NEW METHODS FOR POSITIONAL QUALITY ASSESSMENT AND CHANGE ANALYSIS OF SHORELINE FEATURES

DISSERTATION

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By

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ABSTRACT

In this dissertation, four positional quality measures for linear features presented by Ramirez (2000) were thoroughly investigated on shoreline features including Generalization Factor, Distortion Factor, Bias Factor, and Fuzziness Factor. The investigation addresses the uniqueness of each one of the four measures and the effect of random errors, systematic errors and blunders in the shoreline on the four measures. The results show that these four measures describe different characteristics of a shoreline.

Also a new shoreline change modeling method was developed in this study based on a new concept known as shoreline-segment orientation. This method helps to better analyze shoreline-change at the segment level by studying the angular deviation from the surrounding segments and also from the whole shoreline. Shoreline segment orientation is critical in shoreline erosion analysis because it considers the direction of the incoming waves towards the shoreline. The results of analyzing shoreline change in the study area based on this concept of segment orientation have been found to correlate to the recorded change in the period of study.
Using shoreline segment as a modeling unit, a new shoreline change forecast model was developed to analyze changes and furthermore to predict future shoreline positions. This model has the advantage of capturing the physical movement of a given shoreline segment through time by two indices. These indices represent the effects of scale-and-rotation and translation that have occurred to shoreline at a previous time causing the change. These indices are assumed to encapsulate the effects of the coastal erosion processes in the study area including shoreline shape, water-level change, shoreline geology or soil types, and erosion structures. The model uses the recorded change in the period of study to capture the pattern of shoreline-change at the segment level. Furthermore, the incorporation of shoreline positional quality information in the shoreline-change model has been addressed in this study.

The significance of the models developed in this research is demonstrated by the quality of the results obtained in the case study. Also this study showed the need for future research on the Bias factor for positional quality assessment, and further investigation to expand the linear quality metrics for assessing the positional quality of other types of linear features.
To my beloved parents,

Abdelgayoum Ali and Elshaffa Alboub
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CHAPTER 1
INTRODUCTION

1.1 Coastal processes and shoreline changes

Coastal zones are exposed to a series of processes that have a dynamic nature that usually causes changes on long and short time spans. Examples of these processes include coastal erosion, sediment transport, environmental pollution, and coastal development. The impacts of these coastal changes include loss of life and property, security of harbors, change of the coastal socio-economic environment, and decrease of coastal land resources.

The coastal erosion, as an example of coastal processes transports soil particles that are suspended in the water for some time causing sunlight blockage in the water column. Sunlight blockage in the water column results in water column with higher temperature. Coastal erosion also results in the loss of coastal property, which in turn affects coastal land use practices. As direct drawbacks of coastal erosion, water quality degradation and volatile soils affects the coastal ecosystems resulting in major changes in the coastal biomass.
Among the processes that cause shoreline erosion and hence result in shoreline change two factors are essential. These are the breaking waves in the near-shore zone and the near-shore currents. The breaking waves in the near-shore zone and the near-shore currents transport coastal sediments from one part of a shoreline to another part resulting in shoreline changes. This is part of a larger-scale process known as littoral transport, which moves coastal sediments by the action of waves and near-shore currents causing erosion, accretion or state of balance in a given part of a shoreline.

Shorelines could generally be categorized into beach and non-beach shorelines. The dominant geological material of most of recreational beach shorelines is sand, which is not necessary true in the case of non-beach shorelines. Also most of non-beach shorelines are built-up of geological materials other than sand such as rock, silt or clay. While it is obvious that sands are easier to move by the action of waves and near-shore currents than rocks, only the strength and the intensity of waves and near-shore currents acting on a specific area determine the ease and the time to fracture and thereafter transport rock materials. On the other hand, silts and clays are the geological materials that compose most of the non-beach shorelines.

Over short time periods erosion may take place in a part of a beach shoreline followed by an accretion of sand in the same part by means of coastal sediment transport processes resulting in an apparent situation of no-erosion. A reduction in the buildup of sediment in a part of a shoreline creates a deficit in that part resulting in increased shoreline erosion. However shoreline erosion takes place due to these
natural causes mentioned above, building erosion protection such as jetties, sea walls, groins etc could reduce it. On the other hand, this complex nature of the processes made shoreline erosion modeling a difficult job. Consequently most of the existing models of shoreline change are based on assumptions that make them only approximate models.

The analysis of shoreline change and erosion cause utilizes information about natural processes, such as shoreline deposits, shoreline material, and slope of coastal zone. Monitoring of shoreline change needs a long-term commitment and is based on the temporal change modeling using a GIS database. Objective decisions on shoreline change are usually made based on shoreline and erosion monitoring data that are usually acquired cumulatively over a long period of time (Ali and Li, 2000; Li et al., 2001a; Li et al., 2001b).

Among the commonly used shoreline change prediction models is the one-line model that has been used successfully in various studies to calculate shoreline changes (U.S. Army Corps. of Engineers, 1992; Li et al., 2001b). This model has been employed intensively over the years to compute the long-term shoreline change and have been extended to deal with the cross-shore sediment transport as well. This model is based on the assumption that the geometric shape of the shoreline does not change and that the change occurs only at right angles to the shoreline. This implies that the sediment transport is uniformly distributed over the moving portion of the shoreline profile.
The quantification and analysis of shoreline changes require not only the consideration of both spatial and temporal attributes, but also their integration into the GIS database. This is because GIS is an important digital mapping and analysis tool in coastal areas needed to store, retrieve, manipulate and analyze coastal data. However, most commercial GIS’s are fully capable of handling the unique coastal data. This deficiency narrows the utilization of GIS for coastal mapping purposes where the system’s dynamics need to be represented. Accordingly efficient methods are needed to handle the spatio-temporal data of coastal applications within a GIS environment.

1.2 Positional quality assessment

Quality of geo-spatial data is a fundamental issue in mapping and GIS. This is why there is an increased concern for positional quality in this field as the utilization of spatial data is expanding rapidly. In general, quality has always been defined as fitness for use, but in mapping and GIS field, it is defined specifically as the suitability for the specific mapping application. It is not hard to notice that quality is a relative measure rather than an absolute one. Therefore, most of the mapping standards shown below estimate the positional accuracy of a given mapping product with reference to another source of higher accuracy and use that to measure the quality of the product.

“Quality measurement can be envisioned as a mechanism that deals with quality at a quantitative level at which establishment of units of measurement is
needed. Ramirez (1988) has extended the concept of linguistic levels on maps so as to establish the structural basis of cartographic representation in order to identify the basic units of measurement of information on a map. This highest level of perception of cartographic information helped in identifying basic units of measurement of information on maps. This high-level cartographic representation method includes a collection of operations, a set of cartographic rules, and a formal writing mechanism” (Schmidley, 1996). Although this study does not focus on restructuring the cartographic information on mapping products in that framework, it is worthwhile to mention it since if implemented in the digital mapping environment, the processes of quality assessment will undergo a dramatic change.

The National Standard for Spatial Data Accuracy (NSSDA) implements a statistical and testing methodology for estimating the positional accuracy of points on maps and in digital geo-spatial data, with respect to geo-referenced ground positions of higher accuracy (FGDC, 1998). The standard ensures flexibility and inclusiveness by omitting accuracy metrics, or threshold values, that data must achieve. However, agencies are encouraged to establish “pass-fail” criteria for their product standards and applications and for contracting purposes. Ultimately, users must identify acceptable accuracies for their applications.

According to (FGDC, 1998) accuracy testing by an independent source of higher accuracy is the preferred test for positional accuracy. Horizontal accuracy should be tested by comparing the planimetric coordinates of well-defined points in the dataset with coordinates of the same points from an independent source of higher
accuracy. A minimum of 20 checkpoints shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. Also the National Map Accuracy Standards of 1947 (FGDC, 1998) states that “For maps on publication scale larger than 1:20,000, no more than 10 percent of the points tested shall be in error by no more than 1/3 inch, measured on the publication scale,” and, “These limits of accuracy shall apply in all cases to positions of well defined points only”. However, there is no standard procedure that describes how to identify these well defined points.

Shorelines are special class of linear features that are characterized by their dynamic nature due to the fact that they represent the interface between water and land. The dynamic nature of water and land results from dynamic processes that are in play in coastal areas such as water level change, littoral transport, shoreline erosion, breaking waves, near-shore currents and coastal development. This dynamic nature of shorelines makes the processes of mapping and representing them more difficult compared to other classes of linear features and as well introduces more uncertainties in the representations.

Because of all of the above, evaluating the quality of shoreline representation in a database is very important, not only to quantify the temporal change, but also to enable the maintenance of appropriate levels of quality in the production of digital shorelines for coastal applications. Hence, one of the goals of this research is to investigate the development of linear metrics for the evaluation of the quality of shoreline representation in digital mapping and GIS.
In the literature of positional quality assessment of linear features, not much work has been done to develop methodologies that are compatible with the field of automated or digital mapping and GIS. Tveite and Langaas (1999) have presented a method called the buffer-overlay-statistics method (BOS) that is based on comparing a line data set of unknown quality to another of known or significantly higher quality (Tveite and Langaas, 1999). The procedure starts by creating buffers with different widths around both of the line features, overlay the two buffers, and then create statistics, which is better visualized using charts. Another method proposed by Goodchild and Hunter (1997) uses the buffer-overlay concept, but it calculates statistics as a percentage of the length of the assessed line features within the buffer zones around the reference data set. This method is statistically based, and can be implemented through standard functions in vector or raster GIS (Goodchild and Hunter, 1997).

1.3 Research problems

In coastal regions changes take place over a variety of time spans due to the coastal processes that are both complicated and dynamic. Furthermore, the expanding data acquisition techniques make it easy to record data about coastal objects more frequently. Shorelines are the most essential coastal features as they depict the land-water interface with its unique characteristics and dynamics. Consequently, appropriate representations and frequent updates of shorelines are made available through Geographic Information Systems (GIS) models that store the position and the
attribute information. Two critical concerns arise in this case that include 1) the assessment of positional quality of shorelines and 2) the appropriate modeling of shoreline changes.

This research investigates the development of new metrics for evaluating the quality of shoreline representation and assessing the positional change of shoreline features. The study explores the nature of the temporal change of shorelines by studying the fundamental concept and the way the shoreline is affected by the positional quality. Modeling of shoreline changes on the other hand, helps to identify states and episodes of the coastal processes that cause the change. This is important as it provides means for forecasting future changes that are necessary in providing support to the coastal decision-making processes.

Shoreline changes can be categorized into two general types including temporal and non-temporal. Temporal shoreline changes are those take place with change of time. Non-temporal changes on the other hand are those detected in the geometry or the attributes of the shoreline without change in time. This type of changes takes place as a result of using different mapping methods or by applying different transformation procedures when representing the feature.

1.4 Introduction to the notion of change and temporality in GIS

Current Geographic Information Systems (GIS’s) store geometry and attribute information of features corresponding to the time of data acquisition. Also, mapping of spatial feature is the key to monitor changes in the feature’s geometry or attributes.
In this study, two types of changes are introduced including temporal and non-temporal changes.

GIS spatio-temporal applications have been researched intensively during the last ten years (Claramunt and Theriault, 1995; Pfoser and Tryfona, 1998; Erwig et al., 1999. However these research efforts were substantial, still an efficient spatio-temporal model to handle the dynamic geographic phenomena does not exist. This is because the problem is of two-folds; the definition of the appropriate metric along the time dimension and the identification of the proper time scale. More importantly, is the proper integration of these two folds of the problem in the spatial context.

Although no spatio-temporal data model so far exists in the GIS environment, there are some existing models that allow for some kind of space-time modeling. “However, it is easy to notice that all of these models use some form of discrete difference modeling approach that proceeds step-by-step, where each new step is the result of some GIS function applied to a new GIS layer but impacted by the output results and conditions resulting from the previous step” (DeMers, 2002). The analysis of spatial changes has also been one of the principal directions of the GIS research agenda over the past ten years (Peuquet, 1994). Several classifications of spatial changes have been proposed (Cheylan and Lardon, 1993; Claramunt et al., 1997; Frank, 1994), although temporal variables also need to be incorporated in current GIS’s to enable the representation of dynamic phenomena. The research on spatio-temporal GIS has always been envisioned in a framework that emphasizes only the
spatial component, a concept that suits static representation rather than dynamic representation of spatial phenomena (Peuquet, 2001).

Traditionally, spatio-temporal GIS issues have been addressed as a series of snapshots in the spatial domain. This inspired the idea of representing change in state as an episode and the sequence of episodes are recorded as episodes-list. However, this approach may help to analyze the dynamics of geographic phenomena, it lacks the capability to produce intermediate realizations for the phenomena at times no records are available. Therefore, this episodes-list approach is insufficient since the pattern of change of the geographic entity in the snapshot is hard to capture as changes do not necessarily take place on the whole or part of the geographic entity exactly at the same time.

The capability to analyze dynamic geographic processes is also influenced by the availability and quality of previous or historical data. The availability of previous data helps to create a more complete pattern of change and the quality of the data directly affects the quality of the results of the spatio-temporal analysis. Geographic representations of a entities in a GIS, whether in raster or vector format are normally produced from remote sensing or photogrammetric imagery and are temporally attributed with the corresponding acquisition time. Raster spatial data model represents geographic phenomena in matrix format with a basic unit known as cell or pixel. Vector spatial data model represents data as objects such as points, lines or polygons. Recently data about coastal objects are made available in raster and vector formats over large time spans including: water level data, sediment and nutrient data,
shoreline data and others, resulting in increased necessity for incorporating dynamic representations in GIS for a better understanding of the patterns of coastal change and the processes that cause it.

Some methods have been presented by the Coastal GIS community to model shoreline change including mathematical models such as higher-order polynomials (Li et al. 2001b) and algorithmic model for marine GIS (Gold, 2000). The two approaches, however, did not discuss the establishment of the correspondence between shoreline representations, and also the second method did not present a procedure to analyze shoreline changes. A traditional approach for modeling shoreline change and predicting future changes, divides shorelines into smaller segments and creates transects at right angles to a master shoreline. Shoreline changes along these transect are computed and further used to predict future shoreline change (Carter and Guy, 1983; Carter et al., 1986, Liu, 1998).

Liu (1998) and Li et al. (2001a) have presented another method for shoreline change modeling and analysis in GIS environment using the dynamic segmentation concept. This concept is originally based on ESRI’s Arc/Info dynamic segmentation data model for linear features in which any length of the shoreline could be attributed precisely unlike the traditional arc-node data model for linear features. The advantage of this model is that, it preserves the topological relationships between the shoreline and coastal features, which are essential for spatial analysis. Using this linear data model a shoreline is divided into variable segment lengths according to the locations where shoreline attributes change without breaking the actual line into pieces (Liu,
Moreover, Ali et al. (2001) have developed an erosion analysis method based on the conservation of soil mass principle to estimate the spatial distribution of coastal erosion in an Ohio Lake Erie coastal area. The method computes on a cell-by-cell basis the volume of soil loss due to shoreline erosion over time using a grid-based coastal terrain surface.

1.5 Research study area and data

Digital shoreline data are becoming more and more available from federal and state agencies. At the federal level, the National Oceanic and Atmospheric Administration (NOAA) is responsible for shoreline mapping with focus on safe navigation. The United States Geological Survey (USGS) is responsible for mapping shoreline for coastal erosion monitoring and other purposes. The US Army Corps of Engineers (USACE) is responsible for developing a National Shoreline Management Study according to the Water Resources Development Act of 1999. These federal agencies collect and process shoreline data and distribute the data in paper and digital formats, each focusing on its area of interest. For example, the USGS has produced shoreline data through its hydrographic data set, which is available in the Digital Line Graphs (DLG’s) format in scales ranging from small to large with different levels of accuracy. This data set was originally produced from aerial photography acquired in 1979. The largest-scale, 1:24,000 hydrographs correspond to the USGS 7.5 minute quadrangles.
At the state level, the Ohio Department of Natural Resources (ODNR) provides shoreline data focusing on coastal erosion. ODNR has determined shoreline recession rates using a 1:10,000 scale U.S. Lake Survey charts and 1:12,000 and 1:4,800-scale aerial photographs in the period from the 1930’s to 1990. Shoreline positions from these charts and photographs were transferred to 1:2,400-scale enlargements of aerial photographs taken in 1990. In addition, ODNR has released the Lake Erie Coastal Erosion Area Maps in late 1996, as part of the Ohio Coastal Management Program to show the location of shoreline recession lines for 1973 and 1990, respectively (Mackey, 1994; Liu, 1998). ODNR is required by law to identify coastal erosion areas along Ohio Lake Erie coasts and to enforce a permit system to manage the new construction and development in these designated areas.

The study area for this research has been selected along Lake Erie coast extending for fifteen kilometers from Sheldon Marsh Preserve to Vermillion East along the southern shore of Lake Erie (Figure 1.1). This specific study area has been chosen merely based on the availability of shoreline data and for the severe shoreline change recorded by the geology section of the Ohio Department of Natural Resources (ODNR). This study area is basically composed of easily eroded material including sand, till, or clay as illustrated in Figure 1.1 (ODNR, 1996).

There are a number of digital shorelines in this study area produced by the Mapping and GIS Lab of the Ohio State University (OSU) and federal and state mapping agencies. They include a 2001 shoreline produced from IKONOS 4-meter resolution multi-spectral imagery, a 2000 shoreline produced from IKONOS 1-meter resolution multi-spectral imagery, and others.
resolution panchromatic imagery, a 1979 USGS shoreline from the hydrographic layer, a NOAA shoreline from the T-sheet, and two 1997 shorelines (one produced from NOAA NGS aerial photography using a set of control points surveyed by OSU and the other generated through intersecting the water level obtained from the Lake Erie Forecasting System and a digital elevation model produced by the Mapping and GIS Lab (Li et al., 2002)). It is clear that the availability of these various shoreline data sets in digital format was one of the main reasons behind selecting this specific area as a study area given that there is severe shoreline change and coastal erosion recorded in the area.

Figure 1.1: The research study area
1.6 Organization of the dissertation

In this dissertation, a comprehensive presentation of the theory and practice of the positional quality assessment and shoreline change modeling methodology developed in this research-work is given. This dissertation is organized in six chapters. Chapter 1 introduces the purpose of the research, research background and literature review, philosophical concepts, data description and the case study. Chapter 2 provides a literature review, a detailed description of the development of the new metrics for evaluating the positional quality of shorelines, study of the independence of the quality metrics, and the automation of the quality metrics in GIS and digital mapping environment.

Chapter 3 presents a new methodology for shoreline and shoreline-change modeling. Chapter 4 presents the linear quality metric system development and the results of implementing the linear quality metrics on the case study data. Chapter 5 presents the results of employing the shoreline and shoreline-change modeling and analysis method developed in Chapter 3. Chapter 6 summarizes the research conclusions, illustrates the significance of the methods developed in the study and identifies the topics that need to be investigated in future research.
CHAPTER 2

ASSESSMENT OF THE POSITIONAL QUALITY OF

SHORELINES

2.1 Introduction

Spatial information is generally categorized into geometric, attribute, and topological information. The positional information of a spatial entity composes the geometric part, and the description of the characteristics of the spatial entity composes the attributes part of the spatial information. Topological information describes the relationships between the spatial entities. It is therefore important to notice that in order to control the quality of spatial information, the control of the quality of the geometric and attribute components of the spatial information is necessary.

The simultaneous increase of spatial data acquisition systems and digital mapping and Geographic Information Systems (GIS) has resulted in spectacular increase in the number of spatial information users. This is the reason for the increased demand of spatial data in digital format, which justifies the interest in the investigation and development of quality measures for in the digital context.
Points are the basis of most of the mapping processes as they represent the observed quantity in both the traditional and the new spatial data acquisition techniques. As point constitutes the fundamental object in spatial information, it has been adopted as the foundation for defining spatial quality in the U. S. National Mapping Accuracy Standards (NMAS, 1947). Moreover lines are used in the field of mapping and cartography to represent real world linear phenomenon such as shorelines, roads, railroads, pipelines, contours, transmission lines, boundaries, and rivers. The importance of lines as a fundamental representation in the field of mapping rely on the fact that most of the information on maps whether in paper or digital media is in the form of lines (McMaster and Shea, 1992). In this study, Ramirez (2000) linear quality measures were thoroughly investigated on shoreline features.

2.2 Quality of spatial data

The quality of a product generally refers to its value and worth. This definition completely matches that of Juran and Gryna (2001), which describes quality as customer satisfaction (Juran and Gryna, 2001) in which customer refers to the spatial data user. To ultimately understand this concept of quality in the mapping framework, the interaction between spatial data, spatial data user, and the application for which data is collected needs to be precisely recognized. For example if the quality of a product is poor, it will have less value than a product with better quality. Like any other product, spatial data has a quality that determines the degree of suitability for a
specific application. Furthermore, spatial data with poor quality portray the mapped environment in an incomplete or misleading way. Also the selection of a specific spatial data acquisition method usually depends on the application for which data is collected.

Research on quality has identified two components for customer satisfaction, which are quality of design and quality of conformance. Quality of design deals with the issue of a product having all the features desired by the customer. Quality of conformance deals with the issue of a product’s conforming to design specifications set or expected by the customer (Schmidley, 1996). Quality control according to Pyzdek (1989) is the science of discovering and controlling variation (Pyzdek, 1989). The purpose of quality control is to establish and maintain conformance of the product with design specifications and requirements. In agreement with Juran and Gryna (2001), the following universal sequence of steps needs to be accomplished in order to control the process quality: 1) Choosing the control subject, 2) Choosing a unit of measure, 3) Setting a goal for the control subject, 4) Creating a sensor which can measure the control subject in terms of the unit of measure, 5) Measuring the actual performance, 6) Interpreting the difference between actual performance and the goal and, 7) Taking action, if any on the difference (Juran and Gryna, 2001).

In order to establish an efficient control of the quality of digital spatial data, the integrated affect of all the processes involved in spatial data production should be considered. These processes include data acquisition, database development, and the extent to which spatial data may be utilized. The first two processes, spatial data
acquisition and spatial database development are both related to the data producer while the spatial data utilization involves spatial data user.

### 2.3 Spatial data quality standards

There are several standards for spatial data quality at the national, regional and international levels (FGDC, 1995; ASPRS, 1990; ISO, 1999). In view of that, components of the quality of spatial data are defined, which include positional accuracy, attribute accuracy, logical consistency, completeness, and lineage. Since the positional accuracy component is the most related components to this study, the other four components of the spatial data quality are introduced first and then the positional accuracy component is presented in more details in the next section. Attribute accuracy, the second component of quality of spatial data addresses the quality of the characteristics of spatial data and how well that matches reality. Logical consistency is defined as the fidelity of relationships described by the data structure. Completeness refers to mapping rules applied in equal way to all data and is sometimes referred to as exhaustiveness. It identifies gaps in the data progression and indicates whether missing values have been encountered. The lineage of a database includes reference to source materials, data collection procedures, and preprocessing including geometric transformations applied to the spatial data.

The definition of horizontal accuracy in the National Map Accuracy Standard (NMAS) states that "90 percent of all well defined features be located within 1/30 inch at map scale of their true position". The same standard states, “For maps on
publication scale larger than 1:20,000, no more that 10 percent of the points tested shall be in error by no more than 1/30 inch, measured on the publication scale,” and, “These limits of accuracy shall apply in all cases to positions of well defined points only” (NMAS, 1947). Unlike the NMAS, the ASPRS standards provide acceptable error tolerances for map of scales larger than 1:20,000 (ASPRS, 1990) given that using a minimum of 20 checkpoints of the data points shall be used. Although these accuracy standards provide a framework for evaluating the quality of the spatial data, data producers usually do not have the budget and the time required to collect a sufficient number of checkpoints to properly estimate the quality. The user in this case has no choice, but to make assumptions about the errors in the data source and the accumulation of errors during data conversion and processing. This sub-process of the positional accuracy estimation is known as the deductive estimate and is usually done based on the experience and the knowledge of errors in each data production step.

The Geo-spatial Positional Accuracy Standards Part 3, which is the National Standard for Spatial Data Accuracy (1998, only deals with point features as it implements a statistical testing methodology for estimating the positional accuracy of points on maps and in digital geo-spatial data (FGDC, 1998). According to the United States Spatial Data Transfer Standard (SDTS), accuracy testing by an independent source of higher accuracy is the preferred test for positional accuracy. It is suggested that horizontal accuracy shall be tested by comparing the planimetric coordinates of well-defined points in the dataset with coordinates of the same points from an
independent source of higher accuracy. A minimum of 20 checkpoints shall be tested, distributed uniformly to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95% confidence level 4 allows one point to fail the threshold given in product specifications (FGDC, 1998).

The International Standards Organization (ISO) has established two types of spatial quality evaluation methods, full inspection evaluation and sampling evaluation (ISO, 1999). These include inspection by an attribute, which is referred to as ISO 2859 and inspection by variables, which is referred to as ISO 3951 in the standards. In these methods, the data quality scope is divided into statistical homogeneous lots that are evaluated based on the source data of production, production system, and complexity and density of features. A lot is the smallest unit to which the result of quality evaluation is attached. If the lot does not pass inspection, all the items in the lot may be discarded or reproduced. In this sense, the definition of a lot is strongly related to the production process. The number of these units should be taken from the sequential sampling plans for inspection by attributes (ISO 8422) and the sequential sampling plans for inspection by variables (ISO 8423) in the standards.

The noticeably common thing among these spatial data quality standards, is they all pointed-out that the best testing method for the positional or geometric accuracy, is to compare the coordinate values of points in the data set with coordinate values of points from a source of higher accuracy that represents features on the ground.
2.4 Literature review

Quality assessment is the heart of the quality control process as it produces the values that are used to come up with estimates for the quality of spatial data and allows for a judgment to be made about spatial data using specific units of measurement. From this perspective, quality measurement could be envisioned in agreement with Juran and Gryna (2001) as a mechanism that reduces the characteristics of quality to a quantitative level at which a unit of measurement in terms of values can be established.

The Spatial Data Transfer Standard (SDTS) identifies four methods for assessing positional accuracy of a digital dataset. These include deductive estimate, internal evidence, comparison to source, and comparison to independent source of higher accuracy. Deductive estimate is the practical estimates of errors in the source of spatial data including the assumptions made about error propagation. Internal evidence refers to all possible statistics or adjustments that may be used on the spatial data. Comparison to the source means comparing the derived spatial data with the original source. Comparison to an independent source of higher accuracy is the preferred method for assessing positional accuracy of a digital dataset (USGS, 1999).

“One common goal among the researchers in the spatial data quality field is to develop models that are capable of assessing the values of error in spatial data by tracking errors as they propagate during spatial processes and document the quality information associated with outputs from every process” (Goodchild, 1989). Since one of the goals of this study is to develop means for measuring geometric or
positional quality of linear features in the digital environment, the following review is only focused on related work for vector spatial data.

A specific model to describe the spatial uncertainty around lines is the epsilon band model, which states that errors in digital lines fall within a distance epsilon from the position of the true line, given that a probability density function represents the likelihood of the band around the true line (Dunn et al., 1990). “Although the epsilon band model has been adopted by a number of researchers over the years (Blakemore, 1984; Dunn et al., 1990), other researchers have criticized the model as it provides no means for generating distorted realizations of the lines under study” (Goodchild, 1995)

Considering the fact that, most of vector spatial data available in digital format have been manually digitized and that spatial data is an abstraction of the real world, it is not easy to identify a true value in order to estimate the geometric accuracy of a given digital representation. Therefore values believed to be true are adopted instead, in order to assess the geometric quality of spatial data in the vector format. In spite of the existence of some errors in the digitization process, digitizing itself is a not a major source of positional error in the digitized representation.

Propagation of variances has been adopted to describe positional uncertainty in points manually digitized by assuming that; digitization errors follow a normal distribution (Ehlers and Shi, 1996). A similar model for describing positional uncertainty of point vector data assumes uncorrelated circular normal distribution around the line’s end nodes and vertices (Leung and Yan, 1998), however it does not
seem convincing to assume uncorrelated errors in the digitized line nodes and vertices. This agrees with Goodchild (1993) who believes digitization generates line’s nodes and vertices whose error is highly correlated and Openshaw (1989) who also believes lines are subjected to correlated error scenarios.

2.5 Geometric quality assessment of linear features

2.5.1 Motivation

Hydrographic linear features such as shorelines are represented as linear features in maps and geo-spatial databases. This means the positional or the geometric quality of their representations should not depend on the individual points, which are part of its representation, but on the interrelationships and precise portrait of all these points. In addition, the quality of the information attached to each feature and the quality of the interrelationships with other objects are factors that need to be considered in evaluating the quality of spatial objects such as shorelines.

Data collection of dynamic linear hydrographic features is difficult because it is done from static images showing the environment at a specific instant of time. Further, collection of linear features from these images is based on some type of generalization, because only “representative” points along the continuous linear feature are taken to describe and represent the feature. There is no guarantee that even the same operator will collect exactly the same “representative” points in two different data collection sessions or from two different images of the same area taken at different times. Because of these circumstances, generally, the portrait of a
hydrographic feature in a geospatial database is valid only for one particular slice of time and for one particular definition.

Representations of linear hydrographic features at different levels of detail are also common in Mapping and GIS. Cartographic generalization is used to generate more general linear hydrographic features from detailed representations. Cartographic generalization in agreement with Muller (1995) is “an interpretation process which leads to a higher level view of some phenomena looking at them ‘at small scale’.” Cartographic generalization is, therefore, still a human-intensive task, where subjective judgments are prevalent.

Therefore, means to evaluate the quality of linear features need to be investigated, such as shorelines covering steps 1 through 4 of the Juran and Gryna (2001) sequence of steps as mentioned earlier. This is because the available positional quality measures lack the ability to describe the spatial distribution of uncertainty over space. For example, a single Root Mean Square Error (RMSE) value does not capture uncertainty variation over space. Based on that, the objective of this part of the research is to investigate the positional quality measures of Ramirez (2000) as applied to shoreline features in order to enable the maintenance of appropriate levels of quality in the production of digital nautical charts and geo-spatial databases. The specific goal of this research is to investigate appropriate metrics for the evaluation of the positional quality of shoreline features and implement that as a new solution for the evaluation of positional quality of linear features in digital mapping environment.
2.5.2 Digital representation of linear features

In the Euclidean plane, explicit or implicit linear models are used to represent lines geometrically. In one explicit representation, $y$ is presented as a function of $x$ with the line’s slope and intercept as parameters. Problems occur with this type of representation for lines that are parallel to the $y$-axis, as numerical processors can not deal with division by zero. This is why explicit representation is preferred in such cases as both $x$ and $y$ are presented in a mixed linear model with two unknown parameters. These two linear representations substantiate the fact that, three geometric attributes can be used to describe a linear feature, which include the coordinates of the two end points, the length, and the slope of the linear feature as illustrated in Figure 2.1 below.

Figure 2.1: The attributes used to describe a linear feature
A framework exists in digital mapping and GIS that enables representing, storing and analyzing linear features digitally. A formal model in this context is known as the polygonal line representation that stores lines in the spatial database as a series of ordered (x, y) coordinates. As the polygonal line model provides an effective environment to explore and analyze linear phenomena, it has been implemented in several GIS’s including ESRI’s Arc/Info®. This data structure stores and references linear features in such a way that an ordered series of points, called vertices construct arcs whereas nodes define the two endpoints of an arc.

ESRI® (2003) has introduced a marine data model to the coastal and GIS community that provides a framework to deal with and integrate marine data. For example, an instantaneous point such as a gauge point is represented in the model by its location, elevation and time. Although the model enables the representation of dynamic points on the shoreline as instantaneous points, representing shorelines as dynamic manner still remains a challenge (ESRI, 2003).

### 2.5.3 Development of quality metrics for linear features

The basic idea behind the assessment of linear quality is to find a way of measuring the similarity between two line representations given that the two lines basically represent the same feature on the earth surface. A firm way of doing this is to introduce the concept of metric spaces in which the similarity between two representations makes sense since the lines to be compared are digitally represented in the geo-spatial database. A metric space in this framework is the set of line
representations together with a metric or metrics. To define a metric, let \( L \) be a non-empty set. A metric on \( L \) is an assignment of a distance \( d(x, y) \in \mathbb{R} \); the set of real numbers, to every pair of points \( x, y \) in \( L \), which is \( d: L \times L \in \mathbb{R} \), satisfying the following conditions:

i. **Positivity:** For all \( x, y \in L \), \( d(x, y) \geq 0 \), and \( d(x, y) = 0 \) implies that \( x = y \).

ii. **Symmetry:** For all \( x, y \in L \), \( d(x, y) = d(y, x) \), and

iii. **Triangle inequality:** For all \( x, y \in L \), \( d(x, y) \leq d(x, z) + d(z, y) \)

Based on the metric concept introduced above, Ramirez (2000) positional quality metrics for linear features were presented and thoroughly investigated as applied on shoreline features in this part of the research. These linear quality metrics include the generalization factor, the distortion factor, the bias factor, and the fuzziness factor. Note that all of the four quality metrics conform to this metric concept, not individually. Specifically, this part of the dissertation focuses on three issues including: 1) the study of the independence of four linear quality metrics, 2) The investigation of the four metrics as applied to shoreline features, 3) Investigating if these four metrics are enough to completely describe shoreline features. The first issue is important since without being independent, the metrics will not be efficient to measure the characteristics discussed above in section 2.5.2. The successful implementation of these metrics on shoreline features is essential since coastal databases can be populated with linear quality information using this methodology.
A. Generalization Factor

The generalization factor compares the length of two corresponding line segments, for example, the shoreline generated from a higher quality data source with the equivalent shoreline generated from lower quality data. One of them will be a more detailed representation of the shoreline. Therefore, if the higher quality line segment is considered to be the more detailed one and is stretched until it is transformed into a straight line, and the same is done for the one with lower quality, the result will be two lines with different lengths as shown in Figure 2.2 below.

A good example would be two representations of a shoreline that are extracted from different data sources such as LIDAR and LANDSAT. If these shorelines are stretched until they become straight, the result will be two lines of different lengths as depicted in Figure 2.2 below. The larger the difference in the length of the two lines, the greater the amount of generalization in the less precise representation as Figure 2.3 below shows. This relationship could be expressed as follows:

\[
GF = \frac{AB}{A'B'}
\]  

(2.1)

where \(AB\) is the length of the less precise shoreline (for example, LANDSAT), A’B’ is the length of the more precise shoreline (for example, LIDAR), and GF is the generalization factor. A value of 1 will indicate no generalization, and a value smaller than 1 will indicate the amount of generalization. For example, 0.7 will indicate a more generalized feature than 0.8.
**B. Distortion Factor**

Distortion factor is computed using standardized parameterization of the two shorelines under comparison. The two shorelines are standardized as vector-valued functions in the interval \([0,1]\) and then, comparable points are located on each standardized segment at the same interval. This method develops a set of line sub...
segments that are meaningfully comparable under the measure of closeness. Subsequently, comparable points are located on each standardized sub-segment given that the parameterization maintains the same interval for both lines. The geo-spatial locations of these comparable points are then evaluated and the average deviations of their $x$ and $y$ components are computed. Larger average deviation may indicate inconsistent generation and/or generalization procedures.

To establish correspondence between the two line representations, the standardized parameterization method was adopted to create comparable points on the two lines at the same interval following Schmidley (1996). This method of correspondence discovery is justified by the arc length concept, as the stored representations of linear features in a geo-spatial database are actually abstractions of the real world phenomenon, which most likely be curved rather than straight lines.

To introduce the concept of arc length, suppose that the curved line $f$, which is shown in Figure 2.4 below is continuously differentiable on the interval $[a, b]$. Let's derive a formula for the length $L$ of the curved line $f$ in the interval $[a, b]$ along $x$-axis. To do so, subdivide the interval $[a, b]$ into $n$ subintervals $[x_0, x_1], [x_1, x_2], \ldots, [x_{n-1}, x_n]$ where $a = x_0 < x_1 < \ldots < x_{n-1} < x_n = b$. Then, introduce the line segments between $(x_0, f(x_0))$ and $(x_1, f(x_1))$, $(x_1, f(x_1))$ and $(x_2, f(x_2))$, ..., $(x_{n-1}, f(x_{n-1}))$ and $(x_n, f(x_n))$. Notice that, this resulting polygonal path approximates the curve given by $y = f(x)$, and its length approximates the arc length of $f(x)$ over $[a,b]$. So adding up the lengths of these individual line segments approximates the whole length of the whole polygonal path.
Figure 2.4: A curved line f drawn in the interval [a, b] in the plane

Figure 2.5 below illustrates the concept of Distortion Factor. Two shoreline representations of different resolutions are shown (AB and A’B’). A’B’ has a higher resolution. Both representations are standardized as vector-valued functions on the interval [0,1] (their lengths are considered to be 1). Then, a set of individual points is generated in each standardized line. These individual points are taken 0.2 apart in this example. Six equivalent points are generated in each standardized line (including the end points). The Distortion factor (DF) is then estimated for the n corresponding point sets using the discrepancies between corresponding points on the two lines such that \( Df_i \) is the discrepancy between the \( i^{th} \) corresponding point set using the following formulas and as explained in Figure 2.5 below.
\[ \text{DF} = \frac{1}{n} \sum_{i=1}^{n} \text{DF}_i \quad \text{where;} \]

\[ \text{DF}_i = \sqrt{(\Delta F_{x_i})^2 + (\Delta F_{y_i})^2} \]
C. Bias Factor

The Bias Factor compares the relative location of a shoreline segment that is less precise to another similar shoreline segment that is more precise. When the two shorelines are superimposed upon each other, the number and lengths of sub-segments of the less precise shoreline that fall to the right of the more precise segment will be computed and compared to the number and lengths of the less precise shoreline sub-segments that fall to the left of the more precise segment. In an unbiased process an equivalent number of sub-segments and equivalent overall length should be expected to the right and to the left of the most precise shoreline segment. Figure 2.7 illustrates the concept of the Bias Factor. Two representations of the same shoreline segments are shown at the left of Figure 2.7. The blue one is the most precise shoreline representation. At the right of Figure 2.7 a small portion of the two shorelines is shown with the corresponding left or right segments.
These relations can be summarized as follows:

\[
\begin{align*}
\text{If } \sum d_{L_i} &= 0 \text{ and } \sum d_{R_i} = 0 & \text{Then No Bias} \\
\text{If } \sum d_{L_i} &= 0 \text{ and } \sum d_{R_i} \neq 0 & \text{Then Right Bias} \\
\text{If } \sum d_{L_i} \neq 0 \text{ and } \sum d_{R_i} = 0 & \text{Then Left Bias} \\
\text{If } \sum d_{L_i} \neq 0 \text{ and } \sum d_{R_i} \neq 0 & \text{Then Equal Left and Right Bias} \\
\text{If } \sum d_{L_i} &= \sum d_{R} & \text{Then Equal Left and Right Bias}
\end{align*}
\]

(2.4)

where \(d_{L_i}\) and \(d_{R_i}\) are the \(i^{th}\) parts of the shoreline with unknown or low positional quality to the left and right of the shoreline with known or higher positional quality respectively.
Figure 2.8 illustrates two possible situations; the first shows a less Bias situation while the second one shows a major bias in the generation of the less precise shoreline.

![Bias between two sets of shorelines](image)

**Figure 2.8: Bias between two sets of shorelines**

### D. Fuzziness Factor

Fuzziness is the factor related to the definition and identification of the end points (also known as nodes) of the two shoreline representations to be compared. This is true because for the purpose of this research a specific study area is defined, hence the shoreline in the study area has two end points. As indicated earlier, shorelines are dynamic entities in constant state of change and subject to the effect of natural forces. Therefore, whenever two shoreline representations of the same coastal area are extracted from different data sources, there is a high possibility that they may be different. As a result, these two line representations may have nodes with different
positions. The following method is presented to evaluate the discrepancy or the variation between the end points of the less precise line with respect to the end points of the most precise one.

![Diagram](image)

Node separation is $r_s$

Node separation is $r$

Figure 2.9: The Fuzziness Factor concept

Figure 2.9 above illustrates the concept of the Fuzziness Factor by representing the variability of the end points of the least precise shoreline segment shown in red color with respect to the more precise shoreline segment shown in blue by two circles. The radii of the circles shown in Figure 2.9 above are $r$ and $r_s$ respectively, which are the distances that separate the corresponding nodes of the two shorelines such that $r > r_s$. In order to compute the Fuzziness factor, the largest separation between the corresponding nodes; $r$ is used as a radius to draw a circle.
around the two corresponding nodes that are separated by the smallest distance $r_s$.

Then the Fuzziness factor is obtained by dividing the common area between the two circles by the area of the circle ($\pi r^2$) as expressed in Equation 2.5 below. A formula for the Fuzziness factor as a function of the distances of separation $r$ and $r_s$ is obtained as shown in Equations 2.6 below. Figure 2.10 below illustrates the geometry used to drive the formula of Equation 2.6.

![Figure 2.10: The geometry of the Fuzziness Factor](image)

Figure 2.10: The geometry of the Fuzziness Factor
The fuzziness factor is computed as the ratio of the common area (the area of overlap) of the two circles to the area of the corresponding circle.

\[
FF = \frac{\text{Common Area}}{\pi \cdot r^2} \quad (2.5)
\]

This relationship can be expressed as shown below in agreement with Figure 2.10 above:

\[
FF = \frac{2\theta}{\pi} - \frac{r_s}{\pi \cdot r^2} \cdot \sqrt{\left(r^2 - \frac{1}{4} \cdot r_s^2\right)} \quad (2.6)
\]

where \(r\) and \(r_s\) are the distances that separate the corresponding nodes of the two shorelines respectively such that \(r > r_s\), and \(\theta\) is the angle \(\sin^{-1}(r_s/2r)\).
Figure 2.11 below illustrates extremes cases for the Fuzziness Factor, are shown below:

\[ FF = 1 \text{ No Fuzziness} \]
\[ FF = 0 \text{ (worse case)} \]

2.5.4 Study of the independence of the four positional-quality measures

Independence in this context is defined as the characteristic of each one of the positional-quality measures being unique and independent of the others. To study the independence of these four measures of the quality of linear features including Generalization Factor, Distortion Factor, Bias Factor, and Fuzziness Factor, the geometric characteristics of shorelines that are measured by each one of these factors need to be examined. As introduced in section 2.5.2, the combination of the three geometric attributes: the coordinates of the end points, the length, and the slope are used to completely describe a linear feature. These three geometric attributes have
been used to analyze the independence of the four quality metrics as shown in Table 2.1 below. The table summarizes the combination of these geometric attributes that are measured by every one of the four factors.

<table>
<thead>
<tr>
<th>Positional quality factors</th>
<th>The geometric attributes of a linear feature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Endpoints coordinates</td>
</tr>
<tr>
<td>Generalization Factor</td>
<td>NO</td>
</tr>
<tr>
<td>Distortion Factor</td>
<td>YES</td>
</tr>
<tr>
<td>Bias Factor</td>
<td>YES</td>
</tr>
<tr>
<td>Fuzziness Factor</td>
<td>YES</td>
</tr>
</tbody>
</table>

Table 2.1: The four quality factors and the geometric attributes of lines they describe

From Table 2.1 above, the following remarks can be drawn:

1. Distortion, Bias, and Generalization Factors describe different combinations of the geometric attributes of linear features, they are therefore independent and

2. Fuzziness Factor measures only the endpoints coordinates attribute, which is also measured by the Distortion and the Bias factors.
On the contrary, it is evident that from (1) above, Distortion and Bias factors are independent. So the independence of Fuzziness and Distortion factors needs to be studied. To make sure that the Fuzziness and Distortion factors are independent, the following analysis for both of the factors was conducted considering the fact that Fuzziness factor measures the end points of the linear feature whereas the Distortion factor measures the deviation between corresponding points along both of the lines. Figure 2.12 below shows some two cases to help us understand the difference between these two factors. At end A the two line sets in Figure 2.12 have the same amount of deviation $d$ between the endpoints of the two lines shown in read and blue. At end B deviation between the lines is 0. In this case only the deviation at end A will govern the Fuzziness factor value. However, the distortion factor will base on the deviation between all of the vertices in the two lines including the end nodes. Therefore the same Fuzziness factor values are obtained in the two cases however the Distortion factor values are different.

![Figure 2.12: Fuzziness and Distortion Factors independence](image)
2.6 Summary

In this chapter, the issue of quality of a product was presented and discussed in general and in more details the definition of the quality of spatial data was presented. Also, a robust definition of spatial data quality that integrates measures for the spatial characteristics of the data based on its conformance to the producer’s specifications and user’s fitness for use was outlined. Furthermore, spatial data quality standards at the national, regional, and international levels have been reviewed and analyzed as relevant to this study. It has been found that, all of spatial data standards presented herein have established a testing framework for the assessment of positional quality of geo-spatial datasets, but only with reference to points in the dataset. In particular, these standards have established no means for testing the positional quality of linear feature, but the standards encourage spatial data producers to establish their own testing procedures.

In the review of the related work a specific model was found that describes the spatial uncertainty around line features known as the epsilon band model (Dunn et al., 1990). In spite of the popularity of this model, it has been criticized by Goodchild (1995) as it provides no means for producing distorted realizations of the modeled line. Also two different models based on the principle of propagation of variances have been adopted to estimate the positional uncertainty in the digitizing process (Ehlers and Shi, 1996; and Leung and Yan, 1998). The model of Leung and Yan (1998) assumes uncorrelated errors in the nodes and vertices of a digitized line, which explicitly disagrees with Goodchild (1993) and Openshaw (1989).
Two approaches for the assessment of positional quality of linear features found in the literature are of particular relevance to this study (Goodchild and Hunter, 1997; Tveite and Langaas, 1999). The two approaches use the buffer overlay concept and they are both of statistical nature. The statistical nature of these approaches minimizes their ability to describe the distribution of linear geometric quality more rigorously. This is because statistical measures lack the ability to describe the distribution of spatial uncertainty over space, a crucial attribute that should be maintained by any efficient quality measure. Therefore more robust means to evaluate the quality of linear features in the digital mapping environment are needed.

New metrics proposed by Ramirez (2000) for the assessment of the geometric quality of linear features have been investigated in this study for shoreline features including Generalization Factor, Distortion Factor, Bias Factor, and Fuzziness Factor. The results show that these four factors describe different characteristics of a linear feature and that they complement each other. Based on that a Linear Quality Metric System (LQMS) for shoreline features was developed and tested as presented in Chapter 4.

It is worthwhile to mention that these quality metrics could also be used as alternatives to the existing methods that assess the quality of geo-spatial surfaces for example Digital Elevation Models (DEM’s), where the quality evaluation is usually done for representative profiles along the surface. Two methods are in common use for this purpose. One is qualitative, in which the surface is visually inspected and the other is quantitative, which uses Fourier analysis to generate Modular Transfer
Functions (MTF’s) for representative profiles along the surface to be evaluated and the surface with higher quality. The latter approach compares the amplitudes of the corresponding frequencies along these representative profiles on the two surfaces.
CHAPTER 3
SHORELINE-CHANGE ANALYSIS

3.1 Introduction

Coastal changes are very important environmental indicators as they directly impact the coastal economic development and land management, that's why coastal terrain and shoreline changes are attracting more focus (Welch et al., 1992; Stokkom et al., 1993). For this reason shorelines are considered crucial terrain features; for example the International Geographic Data Committee (IGDC) has recognized them as one of the 27 most important geographic features on the earth’s surface (Li et al., 2002). Also, shoreline positional and attribute information are important to a large group of data users of the coastal community (Lockwood, 1997).

Shorelines are the linear representations that depict the water and land interface. In general, two shoreline definitions exist including abstract and exact definitions. At the abstract level, a shoreline known as tide coordinated shoreline exists, which is referenced to a stable vertical frame such as a tide gauge datum. The tide coordinated shoreline is the shoreline estimated through the intersection of the land surface and an average water surface over the last 19.2 lunar years. Tide-
coordinated shorelines are established by the National Oceanic and Atmospheric Administration (NOAA) and are used by coastal authorities. An exact shoreline on the other hand is the instantaneous shoreline, which represents the intersection between instantaneous water surface and land at a specific time. For example, all shoreline representations that exist on images are instantaneous shorelines. The locations of the instantaneous shorelines for a specific area over a period of time are commonly used to study shoreline change in that area, for example for coastal planning and decision making purposes. In this study, the locations of instantaneous shorelines over a period of 28 years in the study area are used to analyze and model shoreline changes and further to predict future changes.

Proper shoreline change modeling requires not only a thorough understanding of coastal processes that cause the change, but also the mapping methods that can be used to collect and predict shorelines. Shoreline change modeling is a multidisciplinary problem. From a hydrodynamic perspective, a shoreline results from the action of the breaking waves and the near-shore currents that cause coastal erosion. Coastal erosion is function of wave energy, shoreline material, coastal topography, and the direction of the approaching waves with respect to the shoreline. The breaking waves and currents in the near-shore zone are responsible for the transport of shoreline sediments that results in shoreline change. This scenario is part of a process called littoral transport, which moves the eroded material in the coastal zone by means of waves and currents. From this perspective, several models are available to model shoreline change, which are presented later in this chapter.
On the other hand, the mapping community focuses on some specific issues, which are closely related to shoreline changes, such as mapping methods used to acquire shoreline data, models used to represent shorelines in digital format, shoreline change modeling method etc. By knowing the data acquisition method, the inherent errors that normally exist in the underlying measurement or observation processes can be identified or modeled. Also by knowing the models that are used to represent shorelines in the GIS database, the level of abstraction of the real world inherited in these models will be recognized, which directly affect the final results of shoreline change modeling.

There is no single method for shoreline modeling yet exists that has been widely accepted by the coastal community, although in the last ten years we have witnessed a great advancement in mapping technology that have benefited among others, the coastal community. This includes the development of new and precise Global Positioning Systems (GPS’s), deployment of high-resolution satellites such as IKONOS, and development of Light Detection And Ranging (LIDAR) devices for measuring coastal topography.

3.2 Review of shoreline change analysis methods

3.2.1 A hydrodynamic perspective

Although the near-shore processes are of a complex nature and most of the existing shoreline prediction models are based on a lot of assumptions that make them only fairly accurate models, people still employ them but do so with careful
interpretation of predictive results. This is because a model that describes the nearshore waves, circulation, and shoreline evolution with sufficient accuracy needs to consider spatio-temporal variation. Among the common shoreline prediction models are the one-line models that have been used successfully in various studies to calculate alongshore sediment transport rates and long-term shoreline changes (U.S. Army Corps of Engineers, 1992). These models are based on the assumption that the geometric shape of the shoreline doesn’t change and that the displacement occurs only at right angles to the shore. This implies that the sediment transport is uniformly distributed over the moving portion of the shoreline profile. The conservation of sediment mass can be written as follows as illustrated in Figure 3.1 below (U.S. Army Corps of Engineers, 1992):

\[
\frac{\Delta x}{\Delta t} + \frac{1}{D_B + D_C} \cdot (\frac{\Delta Q_l}{\Delta y} \pm q) = 0
\]

(3.1)

where \(Q_l\) is the alongshore sediment transport rate, \(\Delta x\) is the shoreline-change in the cross shore direction, \(\Delta y\) is the shoreline segment length, \(D_C\) is the offshore closure depth, \(D_B\) is the berm crest elevation, \(q\) is a line source such as rivers and coastal bluffs or sink that might be caused by sand mining, and \(t\) is time. Therefore the incremental volume of sediment in the shoreline segment \(\Delta y\) is simply \((D_B + D_C) \Delta x \Delta y\) (U.S. Army Corps of Engineers, 1992).
It is clear that the above shoreline prediction model is a function of the alongshore sediment transport rate, which needs to be calculated first before being able to estimate shoreline change. This requires the determination of the breaking wave angle relative to the shoreline and then utilizes a wave model, which is computationally intensive. After all there are no means for neither modeling nor controlling the quality of the predicted shoreline change.

Another model proposed by Hitoshi and Suzuki (1982) derives a separate conservation Equation for each fraction of the sediment in the shoreline so as to
simulate the temporal variation of the gain-size change along the shoreline. This model represents a modified version of a conservation Equation to predict the grain-size sorting in the alongshore direction for shoreline advance and shoreline recession. This shoreline change model is based on the mass of sediment as follows (Hitoshi and Suzuki, 1982):

$$\frac{\partial x}{\partial t} + \frac{1}{D} \frac{\partial Q_y}{\partial y} = 0$$  \hspace{1cm} (3.2)

where \( x \) is the magnitude of shoreline change, \( t \) the time, \( Q_y \) the alongshore sediment transport rate, \( D \) the depth of the sediment transportation zone and \( y \) the coordinate along the shoreline. Figure 3.1 above illustrates the conservation of mass principle in this case with two exceptions from the previous case that is demonstrated in Equation 3.1 above. The first exception is that the line source \( q \) is not considered. The second exception is that, the offshore closure depth and berm crest elevations are both replaced with the depth of the sediment transportation zone.

These shoreline change models require the knowledge of the magnitude and direction of the energy flux due to waves breaking along the study area in order to estimate or predict shoreline change. This includes the estimation of several input variables that necessitate carrying out extensive field studies, which are both expensive and time-consuming. Furthermore these procedures have low prediction
capability, as the input variables are themselves random scattered events in the time and space frame.

3.2.2 A mapping perspective

Several methods have been used to model shoreline change using mathematical models such as higher-order polynomials (Li et al. 2001a), however the establishment of correspondence between the available shoreline representations is still an active research issue. A traditional mapping approach for modeling shoreline change and predicting future changes segments shorelines into smaller units by creating transects at right angles on a shoreline, which is chosen to be the master shoreline from a set of shorelines (Figure 3.2). Shoreline changes along these transects are computed and further used to predict future shoreline changes (Carter and Guy, 1983; Carter et al., 1986).

This method has been adopted over the years to establish the correspondence between shoreline models acquired at different times so as to predict shoreline change in paper or digital formats (Fenster et al., 1993). Figure 3.2 below shows the transecting approach as has been implemented at the Geological section of the Ohio Department of Natural Resources (ODNR) to assess shoreline change rates in the time period from 1973 to 1990 for study area along the southern coast of Lake Erie in Ohio from Sandusky to Vermilion in the east (ODNR, 1996).
Rates of change in shoreline positions are then employed to summarize historical shoreline movements and to predict future shoreline positions based on the perceived historical trends. The method most commonly used, especially by coastal land planners and managers, to predict future shoreline changes is extrapolation of a constant rate-of-change value (Owens, 1985). The popularity of this method is due particularly to its simplicity. As with any empirical technique, no knowledge of or theory regarding the sand transport system is required. An assumption which is implicit in this procedure is that the observed historical rate-of-change is the best estimate available for predicting the future. For the purpose of predicting future
shoreline positions for the study area, simple methods or models have been used, such as the End-Point Rate (EPR) method, with which future shoreline positions for a given time could be estimated using the resulting slope and Y-intercept (Liu, 1998; Galgano and Douglas, 2000):

\[
\text{Shoreline Position} = \text{Rate} \times \text{Date} + \text{Intercept}
\]  

(3.3)

This Equation shows that the EPR model employs a line extracted from the earliest end-point and latest end-point. If Y is used to denote shoreline position, X for date, B for the intercept, and m for rate of shoreline movement, this Equation can be simplified as:

\[
Y = m X + B
\]

(3.4)

This linear prediction model does not provide any means of incorporating positional quality information of shorelines. Also, Galgano and Douglas (2000) have found that, this model provides unreliable results for time periods less than eighty years based on a dataset for some U.S East Coast shorelines.

This shoreline change mapping approach makes use of the successive shoreline data available over time, which provides the ability to assess future shoreline changes by reviewing spatio-temporal changes of the shoreline. It is worthwhile to mention that obtaining the change of the shoreline position from successive aerial photos could be used to estimate values for the along-shore sediment
transport rate by substituting the value of the change in the shoreline model. Computing the aerial recession and multiplying that by a representative depth of the sediment transport zone could do this.

Based on the fact that objects within the coastal zone change dynamically as the shoreline itself changes, Liu (1998) and Li et al. (2001a) have presented another method for shoreline change modeling and analysis using the dynamic segmentation concept. This concept is originally based on Esri’s Arc/Info dynamic segmentation data model for linear features in which any length of the shoreline could be attributed precisely unlike the traditional arc-node data model for linear features. The advantage of this model is that, it preserves the topological relationships between the shoreline and coastal features, which are essential for spatial analysis. Using this linear data model, the shoreline is divided into variable segment lengths according to the locations where shoreline attributes change without breaking the actual line into pieces (Liu, 1998; Li et al., 2001).

Ali et al. (2001) have developed a method based on the conservation of soil mass principle to estimate the spatial distribution of coastal erosion in an Ohio Lake Erie coastal area. The method computes on a cell-by-cell basis the volume of soil loss due to shoreline erosion over time using a grided coastal terrain surface.

In summary, a review of the methods that are in use to model shoreline change from different perspectives is presented, but to this end a critical question left to be answered. Do shoreline representations that correspond to different data acquisition times and stored in a GIS database incorporate the effects of the physical
factors that are addressed in hydrodynamic shoreline-change models? Actually, it is not difficult to notice that, these representations encapsulate implicitly the cumulative effects of the underlying coastal processes responsible for shoreline change. This is true since when a shoreline is mapped, its representation illustrates what the mapping sensor has captured during the data acquisition process. Therefore the impact of all physical factors considered in a typical hydrodynamic model on the shoreline change model such as wave flux, wind speed and direction, coastal soil type etc. are all captured in the mapped shoreline positions, which are then stored in a geo-spatial database. Figure 3.3 below illustrates this fact graphically assuming that the shoreline data are updated frequently.

Figure 3.3: A profile across a synthetic shoreline illustrates the coastal processes
3.3 Methodology

In this section, new methods for shoreline-shape modeling and shoreline-change analysis are presented. Shoreline-shape modeling is crucial for understanding the connection between the shoreline change and shoreline curvature. Shoreline-change analysis on the other hand, enables for the better understanding of the pattern of change throughout the period of recorded change. This is important since shoreline curvature is one of the factors that result in increase or decrease of coastal erosion (Murray and Ashton, 2002). Particularly, the development of such a model helps to study the relationship between shoreline curvature and shoreline erosion. Conceptually when waves approach the shoreline from a given direction, they refract based on the curvature of the segment of the shoreline they break on.

The basic modeling component in the two models is the shoreline segment, which results from applying the standard parameterization method that has been introduced in Chapter 2. A shoreline segment is defined as a finite length of the shoreline that is fully identified by its endpoints. The comparable points created on the shoreline models by the mentioned method restructure the shoreline to new sets of corresponding segments, which belong to the spatio-temporal shoreline representations. This strategy therefore enables to determine the appropriate segment length that suits the shoreline set under study based on the shoreline shape.

The shoreline-shape modeling approach that is presented later in this section computes the direction of the normal to every segment in the shorelines resulted from the implementation of the standard parameterization method mentioned earlier and
stores the direction to the normal as attributes (see Figure 3.4). This helps to efficiently understand shoreline shape locally and globally, which is important for identifying segment orientation with respect to the overall direction of the approaching waves. This is critical since the angle with which waves approaches the shoreline is closely related to shoreline orientation. The following paragraphs present the shoreline-shape modeling approach and the shoreline-change method developed in this study. The methods presented in this chapter are based on following fundamental assumptions:

1) The geometric representation of a shoreline at an epoch with or without its positional quality information, encapsulates the effect of the erosion forces that have acted on the shoreline at all previous times.

2) Correspondence between shoreline segments that belong to shorelines acquired at different times is established by the standard parameterization method introduced in Chapter 2.

3) The relation among available shoreline models can be represented in a two-dimensional space.

4) A shoreline segment at time $k = 1$ can be transformed to its corresponding shoreline segment at time $k = 2$ only by the action of erosion forces, which results in the change in the geometric representation of the two segments.
3.3.1 Shoreline-shape modeling

The shoreline-shape modeling approach that is presented in this section computes the normal to every corresponding segment resulting from the implementation of the standard parameterization method mentioned earlier and stores that in GIS as associated attributes. These attributes are used to identify shoreline sections that are most likely to undergo erosion. This is important since the orientation of the shoreline segment with respect to the direction of the approaching waves results in either erosion or accretion at variable rates. This is based on the fact that, concave shoreline segments deviate approaching waves causing coastal erosion while convex shoreline segments absorb wave energy causing accretion (Murray and Ashton, 2002). To better understand this concept, refer to Figure 3.5 below, which illustrates the curvature of a synthetic shoreline with respect to the direction of the approaching waves.
In this new method, two orientations for a given shoreline segment are defined, local and global. Local segment orientation is defined with respect to the immediate neighbor to the right of the segment given that the segments are ordered from left to right as depicted in Figure 3.6 below. By doing so, the curvature of the shoreline is defined locally at every point except the two nodes. Global orientation of a shoreline segment, on the other hand is defined for every segment with respect to a line drawn between the shoreline end nodes. Global orientation is important in defining the overall shoreline orientation with respect to the direction of the approaching waves while local orientation helps to identify the critical angle with which waves approach every point on the shoreline (See Figure 3.6).
This shoreline shape modeling approach computes the direction of the normal of every segment in the shoreline from the global and local references as shown in Figure 3.6 above. The computation of the direction of the normal to every segment of a shoreline is preferred over computing the direction of the segment itself to avoid computation complexity that may arise when dealing with vertical segments.
The segment $S_{mk}$ is the segment number $m$ in the shoreline at time $k$. Accordingly, in Figure 3.6 above the segment $S_{mk}$ is the segment number 3, hence the segment can be written as $S_{3k}$. If the shoreline at time $k$ consists of $M$ segments, the variable $m$ varies in the range $[1, M]$. Also assuming that the shoreline is composed of $N$ points, therefore the relationship between the numbers of segments $M$ and the number of points $N$ is as follows.

$$M = N + 1$$

(3.5)

The direction of the normal to shoreline segments $S_{mk}$ from the $x$-axis is defined by the angle $\beta_{mk}$ as shown in Figure 3.7 and written in Equation 3.6 below. The direction of the normal was chosen to be written in terms of the cosine simply because a consistent normalized scale can be established for the values of the cosine in the interval $[1, -1]$, which corresponds to the angles $[0^\circ, 180^\circ]$. This normalized scale is necessary to obtain a relative measure of the shoreline curvature, which will help to store the values of the direction of the normal to the segment $S_{mk}$ in a GIS in an efficient way.

With reference to Figure 3.7 below, the direction of the normal to shoreline segments $S_{mk}$ ($\beta_{mk}$) can be written as follows:

$$\beta_{mk} = \cos^{-1}\left[\frac{\Delta y}{\|S_{mk}\|}\right]$$

(3.6)
The normal $\mathbf{N}_{mk}$: The direction of the normal $\mathbf{N}_{mk}$ to shoreline segment $S_{mk}$.

Using the formula of Equation 3.6 above, the changes in direction among shoreline segments are obtained in terms of the direction of the normal to shoreline segment $\beta_{mk}$. The value of the angle change $\Delta\beta$ defines three types of local shoreline orientations. These are convex, concave and straight local shoreline orientations as shown in Figure 3.8. These three types of local shoreline orientations, which are presented below take place at the common point between any consecutive shoreline segments.
Using Equation 3.7 above, the local shoreline orientation of the shoreline can be obtained robustly and further stored in a GIS.

\[
\Delta \beta = (\beta_{mk} - \beta_{(m+1)k}) = \begin{cases} 
> 0 & \text{Convex, } \Delta \beta \text{ is in the range } 1^\circ \text{ to } 179^\circ \\
< 0 & \text{Concave, } \Delta \beta \text{ is in the range } -1^\circ \text{ to } -179^\circ \\
= 0 & \text{Straight}
\end{cases}
\] (3.7)

Figure 3.8: The three types of shoreline local orientation
Similarly, the change in direction of the normal to the segment $S_{mk}$ to that of the line connects the shoreline-nodes is obtained as change in the angles $\beta_{mk}$ and $\beta_{shoreline}$ respectively, which defines the global shoreline orientation introducing also three types of global shoreline orientation including convex, concave and straight as shown in Figure 3.8 above.

$$\Delta \beta_{global} = (\beta_{mk} - \beta_{shoreline}) = \begin{cases} 
> 0 & \text{Convex, } \Delta \beta \text{ is in the range } 1^\circ \text{ to } 179^\circ \\
< 0 & \text{Concave, } \Delta \beta \text{ is in the range } -1^\circ \text{ to } -179^\circ \\
= 0 & \text{Straight}
\end{cases}$$ (3.8)

### 3.3.2 A comprehensive model for shoreline-change analysis

According to Platt (1998), the factors that increase or decrease coastal erosion includes shoreline shape, change of water levels, shoreline geology or soil types, and the effects of human activities such as building coastal structures to protect property. Based on Carter and Guy (1983) and Liu (1998), shoreline geology influences shoreline erosion as easily eroded materials do not carry wave force. This is an important issue to be taken into consideration as the study area is generally composed of till with a combination of either sand or clay, which are easily eroded materials. In this section, a new model for shoreline change is presented where the modeling unit is the shoreline segment. The basic idea of this approach is to study the relationship between shoreline segments that belong to shorelines acquired at different times through a mathematical model that geometrically describes the relationship between them.
The development of the shoreline-analysis model presented below is crucial for several reasons. First, existing shoreline-change analysis methods establish the association between points on the historical shorelines by means of transecting shorelines by defining a master shoreline. These transects are drawn at right angles to the master shoreline and across the rest of the shorelines establishing the correspondence between shorelines by the intersections. The problem with this method is the possibility of creating multi-corrrespondent for a single point on the master shoreline when the other shorelines are of complex shape. Second, these existing methods establish the correspondence between shorelines through points, although shoreline erosion occurs on shoreline surface that is the interface between land and water. The new method establishes the correspondence between shoreline based on shoreline-segment, which closely suits the nature of a shoreline as interface between land and water.

The association between the corresponding segments on shorelines acquired at times k and (k-1) respectively is established in this study by the following mathematical model as illustrated in Figure 3.9 below:

\[
S_{m,k} = C_{m,k,(k-1)} \cdot S_{m,(k-1)} + \Delta_{m,k,(k-1)}, \text{ such that } \quad (3.9)
\]

\[
C_{m,k,(k-1)} = R_{m,k,(k-1)} \cdot L_{m,k,(k-1)} \quad (3.10)
\]

where \( S_{m,k} \) and \( S_{m,(k-1)} \) are the segments m on the shorelines of time k and (k-1) respectively. The coefficients \( C_{m,k,(k-1)} \) and \( \Delta_{m,k,(k-1)} \) are assumed to be functions of the following erosion factors: shoreline shape, water-level change, shoreline geology.
or soil types, and erosion structure. The coefficients $\Delta_{m,k,(k-1)}$ and $C_{m,k,(k-1)}$ represent the translation and the combined effect of rotation and scale on the shoreline segment $S_{m,k,(k-1)}$ respectively. The coefficient $R_{m,k,(k-1)}$ represents the rotation and $L_{m,k,(k-1)}$ is the scale factor that are applied by erosion factors on the segment $S_{m,(k-1)}$ resulting in the segment $S_{m,k}$. This mathematical model can be envisioned as a similarity transformation that transforms the shoreline segment $S_{m,(k-1)}$ at time $(k-1)$ to the segment $S_{m,k}$ at time $k$ by the action of the erosion factors mentioned above. The change in the segment shape between consecutive times is assumed to be represented by the coefficient $C_{m,k,(k-1)}$ whereas coefficient $\Delta_{m,k,(k-1)}$ represents the translation being applied to the segment between the times $(k-1)$ and $k$.

Figure 3.9: The concept of the shoreline-change model of Equation 3.9
Every shoreline segment on shoreline at time k is represented in a vector format in terms of the two endpoints. Based on that, the segment m in shoreline at time k is defined by the two endpoints \((x_{(n-1),k}, y_{(n-1),k})\) and \((x_{n,k}, y_{n,k})\), such that the shoreline has N points. Re-writing Equation 3.9 above in vector format in terms of the coordinates of the two endpoints of segment \(S_{m,k}\) to produce the following Equation as shown in Figure 3.10 below.

\[
\begin{bmatrix}
  x_{(n-1),k}, y_{(n-1),k} \\
  x_{n,k}, y_{n,k}
\end{bmatrix} = C_{m,k,(k-1)} \cdot \begin{bmatrix}
  x_{(n-1),(k-1)}, y_{(n-1),(k-1)} \\
  x_{n,(k-1)}, y_{n,(k-1)}
\end{bmatrix} + \begin{bmatrix}
  \Delta x_{(n-1),k,(k-1)}, \Delta y_{(n-1),k,(k-1)} \\
  \Delta x_{n,k,(k-1)}, \Delta y_{n,k,(k-1)}
\end{bmatrix}
\] (3.11)

Figure 3.10: The corresponding segments \(S_{m,k}\) and \(S_{m,(k-1)}\) on the shorelines at times k and (k-1) respectively in terms of the endpoints
To simplify Equation 3.11 above, assume that the relationship between the segment 4 on the shorelines at times $t = 3$ and $t = 2$ needs to be analyzed. According to Equation 3.9, the relationship could be written in the following form

$$S_{4,3} = C_{4,3,2} \cdot S_{4,2} + \Delta_{4,3,2}$$

and according to Equation 3.11 the relation is:

$$\begin{bmatrix} x_{4,3}, y_{4,3} \\ x_{5,3}, y_{5,3} \end{bmatrix} = C_{4,3,2} \cdot \begin{bmatrix} x_{4,2}, y_{4,2} \\ x_{5,2}, y_{5,2} \end{bmatrix} + \begin{bmatrix} \Delta x_{4,3,2}, \Delta y_{4,3,2} \\ \Delta x_{5,3,2}, \Delta y_{5,3,2} \end{bmatrix}$$

(3.12)

which is read as the segment number 4 that connects points number 4 and 5 on the shoreline of time 3, relates to the segment number 4, which connects the numbers 4 and 5 on the shoreline of time 2 by Equation 3.12. Note that the model coefficient $\Delta_{m,k,(k-1)}$ has the vector form shown below.

$$\Delta_{m,k,(k-1)} = \begin{bmatrix} \Delta x_{(n-1),k,(k-1)}, \Delta y_{(n-1),k,(k-1)} \\ \Delta x_{n,k,(k-1)}, \Delta y_{n,k,(k-1)} \end{bmatrix}$$

(3.13)

In this model, the coefficient $\Delta_{m,k,(k-1)}$ is basically a translation vector of either additive or subtractive nature based on the value of the scalar coefficient $C_{m,k,(k-1)}$. Moreover, the coefficient $C_{m,k,(k-1)}$ is a function of the scale-factor and the rotation on the segments of the shoreline at the preceding time resulting in the segments of the shoreline at following time as depicted in Equation 3.10.
3.3.2.1 Forecasting future shoreline positions

To forecast the position of a future shoreline based on the available shoreline data using the model of Equation 3.9, a shoreline segment of order \( m \) at time \( k = K \), where \( k \) is in \([1, K]\) can be rewritten as below:

\[
S_{m,2} = C_{m,2,1} \cdot S_{m,1} + \Delta_{m,2,1} \\
S_{m,3} = C_{m,3,2} \cdot S_{m,2} + \Delta_{m,3,2} \\
S_{m,4} = C_{m,4,3} \cdot S_{m,3} + \Delta_{m,4,3} \\
\vdots \\
S_{m,(K-1)} = C_{m,(K-1),(K-2)} \cdot S_{m,(K-2)} + \Delta_{m,(K-1),(K-2)} \\
S_{m,K} = C_{m,K,(K-1)} \cdot S_{m,(K-1)} + \Delta_{m,K,(K-1)}
\]

(3.14)

In the model of Equation 3.14 above, the forecasted shoreline segment at time \( K \), can be written in terms of any of the segments at preceding times given that the two coefficients \( \Delta_{m,K,(K-1)} \) and \( C_{m,K,(K-1)} \) are estimated based on the whole shoreline dataset as described below. This means, the shoreline segment at time \( K \) can be written in terms of any one of the preceding time shoreline segments going backwards in time from \( k = K \) down to \( k = 1 \). For example segment \( S_{m,K} \) can be written in terms of the segment at the initial time \( S_{m,1} \) as Equation 3.15 below shows.

\[
S_{m,K} = C_{m,K(K-1)} \cdot S_{m,(K-1)} + C_{m,K(K-2)} \cdot S_{m,(K-2)} + \Delta_{m,K(K-1)} + \Delta_{m,K(K-2)} + \cdots
\]

(3.15)
To get the values of the model parameters and then obtain the position of the future shoreline that corresponds to the time \( k = K \), \( C_{m,k,(k-1)} \) for the whole dataset is modeled against the time in terms of its corresponding scale-factor \( L_{m,k,(k-1)} \) and rotation \( R_{m,k,(k-1)} \). Likewise, \( \Delta_{m,k,(k-1)} \) is modeled for the whole dataset against time. This means, the best fit for the whole data set for \( (L_{m,k,(k-1)}, R_{m,k,(k-1)}, k) \) and \( (\Delta_{m,k,(k-1)}, k) \) will be obtained and further used to obtain the values of \( C_{m,K,(K-1)} \) and \( \Delta_{m,K,(K-1)} \). Equation 3.9 can then be used to obtain segment \( S_{m,K} \) in terms of any of the corresponding segments at previous times as has presented in Equations 3.14 and 3.15 above.

Note that, the model of Equation 3.9 allows not only to analyze shoreline-change for the available shoreline, but also to forecast future shoreline positions as has been shown above. The model uses geometric information about the shoreline’s segment shape-change and segment nodes-translations to capture the spatio-temporal change through a modeling unit represented by the shoreline segment. In the next section, the incorporation of positional quality in the model of Equation 3.9 is explained.

3.3.2.2 Incorporation of shoreline positional quality information

The linear quality metrics that were presented in Chapter 2 provide known values for the positional quality of shorelines, which are best characterized as true errors. For example, the values of the Distortion factor basically provide estimates of the deviations \( \Delta x \) and \( \Delta y \) along \( x \) and \( y \)-axes between any set of comparable points on
the shorelines. Based on Mikhail and Ackermann (1976), these metrics can be treated using a principle known as the propagation of true errors, assuming that the values are not associated with random variables. Hence, Equation 3.9 can be rewritten as follows assuming that the positional quality metrics of segment $S_{m,(k-1)}$ is $\delta_{m,(k-1)}$.

$$S_{mk} + \delta_{mk} = C_{mk(k-1)} \cdot (S_{m(k-1)} + \delta_{m(k-1)}) + \Delta_{mk(k-1)}$$  \hspace{1cm} (3.16)

### 3.4 Summary

In this chapter, the concept of shoreline-change from both hydrodynamic and mapping perspectives was introduced. Also, the fact that shoreline representations that are stored in a GIS database reflect the inseparable cumulative effects of the underlying coastal processes responsible for shoreline change. Considering this fact, it is believed that geometric modeling of shoreline-change considers the effects of the physical factors that are part of a typical hydrodynamic shoreline-change model.

A new shoreline-shape modeling method was introduced based on a new concept known as shoreline segment orientation including global and local orientations. Shoreline-segment orientation with respect to the direction of the incoming waves is critical erosion factor as it results in increase or decrease shoreline erosion. Global shoreline-segment orientation is important since it helps to locate the relative direction of the incoming waves towards the shoreline. The local shoreline orientation on the other hand helps to obtain the relative curvature of shoreline segments. Both orientations are estimated as the difference of the direction of the
normal to the shoreline-segment to avoid computation complexity in case of vertical segments.

Using the shoreline segment as a modeling unit, a new shoreline-change model was developed to analyze changes and further to forecast future shorelines. The parameters of this shoreline-change model are assumed to encapsulate the effects of the factors that accelerate the erosion processes in the coastal area including shoreline shape, shoreline geology or soil types and erosion structures. This model allows not only to analyze shoreline-change for the available shoreline, but also to forecast future shoreline positions. This shoreline-change model uses geometric information about the shoreline shape-change and translations to capture the spatio-temporal pattern of change. To forecast future shoreline positions, the model coefficients are used in a curve-fitting process.
CHAPTER 4

IMPLEMENTATION OF THE POSITIONAL QUALITY METRICS

4.1 Development of a system for positional quality of shorelines

A quality metric system is developed to implement the four quality measures for linear features that were presented in Chapter 2. These metrics include generalization factor, distortion factor, bias factor, and fuzziness factor. Based on the theory presented in Chapter 2, algorithms were developed and coded to compute these four metrics in Esri® Arc Macro Language (AML). The linear quality metric system components are shown in Figure 4.1 and the systems’ interface is shown in Figure 4.2. The algorithms are described below:
Quality Metric System

Base Shoreline

New Shoreline

Spatial Database

Generalization

Fuzziness

Distortion

Bias

System Interface

Figure 4.1: The components of the linear quality metric system

Figure 4.2: The interface of the linear quality metric system
Generalization Factor algorithm:

a. Compute the length of the two shorelines AB and A’B’, and

b. Compute the Generalization Factor by dividing the length of the base shoreline AB by the length of the new shoreline A’B’.

Distortion Factor algorithm:

a. Decide the number of the points (n) to be created on the two shorelines, which will be used to establish the correspondence between them.

b. Compute the distances $d_1$ and $d_2$ that will be used to create the new points on the shorelines with higher and lower accuracy respectively by dividing their lengths by $(n + 1)$.

c. Create (n) new points on the two shorelines using the distances $d_1$ and $d_2$ computed above.

d. Compute the distances between corresponding points on the two shorelines. The average distance is then used as a measure of distortion following Schmidley (1996).

Bias Factor algorithm:

a. Compute the geometric intersection between the two shorelines,

b. Identify the total length of the new shoreline on both sides of the base shoreline, and

c. Calculate Bias Factor by dividing the total length of new shoreline to the right of the base shoreline to that on the left of it.
**Fuzziness Factor algorithm:**

a. Obtain the distances between the end-nodes of the two shoreline,

b. Use the largest of the two distances to create circular buffer around the four nodes of the two shorelines, and

c. Calculate the Fuzziness factor by dividing the larger area of intersection between the four buffers by the area of the buffer around one of the nodes of the base shoreline.

**4.2 Testing the four linear quality metrics**

The goal of this procedure is to make the necessary computations to study the validity of results when using the metrics that were presented in Chapter 2. This has been done in the presence of all types of errors in the original shoreline including random errors, systematic errors, and blunders. Randomization was obtained in this experiment by generating six simulated shoreline models from a given shoreline by introducing specific magnitudes of random error. Blunders and systematic errors have also been introduced in the original shoreline model for the same purpose. Below are procedures performed in this study. The original shoreline used in this experiment extends from Sandusky to Vermilion along the southern shore of the Lake Erie. It has been extracted from the 1:24,000 USGS DLG-Hydrographic layer. The next sections illustrate these experiments.
4.2.1 Generating random shorelines

Using stochastic simulation, random shoreline realizations of the true shoreline have been produced in this study. Six normally distributed random shoreline realizations with a zero mean and a RMSE with the levels ±10, ±20, ±23, ±29, ±40 and ±100 meters have been generated from the original shoreline so as to be tested against the original shoreline through running the quality metrics system developed in this study. For example, Rand_20 shoreline in Table 4.1 represents generated with a standard variation of 20 meter. These random shoreline realizations can be thought of as manifestations of shoreline uncertainty that might have occurred at the acquisition or processing stages. The method of uncertainty simulation used here to generate these realizations is called “Monte Carlo technique” (Kalos and Whitlock, 1986), a method that has been adopted frequently by researchers to evaluate uncertainty in spatial and non-spatial data.

Monte Carlo simulation is an empirical process that involves an iterative process of running a model a number of times using perturbed data inputs that are created by random numbers drawn from a probability distribution chosen to represent the effect of data uncertainty. The procedure presented here involves drawing random numbers from a normal distribution that assumes to be characterized by an error model that represents reasonable estimates of the level of uncertainty introduced in the shoreline. In this study, six different levels of uncertainty were introduced to the original shoreline to produce six random shoreline models. That is, six different sets of random numbers, each with a different range of values, were applied to the original
shoreline. The produced random shoreline models are shown below in Figure 4.3 overlaid by the original shoreline.

![Image of Figure 4.3: The original and the six random shoreline models](image)

**Figure 4.3**: The original and the six random shoreline models

### 4.2.2 Testing shorelines with random errors against the original

The produced random shoreline models were then tested against the original shoreline to obtain their spatial quality relative to the original shoreline using the four quality metrics. Table 4.1 below shows the values of the different quality metrics obtained for the six shoreline simulated models. Please note that FF refers to the Fuzziness Factor, GF refers to the Generalization Factor, SF refers to the Similarity.
Factor, BF refers to the Bias Factor, and OVF refers to the Overall quality Factor. The OVF is calculated by assuming equal weights from the GF, BF, and DF.

<table>
<thead>
<tr>
<th>Shoreline Models</th>
<th>ID</th>
<th>FF</th>
<th>GF</th>
<th>BF</th>
<th>DF</th>
<th>OVF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rand_10</td>
<td>1</td>
<td>0.368</td>
<td>1.019</td>
<td>0.365</td>
<td>0.095</td>
<td>0.498</td>
</tr>
<tr>
<td>Rand_20</td>
<td>2</td>
<td>0.222</td>
<td>1.101</td>
<td>1.033</td>
<td>0.069</td>
<td>0.727</td>
</tr>
<tr>
<td>Rand_23</td>
<td>3</td>
<td>0.119</td>
<td>1.121</td>
<td>0.975</td>
<td>0.050</td>
<td>0.708</td>
</tr>
<tr>
<td>Rand_29</td>
<td>4</td>
<td>0.029</td>
<td>1.304</td>
<td>1.377</td>
<td>0.014</td>
<td>0.889</td>
</tr>
<tr>
<td>Rand_40</td>
<td>5</td>
<td>0.220</td>
<td>1.597</td>
<td>0.834</td>
<td>0.466</td>
<td>0.956</td>
</tr>
<tr>
<td>Rand_100</td>
<td>6</td>
<td>0.525</td>
<td>3.012</td>
<td>0.762</td>
<td>0.152</td>
<td>1.296</td>
</tr>
</tbody>
</table>

Table 4.1: The values of the quality metrics for shorelines with random errors

To analyze the sensitivity of the quality metrics on this case study, the values of the FF, GF, BF, DF, and OVF factors were plotted against the different shoreline models as shown in Figures 4.4, 4.5, 4.6, 4.7 and 4.8 respectively. In Figure 4.4, Fuzziness factor values decrease with the increase in the magnitude of the random errors till it reach a random error of ±29 meter and then increase with the increase in the magnitude of random error. Since this Factor measure the separation between the end nodes of the two shorelines under study, the randomness with a global trend is demonstrated. In Figure 4.5, the variation of the values of the Generalization Factor
with the random shorelines is logical since increasing the random errors means adding more length to the shoreline under experiment. Therefore, this factor is very sensitive in capturing random errors. In Figures 4.6 and 4.7, the pattern of change of the Bias and the Distortion Factors with increase in random errors is unclear. This is expected as these Factors are estimated using the total length of the experiment shoreline to the right and left of the original shoreline, and the point-to-point distance between the shorelines, which in both cases difficult to follow a specific pattern, as the process is random. In Figure 4.8, the values of the OVF Factor, which are estimated with equal weight from the BF, GF and DF, increase with the increase in the random errors showing enormous sensitivity to random errors in the shoreline. Therefore, either the Generalization Factor or the Overall Quality Factor can be used to quantify random errors in the shoreline for which positional quality is to be estimated; however the OVF is more sensitive than the GF as the later shows relatively small increase in values.
Figure 4.4: The Fuzziness Factor values for the random shorelines

Figure 4.5: The Generalization Factor values for the random shorelines
Figure 4.6: The Bias Factor values for the random shorelines

Figure 4.7: The Distortion Factor values for the random shorelines
4.2.3 Testing shorelines with blunders against the original

Introducing some measurement mistakes in a point of the original shoreline at a time is the procedure adopted to launch blunders in the original shoreline model in this experiment. Blunders of 50-, 100- and 250-meters have been introduced into the x- and y- coordinates of the point (365056.6568, 4587245.389), which has the 19th order in the original shoreline point-series. The three blundered shoreline models were then tested against the original shoreline to obtain their linear quality relative to the original shoreline using the metrics. Table 4.2 below shows the values of the different quality metric factors obtained for the two blundered shoreline models.
Table 4.2: The linear quality metrics in the case of shorelines with blunders

To study the sensitivity of the linear quality metrics in the case of shorelines with blunders, the values of the GF, BF, DF, and OVF factors have been plotted against the three shoreline with blunders as shown in Figures 4.9, 4.10, 4.11 and 4.12 below. The values of FF were not plotted, as they stayed constant.

<table>
<thead>
<tr>
<th>Shoreline model</th>
<th>ID</th>
<th>FF</th>
<th>GF</th>
<th>BF</th>
<th>DF</th>
<th>OVF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blundered-shore1</td>
<td>1</td>
<td>1.000</td>
<td>1.012</td>
<td>0.899</td>
<td>0.998</td>
<td>0.960</td>
</tr>
<tr>
<td>Blundered-shore2</td>
<td>2</td>
<td>1.000</td>
<td>1.142</td>
<td>0.801</td>
<td>0.832</td>
<td>0.916</td>
</tr>
<tr>
<td>Blundered-shore3</td>
<td>3</td>
<td>1.000</td>
<td>1.303</td>
<td>0.700</td>
<td>0.745</td>
<td>0.907</td>
</tr>
</tbody>
</table>

Figure 4.9: The Generalization Factor values for the shorelines with blunders
Figure 4.10: The Bias Factor values for the shorelines with blunders

Figure 4.11: The Distortion Factor values for the shorelines with blunders
In Figure 4.9, it is normal to see the Generalization Factor values increase with increasing the magnitude of the blunders introduced in the shoreline since the blunders add more length to the shoreline. As blunders increase, both of the Bias and the Distortion Factors decrease as depicted in Figures 4.10 and 4.11 above. The Bias and the Distortion Factors follow the same pattern of change of the Overall Quality Factor in Figure 4.12. So in the case of blunders, it is sensible to use any of the BF, DF or the OVF to capture blunders rather than using the GF, which gives an opposite response in this case.
4.2.4 Testing shorelines with systematic errors against the original

Systematic errors have also been introduced in the original shoreline model by launching an error of ±10 and ±25 meters into the x- and y- coordinates of all of the original shoreline points. Accordingly four shorelines have been generated from the original one with four systematic error levels.

The four shoreline models generated from the original one by introducing systematic error of ±10 and ±25 meters respectively were then tested against the original shoreline to obtain their quality relative to the original shoreline using the four metrics. Table 4.3 below shows the values of the different quality metric factors obtained by running the metrics algorithms on these shoreline models.

<table>
<thead>
<tr>
<th>Shoreline model</th>
<th>ID</th>
<th>FF</th>
<th>GF</th>
<th>BF</th>
<th>DF</th>
<th>OVF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic_minus10</td>
<td>1</td>
<td>0.296</td>
<td>1</td>
<td>0.136</td>
<td>0.161</td>
<td>0.42801</td>
</tr>
<tr>
<td>Systematic_plus10</td>
<td>2</td>
<td>0.602</td>
<td>1</td>
<td>0.276</td>
<td>0.161</td>
<td>0.47421</td>
</tr>
<tr>
<td>Systematic_minus25</td>
<td>3</td>
<td>0.401</td>
<td>1</td>
<td>0.288</td>
<td>0.098</td>
<td>0.45738</td>
</tr>
<tr>
<td>Systematic_plus25</td>
<td>4</td>
<td>0.733</td>
<td>1</td>
<td>0.504</td>
<td>0.098</td>
<td>0.52866</td>
</tr>
</tbody>
</table>

Table 4.3: The values of the metrics for the shorelines with systematic errors
To study the sensitivity of the quality metrics in this case, the two shorelines with systematic errors were tested against the original shoreline to obtain values for the metrics FF, GF, BF, DF, and OVF. Figures 4.13, 4.14, 4.15 and 4.16 below depict the variation of the values of the quality metrics FF, BF, DF and OVF plotted for the shorelines with systematic errors. The values of GF have not been plotted, as they do not change.

![Figure 4.13: The Fuzziness Factor values for the shorelines with systematic errors](image-url)

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Figure 4.14: The Bias Factor values for the shorelines with systematic errors

Figure 4.15: The Distortion Factor values for the shorelines with systematic errors
As Figures 4.13, 4.14, 4.15 and 4.16 illustrate, all of the quality factors plotted here show the same response to systematic errors. The only exception is the Generalization Factor for which the values have not been plotted, as they stayed unchanged.

4.3 Experiments on the actual shorelines of the study area

Following Li et al (2002), the estimated accuracy of the shorelines used in this study ranges from 2 to 12 meters as shown in Table 4.4 below including the shorelines NOAA T-Sheet, IKONOS 1-m, IKONOS 4-m, ODNR 73, ODNR 90, Aerial Orthophoto, and digital shoreline obtained by the intersecting Coastal Terrain Model (CTM) and Water Surface Model (WSM). Detailed information about these
shorelines could be found in section 3.3. Note that the accuracies of the shorelines obtained from the NOAA T-Sheet, USGS DLG (1:24000), and ODNR (1:12,000) have been estimated based on a 0.5 mm on the map as the error source.

<table>
<thead>
<tr>
<th>Shoreline model</th>
<th>ID</th>
<th>Estimated accuracy (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAA T-Sheet</td>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>USGS DLG</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Intersection method</td>
<td>3</td>
<td>2.0</td>
</tr>
<tr>
<td>Aerial Orthophoto</td>
<td>4</td>
<td>2.6</td>
</tr>
<tr>
<td>IKONOS 1-m</td>
<td>5</td>
<td>2 - 4</td>
</tr>
<tr>
<td>IKONOS 4-m</td>
<td>6</td>
<td>8.5</td>
</tr>
<tr>
<td>ODNR 73</td>
<td>7</td>
<td>6.0</td>
</tr>
<tr>
<td>ODNR 90</td>
<td>8</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Table 4.4: The estimated accuracy of the study shorelines

4.3.1 Testing the shorelines in the study area

Five experiments were conducted with the linear quality metric system using IKONOS 1-m shoreline as the shoreline with the higher positional quality (2-meteres) against the ODNR 90, ODNR 73, IKONOS 4-m, Coastal Terrain Model (CTM) and Water Surface Model (WSM) intersection, and the USGS DLG shorelines assuming that all of them are of unknown positional quality. The results of the experiments are presented in Table 4.5 below, and the analysis and the discussion of the results is in the following section.
<table>
<thead>
<tr>
<th>Shoreline model</th>
<th>ID</th>
<th>DF</th>
<th>GF</th>
<th>BF</th>
<th>FF</th>
<th>Overall linear quality metric (Assuming equal weights)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODNR 90</td>
<td>1</td>
<td>0.88</td>
<td>0.873</td>
<td>0.78</td>
<td>0.84</td>
<td>0.82</td>
</tr>
<tr>
<td>ODNR 73</td>
<td>2</td>
<td>0.83</td>
<td>0.888</td>
<td>0.65</td>
<td>0.71</td>
<td>0.74</td>
</tr>
<tr>
<td>IKONOS 4-m</td>
<td>3</td>
<td>0.73</td>
<td>0.930</td>
<td>0.89</td>
<td>0.95</td>
<td>0.90</td>
</tr>
<tr>
<td>CTM/WSM</td>
<td>4</td>
<td>0.94</td>
<td>1.04</td>
<td>0.83</td>
<td>0.98</td>
<td>0.94</td>
</tr>
<tr>
<td>USGS</td>
<td>5</td>
<td>0.62</td>
<td>0.898</td>
<td>0.70</td>
<td>0.89</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Table 4.5: Values of the linear quality metrics for the experiment shorelines

Figures 4.17, 4.18, 4.19, 4.20 and 4.21 below depict the values of the quality metrics DF, GF, BF, FF and OVF plotted for the study shorelines including ODNR 90, ODNR 73, IKONOS 4-m, CTM/WSM and USGS.
Figure 4.17: The Distortion Factor values for the study shorelines

Figure 4.18: The Generalization Factor values for the study shorelines
Figure 4.19: The Bias Factor values for the study shorelines

Figure 4.20: The Fuzziness Factor values for the study shorelines
4.3.2 Analysis and discussion

The quality metrics developed in this study are mainly used to estimate the positional quality of a shoreline feature with respect to another one with higher or known positional quality given that they should both represent the shoreline at about the same time. However it is not the case here. The purpose of this experiment is to test the metrics on real world data, although these shoreline models are representations of the real shoreline at different times. The value of the Distortion Factor obtained for the five shorelines in this experiment show that, the CTM/WSM shoreline has the least distortion and that the USGS shoreline has the maximum. The Generalization Factor values show that IKONOS 4-m and CTM/WSM shorelines are...
the ones with approximately the same detail as the IKONOS 1-m. Furthermore, the Bias Factor values demonstrate the fact that both of IKONOS 4-m and CTM/WSM shorelines fluctuate around the IKONOS 1-m shoreline to left and right to about the same. Moreover, the end nodes of these two shorelines have moderate separation from those of IKONOS 1-m shoreline according to the Fuzziness factor values. This is why these two shorelines have the best overall positional quality, which has been obtained assuming equal weight of the four measures. These values of the quality measures are roughly consistent with the estimated accuracy obtained independently as shown in Table 4.4; however the value obtained for the IKONOS 4-m deviates from that shown on that Table. The overall positional quality values estimated for the ODNR 90, ODNR 73, and USGS shorelines are approximately about the same.

In this experiment it was assumed that the five-shoreline models, which were tested against the IKONOS 1-m shoreline, are of unknown positional quality to be estimated using the linear quality metrics. The results obtained (Table 4.5) do not exactly match the estimated accuracies of these shorelines (Table 4.4). But the general trend illustrates the fact that the shorelines acquired at times close to that of the original shoreline have higher quality indicators because in this case the erosion magnitudes are greater than the shoreline acquisition errors.
CHAPTER 5
RESULTS OF SHORELINE-CHANGE ANALYSIS

5.1 Techniques for shoreline mapping

For shoreline mapping, analytical photogrammetry has always been the primary acquisition method for its reasonable cost and high accuracy; however for shoreline change monitoring the mapping frequency has been an issue. With the advances in data acquisition techniques such as digital photogrammetry sensors, Global Positioning Systems (GPS), and other all-weather sensors, coastal researchers have been exploring the potential of more efficient and economic shoreline mapping methods (Li et al., 2001b). For example coastal mapping professionals have used land vehicle based mobile mapping technology in local shoreline mapping utilizing GPS receivers and a beach vehicle to trace watermarks along the shorelines (Shaw and Allen, 1995; Li, 1997).

A source for shorelines mapping was single photographs, which are processed through a method known in photogrammetry as the single photo resection in which stereo matching is not performed. This is the method used by Ohio Department of Natural Resources (ODNR) to extract 1973 and 1990 shorelines. Also GPS has been applied to provide precise control and orientation
information to enhance aerial photogrammetric triangulation, the process of estimating the object space from the aerial photography (Lapine, 1991; Merchant, 1994; Bossler, 1996). Using GPS in the research study area, a network of ground control was established and further used to control the stereo-matched photographs.

Shorelines are then extracted from these stereo-matched and georeferenced aerial photographs either manually or automatically. The manual extraction of shoreline features is a process that involves the digitization of the borderline between water and land, which is referred to as the instantaneous shoreline as it represents the shoreline at the time of photography. The automatic shoreline extraction process involves the classification of the gray values in the processed photo to separate the water and land to obtain the border between these two classes, which is the shoreline.

Recently, satellite-imaging systems have increasingly improved image resolution including the new generation of high-resolution satellite IKONOS (one-meter) with the capability of stereo imaging (Fritz, 1996; Li, 1998). Since the in-track stereo mode is provided, stereo pairs that are necessary for deriving elevation information of objects can be formed in quasi real time; the cross-track stereo requires additional time allowing the satellite to revisit the same area from a neighboring track. An investigation of shoreline mapping using such high-resolution satellite images demonstrated a promising shoreline mapping accuracy of 2 m and a great reduction of required ground control points (Zhou and Li,
Shorelines are obtained by subtracting the Water Surface Model (WSM) from the Coastal Terrain Model (CTM) where the grid points with zero differential value represent the shoreline. However a number of technical issues need to be addressed before the quality of the digital shoreline can be obtained, this method produced results to an accuracy of 2.0-meters.

Li et al. (2002) have improved Rational Functions (RF) model of IKONOS 1-m for a better ground accuracy and employed it to extract 3-D shoreline for the research study area. Rational Function (RF) model is basically a ratio of two polynomials introduced to approximate the IKONOS 1-meter rigid imaging geometry by transforming image space to object space. This study demonstrates that a shoreline derived from IKONOS satellite imagery can reach a ground accuracy of about 2-4 meters.

5.2 Experiments on the shorelines of the study area

The shorelines used in these experiments include IKONOS 4-m, IKONOS 1-m, the digital shoreline obtained by intersecting the Digital Elevation Model (DEM) and Water Surface Model (WSM), ODNR 90, USGS DLG, and ODNR 73. More information about these shoreline models is available in section 3.3. Table 5.1 below summarizes the temporal and uncertainty information for these shorelines. Figure 5.1 below describes the distribution of the geological material
or soil types in the study area including sand, till and clay that are all easily eroded materials.

<table>
<thead>
<tr>
<th>Shoreline model</th>
<th>Time of mapping (k)</th>
<th>Estimated accuracy (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODNR 73</td>
<td>1973</td>
<td>6.0</td>
</tr>
<tr>
<td>USGS DLG</td>
<td>1979</td>
<td>12</td>
</tr>
<tr>
<td>ODNR 90</td>
<td>1990</td>
<td>6.0</td>
</tr>
<tr>
<td>DEM/WSM</td>
<td>1997</td>
<td>2.0</td>
</tr>
<tr>
<td>IKONOS 1-m</td>
<td>2000</td>
<td>2 - 4</td>
</tr>
<tr>
<td>IKONOS 4-m</td>
<td>2001</td>
<td>8.5</td>
</tr>
</tbody>
</table>

Table 5.1: Temporal and uncertainty information of the case study shorelines

Figure 5.1: The distribution of the soil types along the study area

(Adapted from Liu, 1998)
5.2.1 Shoreline-shape modeling

As introduced in Chapter 3, the shoreline change modeling approach proposed here, computes the direction of the normal to every segment in the shoreline after implementing the standard parameterization method mentioned earlier. Before starting to create the comparable points on the shoreline models, the first step is to find the shoreline with the more details. This is important to identify the sufficient re-sampling distance for creating the set of comparable points on the shoreline models. The shoreline with more geometrical details was found to be the digital shoreline obtained by intersecting Coastal Terrain Model (CTM) and Water Surface Model (WSM).

Based on that, the standard parameterization method presented in Chapter 2 has been applied on the shorelines with a constant standardized sampling step of 18-meter. This has resulted in 801 new points at equal distance of 18-meter and 800 segments on all shoreline models, which extend to about 15-kilometers alongshore. Figure 5.2 below shows the study shorelines with the newly created comparable points. Correspondences among shorelines segments were established accordingly. This means, shoreline segments have been associated according to their order on the shorelines, for example the first segments are assumed to be in correspondence and so on.
The directions of the normal to the shorelines segments \( S_{mk} \), (\( \beta \)) were estimated using Equation 3.6. Also, using Equation 3.7 the local orientations of every shoreline segment were obtained and further classified into the appropriate type of the local shoreline orientation including convex, concave and straight curvature. Figures 5.3, 5.4, 5.5, 5.6, 5.7 and 5.8 illustrate in an ascending timely sequence the variation of the local orientation of the segments of the shorelines of Table 5.1.
Figure 5.3: Variation of local orientation of the ODNR 73 shoreline

Figure 5.4: Variation of local orientation of the USGS shoreline
Figure 5.5: Variation of local orientation of the ODNR 90 shoreline

Figure 5.6: Variation of local orientation of the DEM/WSM shoreline
Figure 5.7: Variation of local orientation of the IKONOS 1-m shoreline

Figure 5.8: Variation of local orientation of the IKONOS 4-m shoreline
To find out whether the local orientation obtained above for the segments of the study shorelines relates to the recorded or the actual shoreline change, the average translation undergone by the segments of the ONDR 73, USGS, ODNR 90, CTM/WSM and IKONOS 1-m shorelines that correspond to the change occurred in the time periods (1973-1979), (1979-1990), (1990-1997), (1997-2000) and (2000-2001) respectively were analyzed against the recorded average translation for every shoreline segment. Figures 5.9, 5.10, 5.11, 5.12 and 5.13 below illustrate the recorded shoreline change occurred at the segment level in the time periods (1973-1979), (1979-1990), (1990-1997), (1997-2000) and (2000-2001) respectively.

Figure 5.9: Recorded shoreline change in the period (1973-1979)
Figure 5.10: Recorded shoreline change in the period (1979-1990)

Figure 5.11: Recorded shoreline change in the period (1990-1997)
Figure 5.12: Recorded shoreline change in the period (1997-2000)

Figure 5.13: Recorded shoreline change in the period (2000-2001)
By comparing the variation of the local orientation of ODNR 73 shoreline (Figure 5.3) and the recorded change in the period (1973-1979) as shown in Figure 5.9, it seems that the bundle of the concave shoreline segments on the second half of the shoreline are one reason for the severe change occurred at four locations on the ODNR 73 shoreline. Also, by comparing the variation of the local orientation of the USGS shoreline (Figure 5.4) and the corresponding change in the period (1979-1990) as shown in Figure 5.10, it was found that the shoreline parts that severely eroded are those with relatively more concavity.

When comparing the distribution of the variation of the local orientation of the ODNR 90 shoreline (Figure 5.5) with the corresponding change in the period (1990-1997) as depicted in Figure 5.11, again a correspondence between the concavity and the actual change was found. Also, by comparing the distribution of the variation of the local orientation of the DEM/WSM shoreline (Figure 5.6) with the corresponding change that took place in the period (1997-2000) as shown in Figure 5.12 above, again a connection was noticed between the concavity and the recorded change.

As well, when the distribution of the variation of the local orientation of the IKONOS 1-m (Figure 5.7) shoreline was compared to the actual change occurred in the period (2000-2001) as shown in Figure 5.13, a correlation between concavity and change was noticed however, the intense pattern on concavity exist on the second half of the IKONOS 1-m shoreline didn’t result exactly in a
noticeable change recorded in this period, which is the only controversy found in this experiment.

To closely look at the relationship between the variation of the local orientation and the recorded shoreline change in this experiment, a measure of concavity was introduced and named concavity-ratio, which is governed by the following formula. This measure determines the number of the concave shoreline segments relative to the shoreline as a whole. So, the closest the value of the concavity ratio to unity, the higher the number of concave segments the shoreline has. In other words, this means if the shoreline has more concave segments than the convex or straight segments, this measure will be as close as possible to unity.

\[
\text{Concavity ratio} = \frac{\text{The number of concave shoreline segments}}{\text{Total number of shoreline segments}}
\]  \hspace{1cm} (5.1)

The concavity ratio and the average shoreline change recorded for the period of study is listed on Table 5.2 below along with the corresponding shorelines that undergone the recorded change.
Concavity ratios and the average shoreline changes shown in Table 5.2 were plotted as illustrated in Figure 5.14 below by exaggerating the concavity-ratio in Table 5.2 five times so that the correlation can easily be detected. It is clear from Figure 5.14 that a correlation exists between the local orientation of shoreline segments and the recorded change in the period of study. Note that, as was illustrated previously in Figure 5.1 that this study area is characterized by easily eroded geological material including sand, clay and till. Based on that, if the geological materials in a study area are easily eroded, the local shoreline shape variation (curvature) plays a major role in determining erosion magnitudes. These results agree with Murray and Ashton (2002), who found that concave shoreline segments diverge wave rays causing more coastal erosion.
Figure 5.14: Relationship between local concavity ratio and average shoreline change

Global shoreline segments orientations were also estimated for shoreline segments using the Equation 3.8. Figures 5.15, 5.16, 5.17, 5.18, 5.19 and 5.20 depict the variation of the global orientation obtained for the study using Equation 3.8.
Figure 5.15: Variation of global orientation of the ODNR 73 shoreline

Figure 5.16: Variation of global orientation of the USGS shoreline
Figure 5.17: Variation of global orientation of the ODNR 90 shoreline

Figure 5.18: Variation of global orientation of the DEM/WSM shoreline
Figure 5.19: Variation of global orientation of the IKONOS 1-m shoreline

Figure 5.20: Variation of global orientation of the IKONOS 4-m shoreline
The global orientation concept was introduced in this study to foresee the angle with which waves approach the shoreline, as it is unknown. To study the relationship between the global orientation and the corresponding average change, again the concavity ratios were estimated, but in this case with respect to the global shoreline direction. Table 5.3 below lists the concavity ratios estimated from Figures 5.15 through 5.20 above and the corresponding average recorded shoreline change. Figure 5.21 below plots the concavity ration against the average shoreline change with five times exaggeration of the concavity ratio so that the correlation can be easily detected. From Table 5.3 and Figure 5.21 it is clear that there is not a clear correlation between global orientation, which was used to represent the direction of the waves and the average shoreline change. Therefore, based on the results of this experiment the hypothesis that the global shoreline-segment orientation is related by some how to the shoreline change was found unclear.

<table>
<thead>
<tr>
<th>Shoreline epoch</th>
<th>Concavity ratio</th>
<th>Average change (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>0.51</td>
<td>7.67</td>
</tr>
<tr>
<td>1979</td>
<td>0.47</td>
<td>14.18</td>
</tr>
<tr>
<td>1990</td>
<td>0.67</td>
<td>6.03</td>
</tr>
<tr>
<td>1997</td>
<td>0.59</td>
<td>7.91</td>
</tr>
<tr>
<td>2000</td>
<td>0.93</td>
<td>8.12</td>
</tr>
</tbody>
</table>

Table 5.3: Relationship between global concavity ratio and average shoreline change
5.2.2 Shoreline-change analysis

5.2.2.1 Estimation of the model coefficients

As mentioned in section 5.2.1, 800 segments were created in every shoreline, so the values of subscript \( m \) are in the interval \([1, 800]\). Also, there are six values available for \( k \), the time as shown in Table 5.1 including 1973, 1979, 1990, 1997, 2000 and 2001. This means that the values of \( k \) are in the interval \([1973, 2001]\). To keep track of the results of shoreline-change analysis in this section in a logical way, the model coefficients \( C_{mk}^{(k-1)} \) and \( \Delta_{mk}^{(k-1)} \) are referred to as the first and second change indices. The values of the first change index, \( C_{mk}^{(k-1)} \), have been calculated for the segments of all shoreline models available for the
study area using Equation 3.10. These values that correspond to shoreline-change in the time periods (1973-1979), (1979-1990), (1990-1997), (1997-2000) and (2000-2001) are depicted in Figures 5.22, 5.23, 5.24, 5.25 and 5.26 respectively.

Figure 5.22: The variation of the first change index $C_{mk(k-1)}$ in (1973-1979)

Figure 5.23: The variation of the first change index $C_{mk(k-1)}$ in (1979-1990)
Figure 5.24: The variation of the first change index $C_{mk(k-1)}$ in (1990-1997)

Figure 5.25: The variation of the first change index $C_{mk(k-1)}$ in (1997-2000)
The values of the second change index, $\Delta_{mk(k-1)}$ have also been calculated using both of Equations 3.9 and 3.10. The values of the second change index correspond to shoreline-change in the periods (1973-1979), (1979-1990), (1990-1997), (1997-2000) and (2000-2001) are depicted in Figures 5.27, 5.28, 5.29, 5.30 and 5.31 respectively.
Figure 5.27: The variation of the second change index $\Delta_{mk(k-1)}$ in (1973-1979)

Figure 5.28: The variation of the second change index $\Delta_{mk(k-1)}$ in (1979-1990)
Figure 5.29: The variation of the second change index $\Delta_{mk(k-1)}$ in (1990-1997)

Figure 5.30: The variation of the second change index $\Delta_{mk(k-1)}$ in (1997-2000)
5.2.2.2 Estimation of existing shorelines

To investigate the shoreline-change model, two existing shoreline models were chosen for estimation, which were the ODNR 90 and the DEM/WSM shorelines. The following procedure has been adopted to estimate these two shorelines:

1. The values for the first and second shoreline change indices in the periods (1973-1979), (1979-2000) and (2000-2001) have been estimated using the same method used in section 5.2.2.1 above. This was done for all of the 800 corresponding shoreline segments in the four shoreline models ONDR 73, USGS 79, IKONOS 1-m, and IKONOS 4-m.
2. The values of the first and second shoreline change indices obtained above are then fitted to sets of second-degree polynomials for all of the 800 corresponding segment sets. Second degree polynomials were preferred in the data fitting process in the study area as they closely approximate the relationships between time and both of the two change indices.

3. These polynomials were then used to estimate the values of the first and second shoreline change indices correspond to the ODNR 90 and DEM/WSM shorelines. The indices values are then used to estimate the to the ODNR 90 and DEM/WSM shorelines shown in Figures 5.34 and 5.35 respectively. Figure 5.32 shows the values of the first change index for the shorelines segments with the numbers 100, 200, 300 and 400 plotted as representative segments against the periods of changes shown above. Similarly, Figure 5.33 below shows the values of the second change index for the shorelines segments with the numbers 500, 600, 700 and 800 plotted against the periods of changes, which were also chosen as representative segments.
Figure 5.32: The values of the first change index for segments 100, 200, 300 and 400 plotted versus time

Figure 5.33: The values of the second change index for the shorelines segments 500, 600, 700 and 800 plotted versus time
Figure 5.34 below depicts the actual ODNR 90 shoreline overlaid with the estimated one. Similarly, Figure 5.35 below shows the actual DEM/WSM shoreline overlaid with the estimated one.

Figure 5.34: An overlay of the actual and the estimated ODNR 90 shoreline
Figure 5.35: An overlay of the actual and the estimated DEM/WSM shoreline

For the estimated shorelines of ODNR 90 and DEM/WSM shown in Figures 5.34 and 5.35 above, the values of the standard deviation are found to be 2.2-meters and 3.4-meters respectively. These values amount to overall quality metric values of 0.965 and 0.903 respectively. Note that the overall quality metric values are calculated here as presented in Chapters 2.
CHAPTER 6

CONCLUSIONS AND FUTURE RESEARCH

As the title implies, this work presents new methods for positional quality assessment and shoreline-change analysis of shoreline features in GIS and mapping environments. Ramirez (2000) linear quality metrics were investigated for the assessment of the positional quality of shoreline features in this study including Generalization Factor, Distortion Factor, Bias Factor, and Fuzziness Factor. The results show that these four factors describe independently different characteristics of a linear feature. Based on that a Linear Quality Metric System (LQMS) for shoreline features was developed and tested. The LQMS consists of four modules to compute the four metrics of positional quality.

The values of the Distortion Factor obtained for the five shorelines in the experiment presented in Chapter 4 show that the CTM/WSM shoreline has the least and that the USGS shoreline has the greatest distortion. The Generalization Factor values show that IKONOS 4-m and CTM/WSM shorelines are the ones with approximately the same details as the IKONOS 1-m. Furthermore, the Bias Factor values demonstrated that both of IKONOS 4-m and CTM/WSM shorelines fluctuate around the IKONOS 1-m shoreline to left and right to about the same. This is why
these shorelines have the best overall positional quality, which was obtained assuming equal weight of the four measures. In summary, the results of this experiment are consistent with the estimated values of the accuracy shown in Table 4.4.

Also a new shoreline-shape modeling method was developed in this study based on a new concept known as shoreline-segment orientations. This methodology helps to better analyze shoreline-change pattern by studying the angular deviation of every segment from the surrounding segments and also from the entire shoreline. This is important since shoreline-segment orientation with respect to the direction of the incoming waves is critical with respect to shoreline-erosion since it results in increase or decrease shoreline erosion. The global shoreline segment orientation was used to foresee the direction of the incoming waves while the local orientation of shoreline-segment helps to obtain shoreline curvature from segment to segment. The results of analyzing shoreline-change based on the concept of local orientation of shoreline segments has demonstrated the importance of this method in view of the fact that the study area is characterized by easily eroded soils.

Using the shoreline segment as a modeling unit, a new shoreline-change model was also developed to analyze shoreline changes and furthermore to forecast future shoreline positions. This shoreline-change model has the advantage of modeling the movement of a given shoreline segment within the whole shoreline through time by two change indices. The change indices of the shoreline-change model were assumed to have encapsulated the effects of the factors that accelerate the
erosion processes in the study area including shoreline shape, water-level change, shoreline geology or soil types, and erosion structures. This model, allows to not only analyze shoreline-change, but also to forecast future shoreline positions. The model uses geometric information about the shoreline’s segment shape-change and translations to capture the pattern of change at the shoreline-segment level. The results of estimating positions of shorelines using the data available for the study are in the time period from 1973 to 2001 were found promising, as the match between the estimated and observed shoreline positions was very high.

For the estimated shorelines of ODNR 90 and DEM/WSM shown in Figures 5.34 and 5.35, the values of the standard deviation obtained for the two shorelines were 2.2-meters and 3.4-meters respectively, which demonstrate the effectiveness of the model. The results obtained from the shoreline-shape modeling experiments have shown a correlation between local shoreline curvature and shoreline change. This analysis demonstrates the consistency of this method for shoreline-change analysis.

The metric system investigated in this study is important as the measures can be used in GIS and mapping environments to assess the positional quality of linear features in general and of shorelines specifically. The four metrics presented in this study were found to independently describe the characteristics of a linear. The results of the experiments performed with these linear quality metrics verify their significance. The originality of this investigation indicates its value as a contribution to assess the positional quality of shoreline features in the GIS and mapping environments.
The close connection that was found between shoreline curvature and the observed shoreline-change shows that the shoreline change modeling method developed in this research is promising. The significance of this model is substantiated by the shoreline-shape modeling results of the experiments performed on the shorelines of the study area as well as by the result of estimating future shoreline positions. The results of this model are in agreement with Murray and Ashton (2002) who suggested a connection between the shape of sandy shorelines and erosion when studying shoreline evolution. The originality of this new concept of local and global orientation of shoreline-segments developed in this study as a base for analyzing shoreline-change when knowing the distribution of geological material makes it a contribution in this area of research.

The shoreline-analysis model developed is important from two points of views. First, the existing methods for shoreline-change analysis, which are in use incapable of robustly establishing the correspondence between historic shoreline representations. Second, modeling shoreline-change at the segment level makes more sense, as the smallest unit of a shoreline is the segment. The significance of this model was demonstrated by the quality of the results of estimating the positions of shorelines within the study period as well as forecasting future positions. In addition, the ability to propagate positional quality information of shorelines to the output of the model when estimating or forecasting is another significant characteristic. The originality, simplicity and the robustness of the results of the experiments performed using the model make it a decent contribution.
This study indicates the need for future research with respect to the following issues:

- Further investigation for the Bias factor, which found to be important linear quality metric in describing the shape of a linear feature is needed.
- The linear quality metrics investigated in this study need to be expanded and tested for utilization to assess the quality of surfaces such as a DEM by applying it along selected profiles.
- This study has shown the importance of shoreline shape or shoreline geometry in accelerating shoreline-erosion since a clear correlation was found between local shoreline curvatures and shoreline-change. Further investigation is needed to study the relationship between shoreline orientation and the direction of the incoming waves since no correlation was found between the global shoreline orientations introduced in this study to reference the direction of the incoming waves.
BIBLIOGRAPHY


Blakemore, M. 1984, Generalization and Error in Spatial Databases, Cartographia, vol. 21, pp. 131-139.


Deming, W. 1986, Out of Crisis, Massachusetts Institute of Technology, MIT Press.


Federal Geographic Data Committee (FGDC) 1995, Content Standards for Digital Geospatial Metadata Workbook, USA.

Federal Geographic Data Committee (FGDC) 1998, Content Standard for Digital Geo-spatial Metadata (CSDGM), A common set of terminology and definitions for the documentation of digital geo-spatial data.


Frank, A. 1994, Qualitative temporal reasoning in GIS-ordered time scales, Sixth International Symposium on Spatial Data Handling, Edinburgh, Scotland, pp. 410-430.


Ramirez, J. 2000, Quality Evaluation of Linear Features, A white paper submitted to NIMA.


