Chapter 15
Coastal Resources

> *Shoreline and beach surveys can today benefit from the state-of-the-art GNSS monitoring techniques, which directly offer both two- and three-dimensional data sets within a short period of time.*
>
> Morton et al. [1]

15.1 Integrated Coastal Zone Management and Its Importance

The extreme importance of coastal zones for countries with highly-populated coastal areas has been discussed in Goncalves and Awange [2] who highlight the concerns about their future, particularly on the state of their natural resources that provide life support and opportunities for economic development and tourism for these countries [3]. However, one of the main environmental problems facing coastal areas the world over is that of coastal erosion, which includes, e.g., beach erosion and other natural and anthropogenic environmental factors that are present along the shoreline. Anthropogenic factors include, for example, settlement near the shore, which aggravates the situation as exemplified in the case of Brazil where hundreds of beaches are under severe erosion [4]. One way of efficiently accomplishing coastal management, therefore, is investing in monitoring of shorelines to support policy formulations.

Continuous monitoring of coastal zones is important for integrated coastal zone management (ICZM) in order to support informed decisions on policies governing coastal development [5–8]. For example, the State of Pernambuco in Brazil established a Coastal Management Policy through legislation (i.e., Law No. 14,258 December 23th, 2010, Pernambuco), which has an overarching policy of guiding the use of natural resources of Pernambuco State Coastal Zone. Among other things, this law aims at:

(i) promoting the development of monitoring activities of natural resources and settlement of the coastal zone,
(ii) promoting recovery actions and regeneration of beaches,

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(iii) promoting the integration of Coastal Management Information System with other State systems of environment, water resources and land use, and,
(iv) promoting and supporting training for coastal zone municipalities staff in order to strengthen the urban environmental control.

All the four itemised components of the legislation above require some sort of shoreline monitoring, which is essential to consistently organise the set of positional data that represents the evolution of a particular case.

Shoreline monitoring is, therefore, essential for integrated coastal zone management (ICZM) where it provides the necessary information needed to manage settlement of coastal areas, establish guidelines for management of social-economics activities within the coastal areas, provide information necessary for recovery actions of beach regeneration, and provides a reference baseline for studies related to climate change in coastal zones. Shoreline monitoring methods are largely dependent on the goals, costs, implementation, and applicability. For monitoring of short coastal shorelines (e.g., tens to hundreds of kilometers), Global Navigation Satellite Systems (GNSS)-based methods are emerging as low cost approaches that offer *rapid*, *weather-independent*, and *quickly updatable* products that could benefit policy makers where high costs of traditional methods such as photogrammetry and remote sensing are of concern. However, various GNSS methods applicable to shoreline monitoring exist, making it difficult for decision makers to choose a suitable approach. Using a case study of Pernambuco state ICZM in Brazil, Goncalves and Awange [2] evaluates three most commonly used GNSS-based shoreline monitoring methods; relative kinematic (RK), real-time kinematic (RTK) and precise point positioning (PPP), and provides a comprehensive analysis of their strengths and limitations. Their results highlight the issues and important considerations in choosing an economically viable GNSS method for mapping shoreline changes, particularly for supporting ICZM policies.

15.2 Marine Habitat

15.2.1 Background

Marine habitats are comprised of zones termed *coastal terrestrial*, *open water*, and the *ocean bottom* until several meters deep. Several physical parameters, e.g., temperature, salinity, tides, currents, winds, etc., play a major role in defining the marine habitat. Malthus and Mumby [9] have listed marine ecosystem to comprise *mangroves, seagrasses, coral reefs, lagoonal microbial mats, shoreline features, sublittoral zone benthos* and *overlaying water column features*. The reflectance of these features can be measured by remote sensing methods to provide synoptic data at various scales. Such data are essential requirements for coastal managers to be able to address issues facing these diverse habitats. In most countries, these environments are either being degraded or not inventoried. This is due partly to inaccessibility and partly due to large spatial coverage, leading to high costs when applying conventional methods.

Remote sensing and Geographical Information Systems (GIS) discussed in detail, e.g., in Awange and Kiema [10] offer possibilities of mapping and inventorying marine habitats, thus enhancing the understanding of the unique characteristic of marine habitats. Malthus and Mumby [9] have indicated that remote sensing could be used to reveal how patterns change across a near-continuum of spatial scales, details of which are useful in identifying the scale at which disturbance such as El Niño-Southern Oscillation (ENSO) causes changes in the marine environment. In what follows, we examine some of the ways in which remote sensing, GIS, and GNSS tools could be used to support mapping of marine habitats.

15.2.2 Satellites Monitoring of Marine Habitats

The presentation in this section shows the complementary nature of remote sensing, GIS and GNSS methods in supporting monitoring of marine habitats. In general, GNSS play the following important roles; (i) that of validation of the remotely sensed data through georeferencing (i.e., the actual validation on the ground of what is seen on the photograph or any other remotely sensed images), (ii) georeferencing of the aerial photographs e.g., Fig. 16.3 on p. 337), and (iii) providing the sampling locations. Remote sensing techniques applicable to marine habitats include, e.g., aerial photography, airborne optical sensors, Synthetic Radar Aperture (SAR), and optical satellite-based sensors. Analysis tools include empirical models and multispectral classifications. Remote sensing and GIS techniques are useful in discriminating marine habitats as demonstrated, e.g., by Call et al. [11] who discriminates coral reef habitats. Held et al. [12] applied hyperspectral and radar techniques to map tropical mangroves. Discrimination of marine habitats requires that the radiative transfer properties of the marine environment be well understood. Effective use of remote sensing to monitor water quality will require an established relationship between water colour and constituent bio-optical water quality parameters such as suspended organic matter and dissolved organic matter [9]. Karpouzli et al. [13] have highlighted the need to understand the spatial and temporal variations in optical water quality parameters and their influence on inherent and apparent optical properties.

Due to the high spatial diversity of marine habitats, high spatial and spectral resolution data are required to discriminate between features. Moderate resolution sensors, e.g., Landsat ETM[1] and SPOT (approximately 10 m) are limited by poor spatial and temporal resolution, spectral capabilities, and important signatures falling outside visible bands. Held et al. [12] and Call et al. [11] demonstrate that sub-pixel-scale mixing prevent accurate identification of features leading to coarse descriptive levels of mapping. One possible way of improving the performance of moderate resolution sensors would be the combination of optical and SAR approaches as demonstrated by

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[1] http://landsat.gsfc.nasa.gov/about/L7_td.html.

Held et al. [12], who combined these sensors for the case of mangroves. In this case, increased classification accuracies with the use of greater spatial data was possible.

Due to the optical similarity in the reflectance between the bottom marine features, leading to subsequent confusion during identification of remotely sensed data, care must be taken in distinguishing different classes (e.g., vegetation) on the basis of spectral reflectance, for instance, higher-spectral resolution reflectance are needed to perceive the subtle differences, see, e.g., [11]. Malthus and Mumby [9] point out that classification based on high-spectral resolution airborne data tends to provide the best results. They advocate the necessity to better understand the depth limits to which useful above surface spectral signatures can be derived, but still allow the discrimination of habitat types, as does the relationship to varying water column optical properties. For example, Call et al. [11] demonstrated that the point at which a signature begins to resemble a water column's optical properties rather than substrate for a coral reef system is 7 m. This applies for certain locations, in others, it is 15 or 20 m such as Ningaloo Marine Park in Australia.

As already pointed out, one of the shortcomings of remote sensing technique in mapping marine habitat is the poor spatial resolution (e.g., 30 x 30 m in a Landsat image). Call et al. [11] highlighted a critical resolution of 4 m for mapping seagrass in their littoral system. High-resolution sensors such as IKONOS and QuickBird could be of use. Mumby et al. [14] evaluated Landsat MSS,[2] Landsat TM,[3] SPOT XS, CASI (Compact Airborne Spectrographic Imager), SPOT pan and a combination of Landsat TM and SPOT-PAN to map Caribbean coral reefs. Landsat MSS was the least accurate sensor while CASI was found to be more accurate than satellites sensors and aerial photographs. They noted that maps with detailed habitat information had a maximum accuracy of 37% when based on satellite imagery, 67% based on aerial photography and 81% based on CASI. In tropical regions, characterized by prolonged cloud cover, low accessibility, high temperature and high humidity, digital airborne colour and infrared photography are useful [9].

Besides using optical remote sensing as a stand alone tool, a combination with other methods such as acoustic, SAR and LIDAR[4] could be useful. Optical, SAR and LIDAR will cover above surface, while acoustic could be used for sub-surface studies. In this combination, LIDAR would offer high data density for bathymetry, optical spectral information with degree of penetration into water column and wide spatial coverage, and SAR the structural components of the habitat (onshore and sub-surface) which are less visible in optical sensors. This could be enhanced by the incorporation of knowledge based processing packages such as ERDAS Images[5] to improve accuracies of classification [9].

To validate remotely sensed data, georeferencing is essential. This could be achieved through, e.g., matching signatures to defined biotopes; assessing changes between images; and applying the results in coastal zone management. Once the

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[2] Multispectral Scanner.

[3] thematic mapper.

[4] Light Detection And Ranging.

[5] http://www.erdas.com/Homepage.aspx.

remote sensing data has been processed, they provide attributes to be used in a GIS system together with other data to generate a marine habitat georeferenced system that can be edited, updated, and queried, which greatly benefits marine habitat management. Ground truthing and georeferencing can also be achieved using GNSS, where positions of selected marked features on a remotely sensed image are determined, e.g., using hand-held GNSS receivers. Besides ground thruthing, GNSS is also useful in providing orientation to aerial photographs (e.g., Fig. 16.3 on p. 337.

Example 15.1 (Application to microbiology monitoring program).

Schiff and Weisberg [15] conducted an inventory to assess the number, type, spatial distribution, and costs of microbiological monitoring programs in southern California marine waters from Point Conception to the US/Mexico border. The location of each sampling site was determined using GNSS, while the estimates of geographic coverage were determined using GIS techniques. A list of organizations that conduct microbiological monitoring in marine waters was compiled by contacting all of the city and county public health agencies and regional water quality control boards in southern California. Monitoring organizations were then surveyed to ascertain the following information about each sampling site: station name, location (latitude/longitude, general description, water body type), depth of sampling, analytes measured, analytical methods, and sampling frequency by season. Where latitude and longitude data were unavailable, the sites were revisited and the position of the sampling sites found using DGPS (Sect. 5.4.4.1). The relative distribution of sampling effort among habitat types was assessed by differentiating sampling sites into offshore and shoreline strata. Shoreline sites were further differentiated into eight categories: (1) high-use sandy beaches, (2) low-use sandy beaches, (3) high-use rocky shoreline, (4) low-use rocky shoreline, (5) perennial freshwater input areas, (6) ephemeral freshwater input areas, (7) embayment, and (8) restricted access areas. This example show the role played by GNSS in providing sampled data locations and field validation through georeferencing.

♣ End of Example 15.1.

Next, another application of GNSS, that is, shoreline monitoring is presented.

15.3 Shoreline Monitoring and Prediction

15.3.1 Definition and Need for Monitoring

A shoreline is defined as the boundary between the continent and the portion adjacent to the sea where there is no effective marine action beyond the maximum reach of the waves, and is identified by cliffs, the boundary between the vegetation and the seashore, by the rocks, or by any other feature that determines the beginning of

Fig. 15.1 Examples of definition of a shoreline; **a** the shoreline is the boundary between the vegetation and the seashore while in **b, c, d**, the shoreline is the boundary between the continent and the portion adjacent to the sea where there is no effective marine action beyond the maximum reach of the waves, characterized by urban settlement and problems of coastal erosion. *Source* Goncalves [18]

the continental area [16, 17]. In Fig. 15.1, four examples of different scenarios that define the position of a shoreline are presented as follows; in (a), the shoreline is the boundary between the vegetation and the seashore while in (b), (c), and (d), the shoreline is the boundary between the continent and the portion adjacent to the sea where there is no effective marine action beyond the maximum reach of the waves, characterized by urban settlement and problems of coastal erosion.

Shorelines are known not to be stable and vary over time causing the effects of progradation (i.e., a shoreline moving towards the sea due to deposit) or retrogradation (i.e., a shoreline moving towards the land due to wave erosion). *Long-term changes* can be related to changes in sea level, sediment supply, wave energy, and geological controls (contemporary and antecedent), causing movements in the position of a shoreline over a period of centuries and millennia. *Short-term changes* on the other hand occur over time scales of 80 years or less and are related to daily, monthly, and seasonal variations in tides, currents, wave climate, episodic events and anthropogenic factors, see, e.g., [19–21]. Very rapid (episodic) changes in shoreline location can also occur as a result of (tropical) storms and hurricanes and can move a shoreline more than 30 m in a day [22]. Fenster and Dolan [23] describe shoreline movement as a complex phenomenon and the difficulties involved in distinguishing long-term shoreline movement (signal) from short-term changes (noise), although for long-term analysis, the effect of storms are not treated as outliers, hence they are considered in the temporal data distribution, e.g., Fenster et al. [24]. The complexity of the definition of a shoreline, mapping, and subsequent utilization are discussed, e.g., in [6, 25].

Monitoring and prediction of shorelines is vital for environmental and resource management. Most coastal areas are known to experience soil erosion (see Fig. 15.2), which in some cases, lead to the disappearance of beaches, destruction of cliffs by gullies, or submersion of parts of the coast. Yet beaches have been known to be a source of revenue for those countries that attract tourism along their coasts. Environmental management is therefore essential in realizing the long term durability of such coastal areas. One way of realizing efficient management of beaches is through constant monitoring of the coastal shorelines. Through continuous monitoring, policy and decision makers are informed of the behavior of forcing and response parameters of shorelines. These forces are, e.g., changes in the forces that move the sand, namely wind, waves, and currents.

Monitoring is therefore essential in improving the database of information on shorelines evolution in an area, thereby indicating the trend in beach loses as demonstrated by Fig. 15.3. Metropolitan Borough of Sefton [26] have listed the benefits of shoreline evolution information as; *providing input to shoreline review plans*, *planned maintenance of coastal defenses*, *achievement of high government level targets*, *determination of appropriate design criteria for coastal works*, *biodiversity action plan*, *implementations of habitats directive*, and *leisure and amenity management of shoreline areas*. Shoreline information have also been used to support other monitoring studies, e.g., in microbiological monitoring of marine recreational waters, see e.g., [15], while accurate interpretation of its movement trends and precisely quantifying the rates of movement are necessary to accurately predict its future positions [1].

15.3.2 Monitoring

Traditionally, monitoring of shorelines and beach dynamics has been undertaken using surveying techniques such as traversing and levelling where shoreline positions are determined in addition to the height information that are linked to a nearby monuments. To infer the rate of erosion, these positions and height information are compared to subsequent beach surveys to yield a two-dimensional cross-sectional area, which represents the amount of beach erosion and deposition that occurred between the surveys. A three-dimensional volumetric change in the beach is derived from the profiles by integrating between adjacent cross-sectional areas [1]. Morton et al. [1] lists the setback of these traditional approaches as (i) loss of the reference monument upon which the heights are referenced through, e.g., erosion (ii) errors in the generation of the cross-sections since subsequent surveys may not traverse the same course, (iii) amount of time required to undertake the extensive survey,

Fig. 15.2 An example of environmental degradation of a coastal area in Brazil through erosion. *Source* Goncalves [18]

Fig. 15.3 Impacts of shoreline erosion in Matinhos District in the coast of Paraná State, Brazil in 2007. *Source* Goncalves [18]

and (iv) the errors incurred in generating a three-dimensional volumetric data from a two-dimensional cross-sectional data.

To remedy these setbacks, shoreline and beach surveys can today benefit from the state-of-the-art GNSS monitoring techniques, which directly offer both two and three-dimensional data set within a short period of time, see e.g., [1]. Other mapping techniques that have benefited shoreline monitoring are photogrammetry, remote sensing, and LIDAR. These methods have been elaborately discussed, e.g., in Gorman et al. [27]. As discussed in details in Goncalves and Awange [2], starting in the 1920s, it was demonstrated that great efficiency gains in shoreline mapping could be realized by transitioning from ground-based methods (e.g., plane tables, alidades and stadia rods) to airborne methods (e.g., photogrammetry and aerial imagery interpretation), see e.g., [28–31]. Beginning in the 1970s, when earth observation satellite data became publicly available, further gains in shoreline mapping efficiency were enabled [32]. Today, photogrammetry, airborne lidar, and satellite imagery are well-established methods of mapping large stretches of shoreline in many areas around the world, see e.g., [29, 33–35]. Additionally, unmanned aerial vehicles (UAVs) (see Chap. 20) and structure from motion are also emerging as viable coastal mapping techniques, see e.g., [36, 37]. However, while the cost per linear kilometer of shoreline data acquisition will generally be lowest for satellites, followed by aircraft, there are a number of important benefits to ground-based shoreline mapping surveys. First, for very small project sites, the total acquisition cost can actually be lower using ground-based methods than for airborne methods. Second, ground-based shoreline surveys typically provide the highest accuracy, as well as the detailed knowledge obtained by "boots on the ground." Therefore, ground-based surveys can provide reference data for calibrating and validating airborne and space-borne shoreline mapping techniques. Third, when shoreline data with high temporal resolution (i.e., short repeat survey periods) are needed, ground-based methods may be the best option.

When and where ground-based survey methods are advantageous for shoreline mapping, GNSS is generally the technology of choice having the advantages of being quicker, all-weather, highly accurate, and capable of generating continuously updatable shoreline positional time series relevant for monitoring and management tasks undertaken by engineers and coastal authorities in cases of extremely small project sites that are located close to a field office and easily accessible. For such small projects, use of traditional remote sensing-based satellite techniques could be costly although this does not apply to all cases. Furthermore, as exemplified by the case of National Oceanic and Atmospheric Administration (NOAA)'s National Geodetic Survey, Coastal Mapping Program,[6] field-based GNSS shoreline surveys are sometimes performed to obtain high-accuracy reference data for evaluating airborne or space-borne shoreline mapping methods, see e.g., [30, 34].

GNSS comprising the use of the US-based GPS (Global Positioning System), Russian's GLONASS (GLObal NAvigation Satellite System), European's (GALILEO), and Chinese's Beidou (or Compass) discussed in Chap. 2 and also in [38] have already

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[6] http://www.ngs.noaa.gov/RSD/cmp.shtml.

been proposed for shoreline monitoring, e.g., by [39]. However, with a large number of types of GNSS surveys, ranging from static surveys to Real Time Kinematic (RTK), Network Real Time Kinematic (NRTK), Post Processed Kinematic (PPK), and Precise Point Positioning (PPP), the Coastal Zone Management (CZM) community needs information on which types of GNSS surveys are most advantageous for shoreline mapping across a range of project types and coastal morphologies. To this end, Goncalves and Awange [2] empirically compared different GNSS survey methods in a study site along the coast of Pernambuco, in the northeast of Brazil. Three common types of GNSS surveys (PPK, RTK, and PPP; see Sect 5.4) were evaluated and the results compared. Their study concluded that the choice of a particular GNSS method is very important for an efficient and reliable shoreline monitoring. In their case study of Pernambuco state in Brazil, the PPP method was considered to be both economical and feasible for the case study and shown to be a reliable alternative for mapping and monitoring of shoreline that could be used to support the Pernambuco legislation presented in Article 10. They however recommend that, in general, other issues such as the use of a shoreline indicator and how to map and monitor it should be considered when choosing a method for mapping positional variations of shoreline to support ICZM policies. Furthermore, they point out other issues of concern such as the extent of the State's GNSS network configuration that does not provide ideal short baselines to support RTK and RK, and the lack of benchmarks in the survey area due to the low geographical density of stations belonging to the network.

White and El Asmar [40] provide an illustration where the Thematic Mapper (TM) imager is used to monitor the changing position of the Nile Delta coastline. To enhance these monitoring mapping tools, GIS techniques are now being used to analyze changes in natural phenomenon according to the evolution in time using spatio-temporal dynamic models in a Coastal Geographic Information System (CGIS). For example, CGIS has been used by Li et al. [25] to monitor the Malaysian shoreline. With respect to GNSS satellites, the following roles are foreseen:

1. Providing orientation to aerial photographs (e.g., Fig. 16.3) and ground truthing data for remote sensing satellites.
2. Provision of *real-time* monitoring of positional data of the shoreline that informs the decision making of environmental (coastal) managers (see, e.g., Fig. 15.4, right).
3. Provision of *historical data* needed for computing the parameters of the predictive models as discussed in the next section.

Example 15.2 (GNSS-based monitoring and mapping of shoreline position in support of planning and management of Matinhos/PR (Brazil) Goncalves et al. [41]).

Monitoring and mapping variations in shoreline location is an activity that can be undertaken using several different techniques of data collection, e.g., photogrammetric restitution, satellite images, LiDAR (Light Detection and Ranging) or classical topographical surveys to support coastal environmental protection such as identifying flood risk areas. The global navigation satellite system (GNSS) has been employed

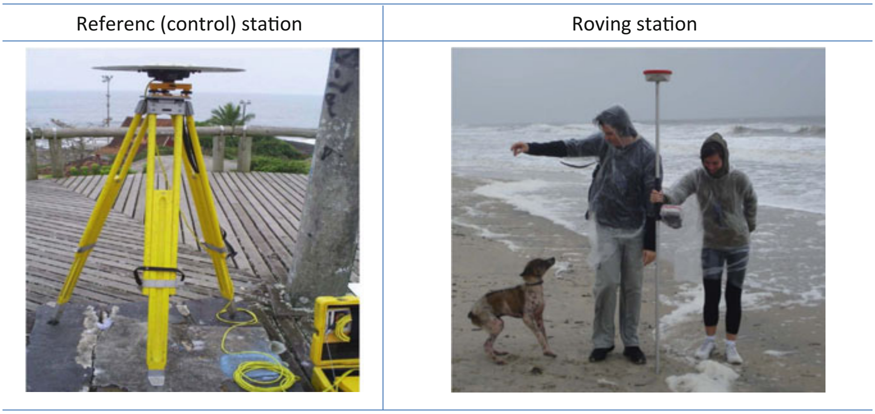


Fig. 15.4 *Left* Base station in Matinhos. *Source* Goncalves [18]. *Right* Real-time GNSS shoreline monitoring. A roving GNSS receiver is used to provide shoreline's location-based data relative to the reference station whose position is known using one of the rapid positioning techniques discussed in Sect. 5.4.5. *Source* Goncalves [18]

by the Federal University of Parana (UFPR) as part of their research into the application of geodetic survey methods for shoreline mapping in coastal environments since 1996. The advantages of using GNSS are accuracy and productivity, given that a great number of points can be determined within a short period of time at decimeter-level accuracy. In this work, GNSS relative kinematic positioning approach was applied to monitor Matinhos coastal district of Brazil. Other important data, such as the high- and low-tide marks, all obtained using GNSS, and thematic maps were incorporated. Through the reanalysis of historical surveys, it was possible to make some conclusions about the shoreline dynamics and to use this information as material in support of the planning and management of the coastal environment, for example, when planning engineering works that set out to minimize coastal erosion and for urban planning. The results achieved in Goncalves et al. [41] include defining the position of the shoreline for 2008, developing the thematic map of the shoreline, the quantification of the advance and retreat of the shoreline between 2001 and 2008, and a map showing those critical areas where the shoreline position is equal to the high-tide water line. GNSS-based method offered quicker, all-weather, highly accurate and continuously updatable shoreline positional time series relevant for monitoring, thus enabling quicker management decisions to be undertaken, which may be of benefit to coastal engineering applications.

♣ End of Example 15.2.

15.3.3 Prediction

Whereas shoreline monitoring is essential as already discussed, predicting its future position is equally vital to support the *environmental impact assessment* and *management* of programs such as predicting increased shoreline erosion [42] and building setbacks to serve as protection for a time comparable to the expected lifetime of new coastal structures, usually 30 or 60 years [43]. According to Morton et al. [1], predicting future rates of coastal erosion and land loss progressed from a purely academic exercise to one of environmental importance since many coastal states and government agencies relied on technical data to determine construction setback lines and insurance hazard zones. This led to the establishment of elaborate networks of closely spaced beach profile monuments that were periodically revisited to assess magnitudes and rates of shoreline movement that were used to establish building zones and to create construction control lines [1]. Going back to Fig. 15.3 for example, if the shorelines had been predicted before the roads were developed, such environmental degradation could have been avoided by constructing the roads further inland.

Crowell et al. [43] states, however, that determining adequate setbacks requires estimating long-term shoreline changing trends from historical data. Fenster et al. [23] developed a predictive method that detects short-term changes in the long-term trend and identifies linear or high-order polynomial models that best fit the data according to the minimum description length (MDL) criterion. In this method, only linear models are extrapolated.

Douglas et al. [44] stressed the need to incorporate long-term erosion trends and historical records of storms, including their impact on shoreline position and beach recovery, in predictive models. Exploiting the relationship between shoreline and sea-level changes (i.e., using series of sparsely sampled sea level values as surrogate data for shoreline changes), they developed an algorithm to evaluate several predictive methods, such as the end-point method, linear regression, and minimum description length criterion. They evaluated several well-known shoreline prediction algorithms and established that linear regression gave superior results, see also [44]. Predictions shaped or influenced by higher-order polynomial schemes can sometimes be superior to those obtained from linear regressions, but they can also be extremely inaccurate [43]. Use of modern more accurate surveying measurement techniques such as photogrammetry and GNSS have also been shown to improve the quality of forecasts. Douglas and Crowell [45] demonstrated that this is achievable even if the inherent variability of shoreline position indicators remains at the level of many meters.

The linear regression models that are usually used to predict shoreline positions work well when the underlying linearity and normal distribution assumptions are fulfilled. In some cases, however, the sources of data, particularly photogrammetric data are of a poor quality. Indeed, this fact is acknowledged, e.g., by Douglas et al. [44] who point out that some data used in predicting shorelines are at times temporally poorly sampled historical shoreline positions, resulting in the violation of the linear

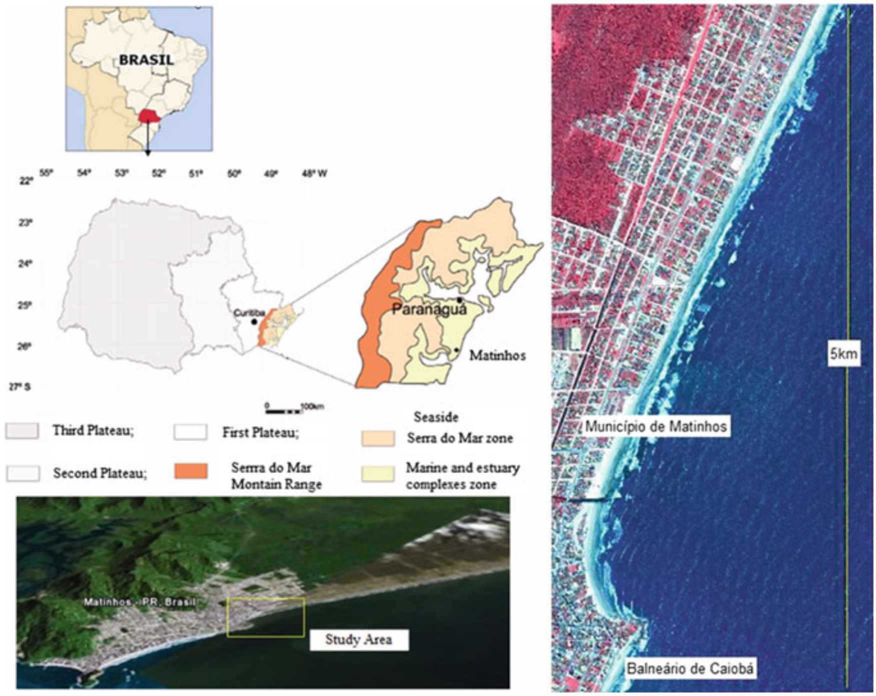


Fig. 15.5 Matinhos District in the coast of Paraná State, Brazil. *Source* Goncalves [18]

regression assumptions. In others instances, the transformation process used to bring all the data into a common coordinate system (e.g., Sect. 5.6.2) may be poorly done, such that the resulting extracted shoreline positions used for predictive purposes are themselves inaccurate. In such cases, therefore, modern techniques such as GNSS provide *fast*, *efficient* and *accurate* means for data capture that support shoreline prediction. In the following example, the use of GNSS in supporting predictions of shoreline positions is illustrated.

Example 15.3 (Shoreline prediction of Matinhos Beaches in Paraná, Brazil) [18].

Background of Matinhos: Matinhos District is located along the coast of Paraná State, Brazil (Fig. 15.5). The coastal region of the State of Paraná, located between the 25–26° S and 48–49° W, is formed by the Serra do Mar mountain range, extensive coastal plains, and estuary complexes.

Exploitation of the Matinhos shoreline started as early as 1920, but the first settlement begun in the 1948 with a hotel built on the sandy shore. By 1949, a murram road had been constructed near the shore (see Fig. 15.6). The settlement in Matinhos occurred near the shore, whereby in some oceanic beaches, the settlement was characterize by constructions on the shoreline or over the sand, leading to the destruction of dunes, wetlands, and forcing rivers to change course. This was a result of unplanned

Fig. 15.6 Photos of the Matinhos shore in 1920, 1948, and 1949. *Source* [47]

Fig. 15.7 Vertical aerial photo taken in 1953. *Source* [46]

settlement that did not take the morphology and coastal dynamic environment into consideration, see e.g., Pierri et al. [46]. For instance, Fig. 15.7 indicates that the main road in front of the beach called Atlantic Avenue in Matinhos was planned to run alongside the shoreline in 1953, but has been faced with soil erosion problems.

Coastal erosion started in the 70s and to date, this environmental degradation continues to be fueled further by the expanding development as indicated in Fig. 15.7. Figure 15.8 shows the walls of concrete and rocks being used as protective tools against the encroaching ocean, but every year over the last decades, storms have destroyed them, exposing the coastal settlement to erosion. For the past 40 years, this beach has continued to languish under these problems. According to Pierri et al. [46], the process of coastal erosion once started has the tendency to grow and is

Fig. 15.8 Photos of the Shore in 1981, 1994, and 1995. Walls of concrete were applied as protective tools against the encroaching ocean. *Source* [47]

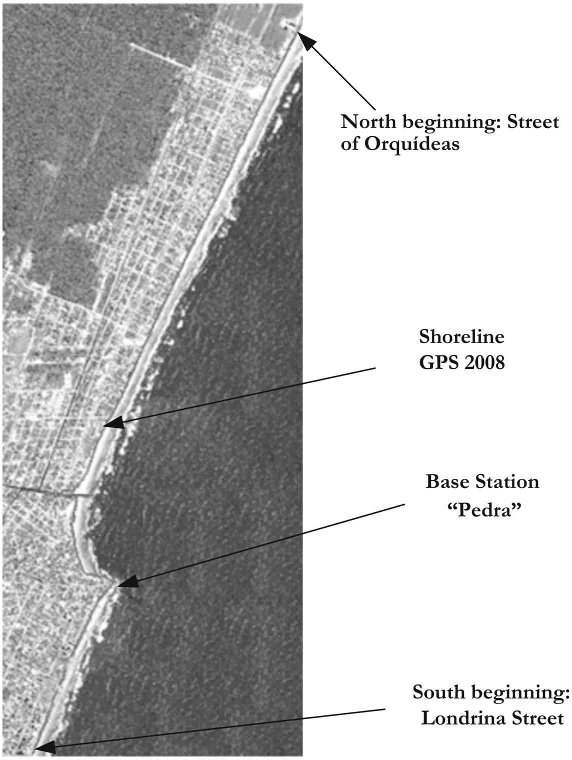
Fig. 15.9 Houses destroyed by an ocean storm in May 2000, and removal of the houses and dune reconstruction in 2004. *Source* [46]

often difficult to reverse thereby calling for prevention as the best cure. When the problems start, depending on the settlement of the shore, the best solution can be the removal of any structure.

In Matinhos, removal of houses was performed on an informal settlement in the central beach after the ocean storm of May 2000, which destroyed several houses. After four years there was a restoration of the beach and dune systems, as can be seen by comparing photographs taken at different times in Fig. 15.9. In May 2001, another storm struck the shore of Matinhos (Fig. 15.10), destroying sidewalks, much of the waterfront promenade, and some fishing families were displaced [48]. Figure 15.3 on p. 318 shows the situation at Matinhos in 2007, indicating that the problems of coastal erosion are still present.

Fig. 15.10 Effects of an episodic event in Matinhos (May, 2001). *Source* [48]

Fig. 15.11 Location of the base station and the extent of the shoreline mapping. *Source* Goncalves [18]



GNSS prediction of Matinhos' shoreline: In order to monitor or predict shoreline position of Matinhos, a combination of various data sources are required. In this example, use was made of aerial photographs and GNSS (GPS) surveys for the years 2001, 2002, 2005 and 2008, to compare short-term prediction models (*robust parameter estimation*, *neural network* and *linear regression*). GNSS data from a geodetic survey of the shoreline in Matinhos was collected using the kinematic relative positioning method (e.g., Sect. 5.4.2). The reference (base) receiver was

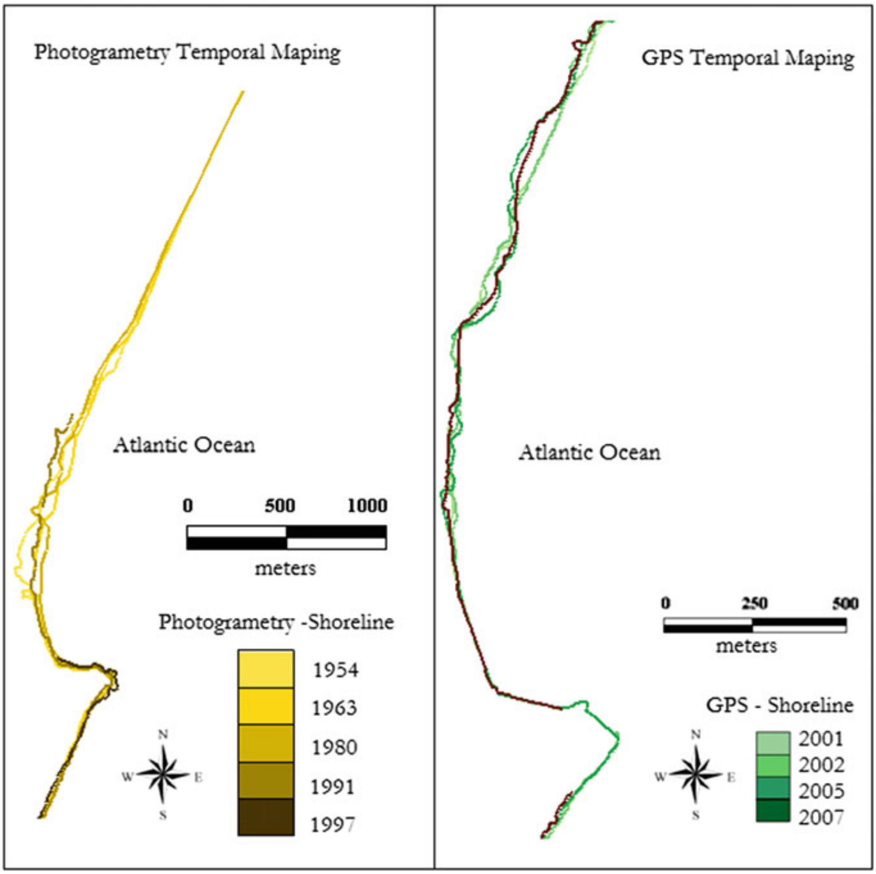


Fig. 15.12 Temporal resolution of the GPS mapping. *Source* Goncalves [18]

stationed at Pedra (25° 49’05”S, 48° 31’49” W) as shown in Fig. (15.4, left). The southern GNSS survey began near Londrina Street, while the northern survey began near the Street of the Orqudeas (see Fig. 15.11). For this survey, dual frequency (L1 and L2) GNSS receivers were employed for the years 2001, 2002, 2005 and 2008 (see Fig. 15.12, right). Figure 15.13 indicate the residual between the predicted shoreline for 2007 compared to the actual shoreline position measured using GNSS.

The result of this comparison showed residuals of less than 8 meters between the predicted values for the year 2007 and the measured values using GNSS. The deviation was within the desired accuracy for predictive models of short-term shorelines, thus indicating the capability of GNSS to provide input data for predictive models and also in validating the shoreline prediction models.

♣ End of Example 15.3.

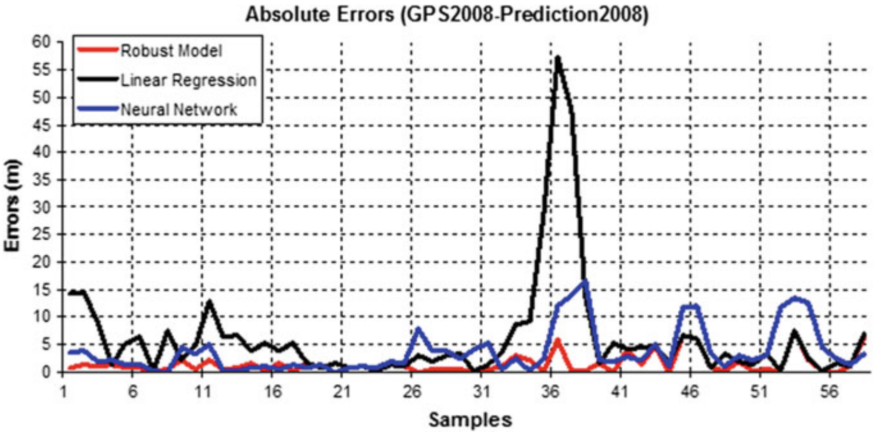


Fig. 15.13 Predicted shoreline using linear regression, neural network and robust estimation models. *Source* Goncalves [18]

15.4 Concluding Remarks

This chapter has presented the applications of GNSS techniques to monitor the advance or retreat of coastal areas as well as marine habitats. GNSS-based methods offers quicker, all-weather, highly accurate and continuously updatable shoreline positional time series relevant for monitoring and management tasks undertaken by engineers and coastal authorities. Their disadvantages, however, are that they are only limited to small monitoring regions such as the case of Brazil considered in Sect. 15.3. For the countries such as Australia with very long coastal lines, the application of GNSS-based approach faces challenges of being time consuming and may require high manpower thus increasing the costs. Also, depending on coastal characteristics, e.g., of escarpment and mangrove trees, data collection using GNSS could be impracticable. In such cases, other techniques such as LIDAR come in handy. However, considering the case of Brazil where the cost of undertaking a GNSS shoreline monitoring is cost effective, the approach presented in this contribution suffices.

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