
1 Introduction

WHY MAP?

The earth's resources are scarce. As we continue to add more people to the earth, the scarcity of resources increases, as does their value. From land use conversion throughout the world, to fragmentation of tropical bird habitat, to acid rain deposition in Eastern Europe, to polar bear habitat loss in the Arctic, to the droughts in Africa, to wars, people have significantly affected the ecosystems of the world. The ever-increasing world population and need for resources continues to cause the price of resources to increase and to intensify conflicts over resource allocation.

As resources become more valuable, the need for timely and accurate information about the type, quantity, and extent of resources multiplies. Allocating and managing the earth's resources requires accurate knowledge about the distribution of resources across space and time. To efficiently plan emergency response, we need to know the location of roads relative to fire and police stations, hospitals, and emergency shelters. To improve the habitat of endangered species, we need to know what the species habitat requirements are, where that habitat exists, where the animals live, and how changes to the habitat and surrounding environments will affect species distribution, population, and viability. To plan for future developments, we need to know where people will work, live, shop, and go to school. Because each decision (including the decision to do nothing) impacts the (1) status and location of resources and (2) the relative wealth of individuals and organizations who derive value from those resources, knowing the location of resources and how they interact spatially is critical to effectively managing those resources and ourselves over time.

WHY ASSESS THE ACCURACY OF A MAP?

Thus, decisions about resources require maps, and effective decisions require accurate maps or at least maps of known accuracy. For centuries, maps have provided important information concerning the distribution of resources across the earth. Maps help us to measure the extent and distribution of resources, analyze resource interactions, identify suitable locations for specific actions (e.g., development or preservation), and plan future events. If our decisions based on map information are to have expected results, then the accuracy of the maps must be known. Otherwise, implementing such decisions will result in surprises, and these surprises may be unacceptable.

For example, suppose that you wish to have a picnic in a forest on the edge of a lake. If you have a map that displays forest, crops, urban, water, and barren land cover types, you can plan the location of your picnic. If you do not know the accuracy of the map, but the map is 100% accurate, you will be able to travel to your forest lakeside location, and in fact, find yourself in a nice picnic spot. However, if the

maps are not spatially accurate, you may find that your picnic location falls in the middle of the lake rather than on the shore; and if the maps are not labeled correctly (i.e., thematically accurate), you may find yourself in a city next to a fountain, or in an agricultural field next to an irrigation ditch. However, if you know the accuracy of the map, you can incorporate the known expectations of accuracy into your planning and create contingency plans in situations when the accuracy is low. This type of knowledge is critical when we move from our lighthearted picnic example to more critical decisions such as endangered species preservation, resource allocation, peace-keeping actions, and emergency response.

There are many reasons for performing an accuracy assessment. Perhaps the simplest reason is curiosity—the desire to know how good a map you have made. In addition to the satisfaction gained from this knowledge, we also need or want to increase the quality of the map information by identifying and correcting the sources of errors. Third, analysts often need to compare various techniques, algorithms, analysts, or interpreters to test which is best. Also, if the information derived from the remotely sensed data is to be used in some decision-making process (i.e., GIS analysis), then it is critical that some measure of its quality be known. Finally, it is more and more common that some measure of accuracy be included in the contract requirements of many mapping projects. Therefore, a valid accuracy is not only useful, but may be required.

Accuracy assessment determines the quality of the map created from remotely sensed data. Accuracy assessment can be qualitative or quantitative, expensive or inexpensive, quick or time consuming, well designed and efficient or haphazard. The goal of *quantitative* accuracy assessment is the identification and measurement of map errors.

The purpose of this book is to present the theory and principles of quantitative accuracy assessment and to instruct readers how to adequately design and implement an accuracy assessment. Throughout the book, we emphasize that no single recipe exists for accuracy assessment. Just as there is no one way to produce a map, there is no one way to assess the accuracy of a map. Instead, this book will teach you to consider every aspect of a mapping project and to design and implement the best possible assessment given the strengths and limitations of each mapping project you conduct, fund, or rely on.

TYPES OF MAP ACCURACY ASSESSMENT

There are two types of map accuracy assessment: positional and thematic. Positional accuracy deals with the accuracy of the location of map features, and measures how far a spatial feature on a map is from its true or reference location on the ground (Bolstad, 2005). Thematic accuracy deals with the labels or attributes of the features of a map, and measures whether the mapped feature labels are different from the true feature label. For example, in the picnic example, the earth's surface was classified as forest, water, crops, urban, or barren. We are interested in both the accuracy of the location of the features so we can locate our picnic spot in a forest on the shore of a lake, and in the thematic accuracy so we truly end up in a forest and not in a city, desert, or agricultural field that was erroneously mapped as a forest.

The accuracy of any map or spatial data set is a function of both positional accuracy and thematic accuracy, and this book considers both. However, because thematic accuracy is much more complex than positional accuracy, the book devotes considerably more attention to thematic accuracy assessment.

CRITICAL STEPS IN ACCURACY ASSESSMENT

As previously stated, there is no single procedure for conducting either a positional or a thematic accuracy assessment. However, all accuracy assessments include three fundamental steps:

1. Designing the accuracy assessment sample
2. Collecting data for each sample
3. Analyzing the results

Each step must be rigorously planned and implemented. First, the accuracy assessment sampling procedures are designed, and the sample areas on the map are selected. We use sampling because time and funding limitations preclude the assessment of every spatial unit on the map. Next, information is collected from both the map and the reference data for each sample site. Thus, two types of information are collected from each sample:

- *Reference accuracy assessment sample data:* The position or class label of the accuracy assessment site, which is derived from data collected that are assumed to be correct.
- *Map accuracy assessment sample data:* The position or class label of the accuracy assessment site, which is derived from the map or image being assessed.

Third, the map and reference information are compared, and the results of the comparison are analyzed for statistical significance and for reasonableness. In summary, effective accuracy assessment requires (1) design and implementation of unbiased sampling procedures, (2) consistent and accurate collection of sample data, and (3) rigorous comparative analysis of the sample map and reference data.

Because there is no single procedure for designing and implementing accuracy assessments, there are a number of important questions to ask and considerations to think about when conducting a valid assessment. This book addresses the most important ones, including the following:

1. Questions concerning the design of an accuracy assessment sample:
 - What are the map classes to be assessed and how are they distributed across the landscape?
 - What is the appropriate sampling unit?
 - How many samples should be taken?
 - How should the samples be chosen?

2. Questions concerning how the reference data should be collected:
 - What should be the source of the reference data?
 - How should the reference data be collected?
 - When should the reference data be collected?
 - How do I ensure consistency and objectivity in my data collection?
3. Questions concerning how the analysis should be conducted:
 - What are the different analysis techniques for continuous as compared to discontinuous map data?
 - What is an error matrix and how should it be used?
 - What are the statistical properties associated with the error matrix and what analysis techniques are applicable?
 - What is fuzzy accuracy and how can you conduct a fuzzy accuracy assessment?
 - How is accuracy assessment conducted on change detection maps?
 - How is accuracy assessment conducted on maps created from multiple layers of data?

ORGANIZATION OF THE BOOK

The organization of this book takes you through each of the previously mentioned fundamental accuracy assessment steps as follows:

- The next three chapters (Chapters 2 through 4) introduce the basic concepts of positional and thematic accuracy assessment. Chapter 2 begins with a review of the history and basic assumptions of map making and accuracy assessment. Chapter 3 introduces the reader to positional accuracy assessment, while Chapter 4 introduces the concepts of thematic accuracy, including the error matrix.
- Chapter 5 reviews sample design considerations.
- Chapter 6 is devoted to factors that must be taken into account during the collection of reference data.
- Chapters 7 through 9 detail thematic accuracy assessment analysis, which is much more complex than positional accuracy assessment analysis. The basic analysis techniques that can be applied to an error matrix are discussed in Chapter 7. Chapter 8 discusses the causes of differences in the error matrix, whether from map errors or from other nonerror sources. Chapter 9 presents a solution to some of the nonerror differences in the error matrix by suggesting the use of fuzzy accuracy assessment.
- Chapter 10 presents a case study that reviews all the design, data collection and analysis methods presented in Chapters 3 through 9.
- Chapter 11 delves into more advanced topics in accuracy assessment, including change detection accuracy assessment and multilayer accuracy assessment.