resolution data such as IKONOS, Worldview1-2, QuickBird, Pleiades, etc., data seems to lag far behind at less than 5%. This high range is as Landsat images are freely available and very useful to diachronic studies. The usage of medium spatial resolution data such as SPOT (1/2/3/4) and Sentinel ranges from 5% to 7% in general. The UAV imagery is noticeable at a rate of 8% and seems that it will be used widely in the future as it is adopted by the researchers from 2015 onwards. Regarding the favorite software in the studies, ArcMap is being used at a rate of 38% of them, while a sum of the studies that have used software without reference to its type or name and software that has been used occasionally one to three times are at a rate of 35%. ArcMap software has those great rates mainly because of the DSAS add-on tool which is very common among researchers. Moreover, the NWDI indicator has been used by most of researchers to delineate land from water at a rate of 37,21%. In addition, we classified the shoreline extraction methods in two main categories a) semi-automatic and b) manual which are equally distributed. Finally, among the tools being used to compute the erosion or accretion rate, coastal vulnerability index (CVI) and volumetric techniques of the amount of the sand being lost are the most common tools among researches and being appeared at a rate of 40% and 26,67%, respectively.

This study is not intended to criticize neither the methods nor the results being mentioned but to give the opportunity to the researchers (especially the new ones) to have an overall view of the subject for the last 20 years with just a glimpse. It should be clear that the
results as represented in the previous pages refer just to the most famous values among the others in the papers being studied and do not propose the best of them because every index has its advantages and drawbacks and moreover the final choice is depended on many factors. We believe that the results represent the researcher’s favorable trend of the materials and methods about the same issue: the coastal erosion and the shoreline evolution.

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Table 6. Top 10 cited articles in Scopus in the present study literature.

| Researchers | Title | Number of citations |
|-------------|-------|---------------------|
| Saravanan, Sakthivel et al., 2014 | Management of Coastal Erosion Using Remote Sensing and GIS Techniques | 471 |
| Paul M. Cooley, David G. Barber, 2003 | Remote Sensing of the Coastal Zone of Tropical Lakes Using Synthetic Aperture Radar and Optical Data | 471 |
| Mujabar, P.S. et al., 2013 | Shoreline change analysis along the coast between Kanyakumari and Tuticorin of India using remote sensing and GIS | 457 |
| Raju Aedla, 2015 | Automatic Shoreline Detection and Change Detection Analysis of Nettavati-Gurpur-Rivermouth Using Histogram Equalization and Adaptive Thresholding Techniques | 159 |
| Cabezas-Rabadán, Carlos et al., 2009 | Characterizing beach changes using high-frequency Sentinel-2 derived shorelines on the Valencian coast (Spanish Mediterranean) | 151 |
| M.A. Davidson et al., 2010 | Forecasting seasonal to multi-year shoreline change | 150 |
| Bera, Rakesh & Maiti, Ramkrishna, 2019 | Quantitative analysis of erosion and accretion (1975–2017) using DSAS-A study on Indian Sundarbans | 146 |
| Bu-Li Cui, Xiaofan Li, 2009 | Coastline change of the Yellow River estuary and its response to the sediment and runoff (1976–2005) | 143 |
| Salim, Fatima et al., 2018 | Application of a Geomatics Approach for the Diachronic Study of the Mediterranean Coastline Case of Tangier Bay | 134 |
| Robertson, William et al., 2004 | Mapping Shoreline Position Using Airborne Laser Altimetry | 129 |
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