AN INVESTIGATION INTO MAPPING WETLANDS USING SATELLITE IMAGERY: THE CASE OF MIDMAR SUB-CATCHMENT

By

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ABSTRACT

A suitable methodology for mapping wetlands in South Africa has not been agreed upon. This investigation aimed at developing a methodology for the accurate and efficient delineation of wetland areas using satellite imagery and other relevant spatial datasets. Both summer and winter LANDSAT ETM+ satellite imagery covering the study area of the Midmar sub-catchment were processed using various image classification techniques. These included the supervised, unsupervised and level slicing classifications. The accuracy of each technique was tested against the only existing verified wetland dataset that covers the study area. A ground truthing exercise was also undertaken.

The different classification techniques resulted in different classification accuracies when compared to the verified wetland dataset. Accuracies for the different classification techniques were as follows: unsupervised 20 class classification (summer) 55%, (winter) 39%, unsupervised 255 class classification (summer) 71%, (winter) 47%; supervised classification (summer) 65%, (winter) 41%; level slicing classification (summer) 65%, (winter) 45%. The inaccuracies could mostly be attributed to a change in land cover as there seems to be an overall loss of wetland areas. However, the ground truthing exercise resulted in higher classification accuracies especially with unsupervised 255 class classification.

This study concluded that LANDSAT ETM+ satellite imagery was useful for detecting wetlands areas during summer by using a fine classification technique (255 class). A finer classification technique is also suited for the detection of both large and small wetland areas. Major recommendations include: the use of summer imagery in a high rainfall period; the unsuitability of using winter imagery due to the spectral confusions created; the use of high resolution satellite sensors (SPOT) for monitoring purposes while lower resolution sensors (LANDSAT) should be used for mapping; the increased use of topographical modelling for wetland detection; the use of an appropriate scaled land cover database and the use of field verification exercises for comparing classifications.

PREFACE

The work described in this dissertation was carried out in the Centre for Environmental and Development, University of Natal, Pietermaritzburg, from August 2000 to December 2001, under the supervision of Drs F. Ahmed and N. Quinn (School of Applied Environmental Sciences). The maps for this dissertation were produced in the Geo-Information Products and Services Unit, Satellite Applications Centre, Council for Scientific and Industrial Research (CSIR).

This study represents original work done by the author and has not otherwise been submitted in any form for any additional degree or diploma to any other University. Where reference has been made to the work of others these are duly acknowledged in the text.

Signed:.......................

D. L. Pillay

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LIST OF ABBREVIATIONS

1. GIS – Geographical Information Systems

2. FCC – False Colour Composite

3. ETM+ - Enhanced Thematic Mapper Plus

4. TM – Thematic Mapper

5. DEAT – Department of Environmental Affairs and Tourism

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CHAPTER ONE: INTRODUCTION

1.0 BACKGROUND TO THE RESEARCH PROBLEM

Wetlands exist in a great variety and produce a remarkable showcase of natural resources. Widely regarded as one of the most productive natural habitats on earth, they cover approximately 6.4 per cent of the land area and are accountable for 24 per cent of total global productivity (Elliot and Hektner, 2000; Dwivedi and Rao, 1999). Despite their importance, wetland habitats are being continually degraded to a point that they are not able to support important ordinary wetland functions such as water purification, flood control and important nodes of biodiversity and wildlife (Anderson and Herdin, 1992; Lunetta and Balogh, 1999; Dwivedi and Rao, 1999; Rao *et al.*, 1999, Breen *et al.*, 1997; Cowan, 1995). As public understanding of the importance of wetlands in maintaining important ecological functions increases, so do legal mechanisms to protect these areas. Both these areas (understanding and legal protection) are further enhanced by developments for better environmental protection, planning and management (Haack, 1996). In the meantime the loss of wetlands continues, especially on private lands (Elliot and Hektner, 2000).

According to Mitsch and Crosslink (1993), there is no way to estimate the impact humans have had on the extent of wetlands. Many cultures in the early civilizations have adapted to live in harmony with wetland areas and in this process have also benefited economically from them. Later other cultures quickly drained these landscapes for development purposes, especially for cultivation. Presently there is a multitude of projects and programmes which are operational at scales for preserving or improving wetland habitats. Some of these initiatives include that of the U.S. Fish and Wildlife Service's National Wetlands Inventory (Mitsch and Crosslink, 1993), the National Wetland Committee in India (Rao *et al.*, 1999) and the Wetlands Conservation Programme of the Department of Environmental Affairs and Tourism in South Africa (Dini *et al.*, 1998). There is an indication from the above programmes that the present priority regarding wetlands is one of preservation, the avoidance of disturbances, and an enhancement of wetland functions.

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1.1 DEFINITIONS AND CLASSIFICATION OF WETLANDS

Wetland definitions are numerous, depending on the country and the landscape settings in which they are found. Sound definitions are nevertheless important as they guide the scientific understanding of these systems and lead to proper management strategies being formulated. According to Mitsch and Crosslink (1993), defining the boundaries of wetlands became important when society began recognizing the value of these systems and translating that recognition into laws to protect society from future wetland losses. Wetlands under the Ramsar Convention Bureau (1997) are defined as: "Areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres" (Dely *et al.*, 1995).

One of the most comprehensive definitions of wetlands was one adopted by the wetland scientists in the United States Fish and Wildlife Service. According to this wetlands are defined as; " land transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water" (Mitsch and Crosslink, 1993). In South Africa, the Wetlands Conservation Programme, which was established within the Department of Environmental Affairs and Tourism (DEAT), was initiated to assist in meeting South Africa's commitment to the Ramsar Convention (Walmsley, 1998). One of the programme's tasks has been the compilation of a database linked to a GIS in which currently approximately 1500 wetland sites are currently documented. Some of the components of this database include information relating to wetland surveys conducted in certain parts of the country, as well as information on the level of threat and the protected status of the sites. In addition to the developments made within the DEAT, several other wetland inventory projects are underway together with the recent commissioning of a review of wetland types in South Africa (Dini *et al., 1998*).

The above-mentioned provide the building blocks of national wetland inventory programme, which is currently being implemented. The DEAT will initially channel its efforts towards finding existing wetland inventory information that could be added into a national inventory. The methodology of a national inventory would be centred around the use of aerial photographs, mapping, field verification, addition of geological, soil, relief, vegetation and climatic data and finally producing status reports on each wetland, quaternary and tertiary sub catchments (Dini *et al.*, 1998).

In order to facilitate the use of South African inventory data in international wetland analyses, it has been requested that the Ramsar classification system be adopted. In the light of several shortcomings, this was abandoned and it was decided to use the Cowardin system for wetland classification (Walmsley, 1988). The figure overleaf (Figure 1.1) shows a summarised version of the proposed South African wetland classification system. Changes to the subsystem and class levels of the classification were proposed in order to adapt the Cowardin system to the South African conditions. For an area to be classified as a wetland in the Cowardin classification system, it must comply with at least one of the following three criteria:

a) At least periodically, the land supports predominantly hydrophytes;
b) The substrate is predominantly undrained hydric soil;
c) The substrate is non-soil and is saturated with water or covered by shallow water at some time during seasons of high rainfall.

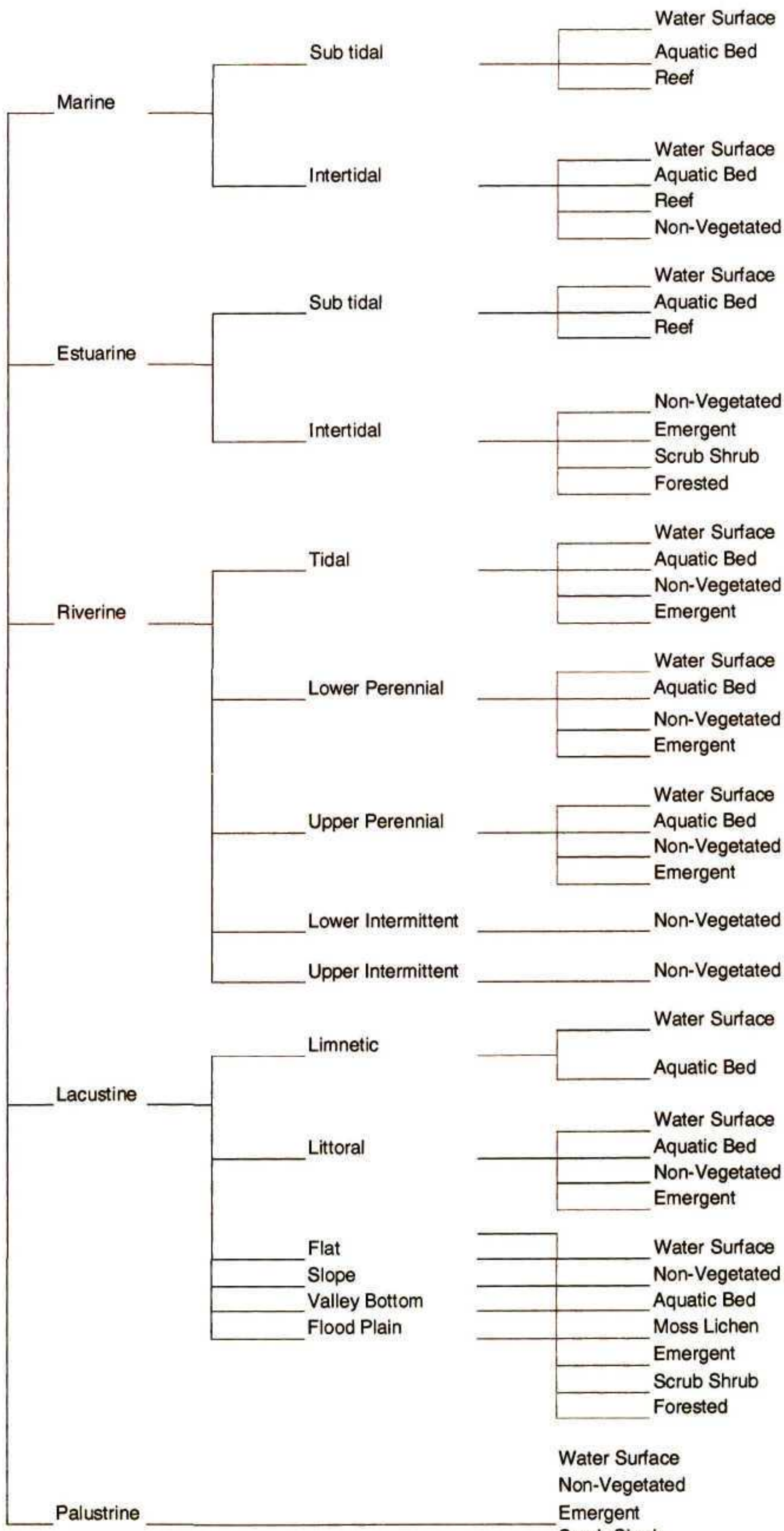


FIGURE 1.1: SOUTH AFRICAN WETLAND CLASSIFICATION SYSTEM

1.2 FUNCTIONS AND VALUES OF WETLANDS

The reason that wetlands are often legally protected lies in their value to society (Mitsch and Crosslink, 1993). Perceived values are determined not only by their ecological functions, but also by human perceptions, the precise location of a particular wetland, the extent of the resource and the human demands on that particular resource. Mitsch and Crosslink (1993) proposes three hierarchical levels according to which wetland values can be arranged. The summary below highlights these three levels according to their hierarchical importance.

a) POPULATION

- Value in this category is in relation to all populations that depend on the wetland habitats for their survival.
- These include smaller fur-bearing mammals, alligators, fish, shellfish, waterfowl and other birds. These animals have a limited range of movement and spend most of their lives in close proximity to their birthplace, which is usually a wetland habitat (Lunetta and Balogh, 1999; Mitsch and Crossink, 1993).
- Where wetlands have the required depth, they provide routes for transport. Communities inhabiting areas close to those wetlands are dependent on water transport to carry out their daily activities (Breen *et al.,* 1997). Wetland areas are also important breeding grounds for endangered and threatened species. According to Mitsch and Crossink (1993), wetlands occupy only about 3.5 per cent of the land area of the United States; of the 209 animal species listed as endangered in 1986 about 50 per cent depended on wetlands for survival and viability.

b) ECOSYSTEM

- At ecosystem level, wetlands are valuable because of their flood mitigation capabilities, storm abatement, aquifer recharge and aesthetics (Mitsch and Crossink, 1993; Dwivedi, 1999; Lunetta and Balogh, 1999).
- By virtue of their location, wetlands help in protecting uplands/ shorelines from erosion (Rao *et al.*, 1999).
- Wetlands also assist with water quality control by removing sediment, water purification, nutrient removal and retention (Breen *et.* al 1997). Wetlands provide valuable " biological laboratories" (Mitsch and Crossink, 1993) where students from elementary, secondary and higher education can learn natural history.

c) GLOBAL

- Wetlands perform an important function in terms of globally regulating nitrogen, methane and carbon dioxide (Mitsch and Crossink, 1993; Dwivedi *et al.,* 1999; Rao *et al.,* 1999).
- The burning of fossil fuels greatly increases the amounts of gases like sulphur and carbon dioxide into the environment and atmosphere. Wetlands play a major role in regulating sulphur by converting it to sulphides, which can be recycled into the atmosphere as hydrogen, methyl and dimethyl sulphides (Mitsch and Crosslink, 1993).

1.3 THE STATUS OF WETLANDS MAPPING IN SOUTH AFRICA

The urgency of conserving wetland areas in South Africa is stated in Section 2 of the National Environmental Management Act (NEMA) 107 of 1998 (RSA 1998), which states that: "Sensitive, vulnerable, highly dynamic or stressed ecosystems, such as coastal shores, estuaries, wetlands, and similar systems require specific attention in management and planning procedures, especially where they are subject to significant human usage and development pressure."

The National Water Act 36 of 1998 (RSA 1998) also makes provision for the protection of wetlands, especially in relation to catchment areas. The Act provides for the establishment of a national water resource strategy that provides for obligatory international rights and obligations; this would include the Ramsar Convention. The implementation of a National Wetlands Conservation Programme was seen as an important point of origin for establishing a system for managing wetlands within the borders of South Africa (Taylor *et al.*, 1995). In South Africa there are now effective legal mechanisms in terms of constitutional regulations to protect wetland ecosystems.

Once wetlands have been defined and classified, an important next step, from a management perspective, is to determine the exact location and extent of these wetlands. According to Lynon and McCarthy (1995), in order to keep track of a changing resource such as wetlands, there needs to be information about the resource on a regular basis. There are a number of options for collecting information on wetlands, but due to its spatial and temporal nature, technologies that capture the synoptic view of the earth are favoured (Haack, 1996). Sources of information in the past included aerial photographs and field verification techniques. Aerial photographs (both colour and black and white) have in the past been used to delineate wetland areas (Beeg 1989), but their use is restricted in terms of input into computerised systems for manipulations, modelling and scale-analysis techniques (Haack, 1996). Acquisition of aerial photographs for large areas require extensive disk storage space as well making sure that the season in which the data is acquired is correct.

Developments in remote sensing have proven useful in evaluating the distribution of wetland resources across the landscape (Lynon and McCarthy, 1995). Since the launching of the first LANDSAT satellite in 1972, there has been an increasing need to use these devices to monitor and delineate the extent of wetlands. Advantages of using satellite observations for wetland mapping include:

a) Satellites are able to frequently acquire information about larger areas;
b) Satellites provide a synoptic view of large wetland areas and maintain a permanent record of the conditions at the time of acquisition (Haack, 1996);
c) Satellite systems possess different spectral and spatial resolutions for capturing different parts of the wetland system (e.g. SPOT and LANDSAT TM);
d) Remotely sensed data received can be easily input into GIS for manipulation and modelling purposes.
e) The frequent revisit capabilities of satellite systems ensures the regular acquisition of data for a particular area.

A major disadvantage of using certain satellites sensors to map wetlands relates to the fact that the spatial resolution is insufficient to delineate smaller wetlands areas. This has been demonstrated by wetland scientists working on the United States Wetland Inventory Programme (Mitsch and Crosslink, 1993). The possibility of merging different satellite images, such the French SPOT 8 m panchromatic bands, with other multispectral bands, such as LANDSAT ETM+, has advantages for wetland mapping applications. The ability to combine satellite data with other digital data sets, such as hydric soils maps and Digital Elevation Models (DEM), has also provided a useful approach for inventorying wetlands in larger areas. The state of Ohio, for example, has adopted this approach and the results have been successful (Mitsch and Crosslink, 1993). Despite given national attention and priority, projects to compile inventories and map wetland areas in South Africa have been severely limited (Taylor *et al.*, 1995; Dini *et al.*, 1998). The Department of Environmental Affairs (DEAT) and Tourism has announced an interest in undertaking a national wetland inventory but a final methodology has still not yet been agreed upon (Taylor *et al.*, 1995).

In South Africa's future wetland mapping the inventory process will be done firstly as pilot studies, using aerial photographs for identifying and delineating wetlands (Dini *et al.,* 1998). The conservation programme fails to take into account the inherent limitations of using aerial photographs which include the fact that the aerial photograph compilation date might not necessarily correspond to the seasonal "wet" period of that year; the question of mapping accuracy has implications for wetland boundaries and the extent of actual wetland areas could differ from the time of photographic compilation to the current year.

With these factors in mind, an urgent need exists to develop suitable criteria and techniques to map wetlands in South Africa, especially in the light of the priority accorded to wetlands in terms of the National Water Act and the National Environmental Management Act. As an alternative method of mapping wetlands, Thompson (1994a,b) evaluated the use of current remote sensing technology for mapping wetlands. The workshop discussions (Thompson, 1994b) produced guidelines on the potential applications of satellite compared to aerial photographs and the applications for which satellite imagery cannot be used. To date, there has been limited use of remote sensing technologies as a means of compiling inventories and mapping wetlands in South Africa, although there has been mention of using such technology in the national inventory (Dini *et al.,* 1998).

Apart from this, there has been no national initiative to evaluate the use of satellite imagery to map wetland areas. With increasing developments in both the GIS and the remote sensing environments, there is now enormous potential for combining advanced technologies to develop feasible ways of mapping wetland areas. This study presents an investigation that utilizes multispectral satellite imagery within a Geographical Information Systems (GIS) to map wetlands in the Midmar sub-catchment area in Kwa-Zulu Natal. The overall aim was to evaluate the use of multi-temporal satellite imagery combined with other spatial datasets to develop a method of extracting wetland characteristics and finally produce a map of all mapped wetlands in that particular area.

1.5 AIM AND OBJECTIVES:

The aim of the study is to develop a methodology for the delineation of wetland areas from the use of satellite imagery and other relevant spatial datasets.

Specific objectives are as follows:

a) Review current techniques for mapping wetlands through remotely sensed data, both internationally and in South Africa.

b) Develop methods for mapping wetlands using satellite data and evaluate the utility of using other spatial datasets to increase visual interpretation of the satellite.

c) Assess the applicability of the methods in specific test sites.

d) Assess the validity and reliability of the developed methodology by comparing with validated data sets by undertaking field verification exercises.

e) Finalise methodology and develop recommendations and guidelines.

1.6 OUTLINE OF CHAPTERS

Chapter one provide an introductory overview of the different aspects relating to wetland ecosystems and includes a brief description of the importance of wetland areas and their value to society. Different working definitions of wetlands are presented in this chapter together with an explanation of the wetland classification system used in South Africa. An evaluation of the status of South African wetlands in terms of the various legal mechanisms are given. The chapter concludes by providing the aim and objectives of the current study and an outline of chapters. Chapter Two provides a description of the study area, including soil characteristics, geological formations, hydrology and climatic characteristics.

Chapter Three provides an extensive overview of wetland mapping studies both in South Africa and selected countries. This chapter focuses on studies done in South Africa and includes techniques used and the success derived from these mapping exercises. Various international studies are then highlighted. Chapter four provides the methodological framework for the current wetland mapping exercise and also includes a flow diagram of all processes done on the satellite imagery. Chapter five presents the results of the mapping exercise and engages in discussions relating to certain aspects of the research and findings. Chapter six presents the recommendations and draws certain conclusions from the research investigation.

CHAPTER TWO: STUDY AREA

2.1 LOCATION OF THE MIDMAR SUB-CATCHMENT

The study area (Midmar sub-catchment) falls within the Mgeni Catchment and therefore shares very similar characteristics to this larger catchment. The Mgeni Catchment covers an area of 4353 km^2 and is located within the province of KwaZulu-Natal on the eastern coast of South Africa. The study area lies between 29°04' S 29° 49' E and 29° 32' S 30° 25' E (Figure 2.1) and falls within the Lions River magisterial district.

The study area represents an important sub-catchment area within the province of Kwa-Zulu Natal. In 1985, water from the Mgeni Catchment supplied a population of 3.6 million people and supported industry and agriculture, which produced 20 per cent of the South African Gross National Product (Tarboton and Schulze, 1992). The area also represents an important node in terms of water storage and many water-based recreational activities (Rivers-Moore, 1997). Water resource management that incorporates catchment management is crucial in this area in order to ensure that the increasing rural, urban, industrial and recreational development does not exceed available water resources (Tarboton and Schulze, 1992).

Numerous wetland areas of various sizes within the Midmar sub-catchment support a rich variety of animal and bird species. The extent and different sizes of these wetland areas make the sub-catchment an ideal location to test the viability of mapping wetlands using satellite imagery. The close proximity and accessibility of the area allows the researcher to perform field verification exercises in different parts of the mapped areas.

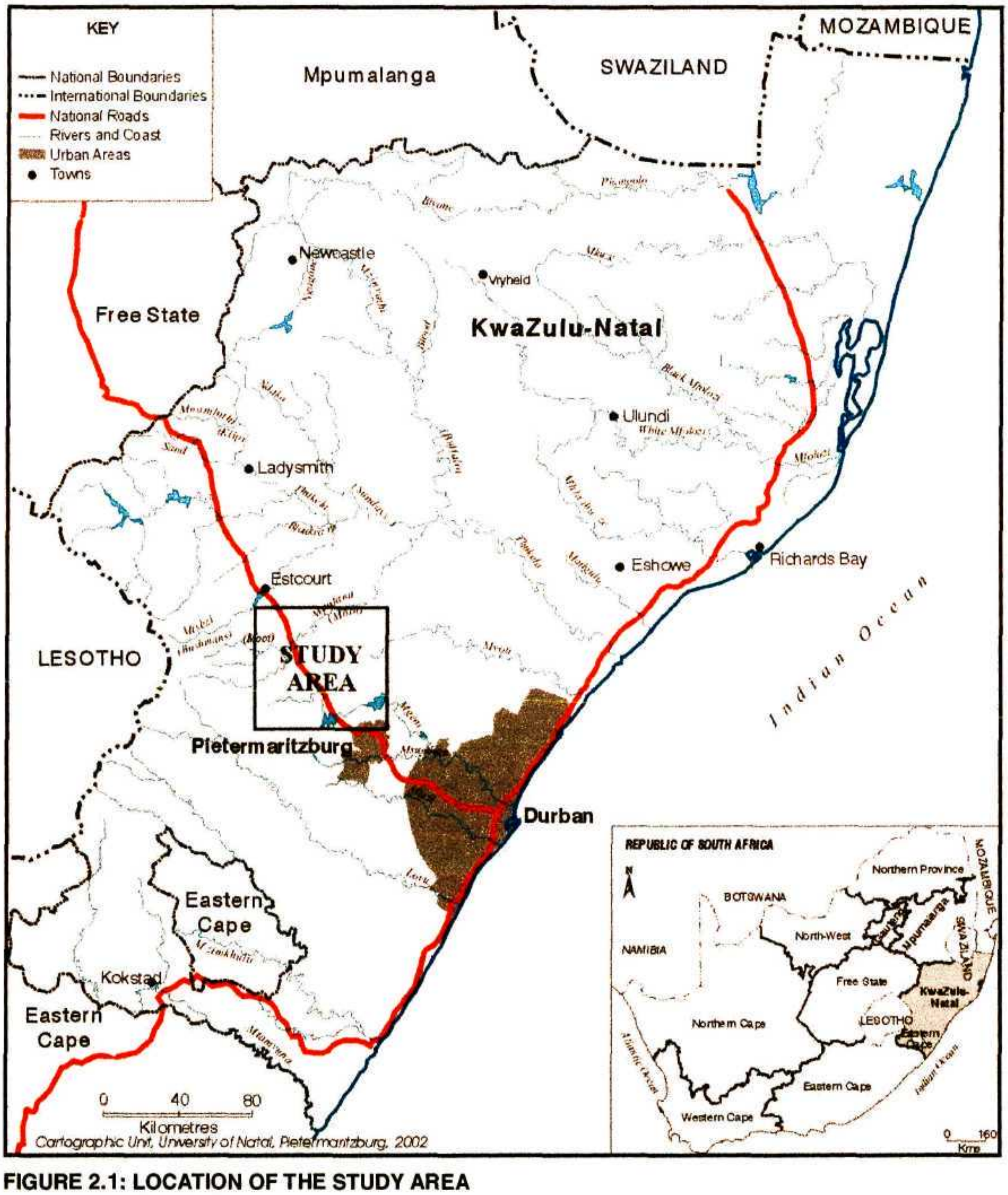


FIGURE 2.1: LOCATION OF THE STUDY AREA

2.2 GEOLOGY

According to Moll (1965, 1976) the geology of the study area comprises rocks of the Beaufort and Ecca Groups of the Upper Karroo Supergroup as can be seen in Figure 2.2. The Ecca Group (blue and grey sandstones and shales) occupies a large part of the study area. The Beaufort Group (mudstones, shale and sandstones) rests on rocks of the Ecca Group.

An abundance of dolerite throughout the study area occurs as horizontal/ inclined sills and narrow vertical dykes, which are intrusive into both the Ecca and Beaufort Groups (Tarboton and Schulze, 1992). The geological setting of the Mgeni Catchment and the surroundings wetlands are important as this region occupies basins that have foundations characterised by Ecca Shale (Smith, 1953). This not only exercises strong structural control over drainage in the area, but also adds to the retention and storage of water (Begg, 1989).

2.3 HYDROLOGY

The Mgeni River forms the main axis of the larger catchment along which four major water supply bodies are located. These include the Midmar, Albert Falls, Nagle and Inanda Dams. The Midmar Catchment is drained by the Mgeni River and both its tributaries, the Lions River and the Dargle Stream (Tarboton and Schulze, 1992). According to Moll (1965) both the Lions and Mgeni Rivers originate in the large permanent wetlands of the Highland region.

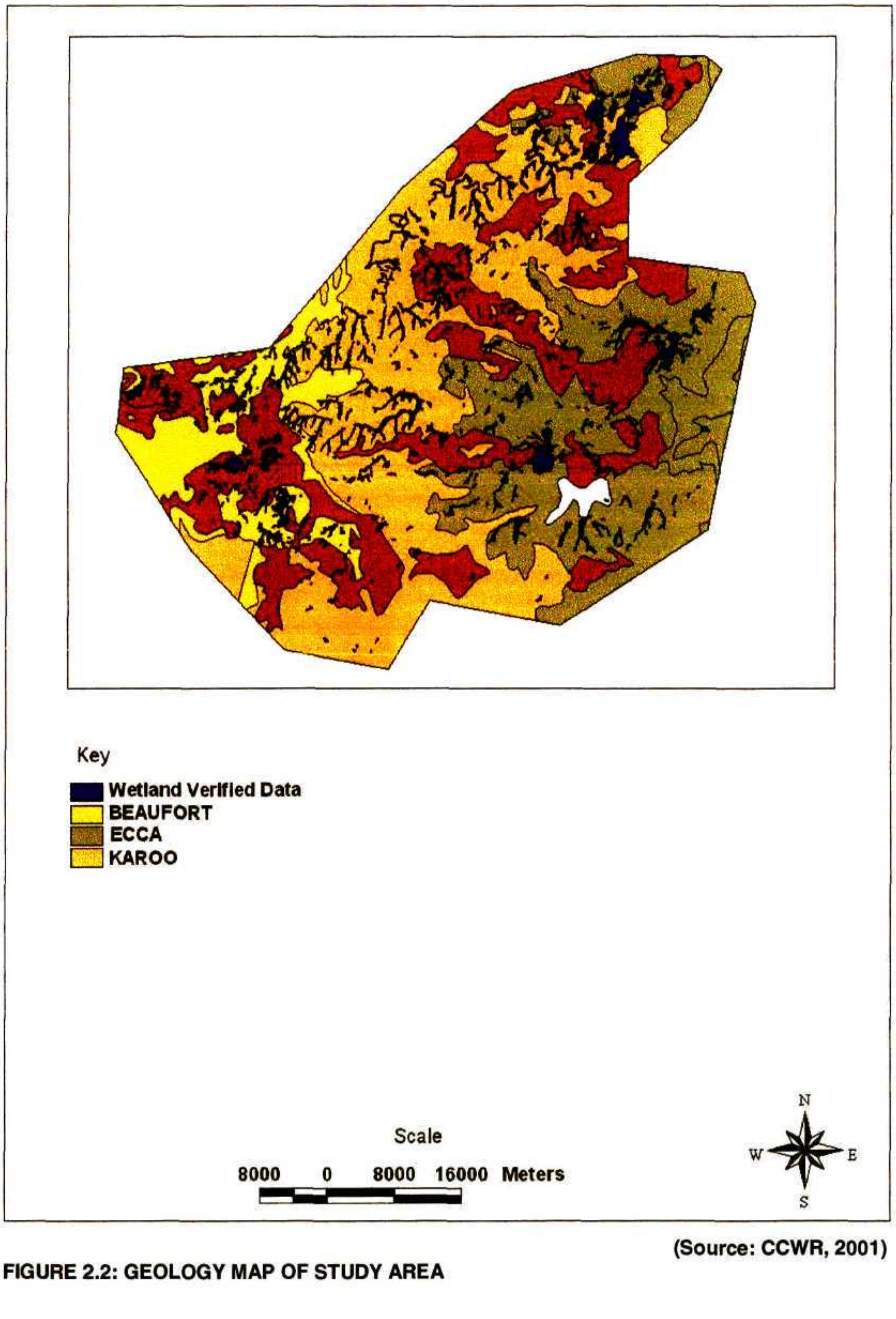
2.4 SOILS

Detailed soil maps were produced by Scotney (1970) for the Midmar Catchment area at a scale of 1:50 000. The soil series described above was later revised for another study (Rivers-Moore, 1997) according to the Soil Classification Working Group (1991).

According to Scotney (1970), the upland soils of the catchment to the north and northwest are highly leached, contain low levels of plant nutrients, and generally of low erosion potential. The soils belong to the Hutton, Griffen, Clovelly, and Mispah soil. The main areas of the Midmar Catchment have upland soils, which are leached and belong to the Hutton, Clovelly, Mispah and Avalon forms. Areas representing the Cedara and Merrivale Basin have upland soils, which are moderately leached, and consist of Shortlands, Avalon, Cartref, Longlands, Wasbank and Mispah forms (Rivers-Moore 1997).

2.5 CLIMATE

The climate of the Midmar catchment is mild (Tarboton and Schulze, 1992). The area is situated in the southern hemisphere, meaning that the north and northwest-facing slopes are drier than the opposite south-facing slopes. As a result, more mesophytic plants are limited to the south facing slopes (Rivers-Moore, 1997). Philips (1973) describes the bio-climate in the region as humid to sub-humid. The lowest temperatures occur in June and the highest temperatures are recorded in January (Rivers-Moore, 1997). The study area falls within a summer rainfall area of southern Africa. The catchment receives on average between 858 and 1047 mm of rain per annum (Rivers-Moore, 1997).



(Source: CCWR, 2001)

FIGURE 2.2: GEOLOGY MAP OF STUDY AREA

CHAPTER THREE: LITERATURE REVIEW

3.1 INTRODUCTION

The international scientific community and various individual governments have shown an interest in the conservation needs of wetlands. This response follows the realization of the economic and ecological consequences of the large-scale destruction of these valuable ecosystems (Roggeri, 1995; Anderson and Herdin, 1992; Johnston and Berson, 1993; Lunetta and Balogh, 1999). Countries like the Netherlands, Germany, Denmark and the United States of America are now attempting to create new wetlands or recreate those that were destroyed (Roggeri, 1995). Wetland inventories in many countries take on the form of first identifying the exact location and type of wetland system and thereafter deciding on the best possible method of mapping the resource (Roggeri, 1995; Mitsch and Crossink, 1993). Wetlands are often distributed across the landscape, and they may therefore differ in their extent depending on the region of a country. Identification and mapping are important first steps for wetland inventories.

Sound decisions in wetland inventory explorations depend on accurate location and attribute information (Cummings, 1977). The Ramsar Convention (1997) has instituted frameworks for each individual contracting party to undertake wetland inventories within their respective areas of governance. Wetland monitoring programmes vary considerably between different countries largely as a result of different levels of technological expertise, financial and human resources required to perform these specialized functions (Johnston and Berson, 1993; Rao *et al.*, 1999). Another consideration is the technological and financial expertise of conservation priorities within that region. The ability of these bodies to undertake holistic integrated wetland programmes is also a factor (Roggeri, 1995). Procedures and techniques to map wetland areas within individual inventory programmes also tend to differ (Begg, 1989; Caldwell and Koeln, 1988; Johnston and Berson, 1993). In many countries wetland delineation has largely depended on the use of aerial photographic interpretation and field surveys (Roggeri, 1995; Begg , 1989).

Technological advances in the fields of remote sensing, GIS and image processing offer an increasing application wetland inventory studies (Lillesand and Kiefer, 1994, Verhoeye *et al.,* 2000). Combined with other ancillary data such as aerial photographs, soils and vegetation data, satellite imagery has proven to be an effective tool by which wetland areas can be delineated (Lynon and McCarthy, 1995; Walmsley and Botten, 1987).

This chapter focuses on studies that have utilized different remote sensing techniques to map wetland areas. The chapter documents international and South African studies, which use both aerial photographic interpretation techniques and space-borne technology to map wetlands in different areas.

3.2 INTERNATIONAL STUDIES

Wetland ecosystems are seen as valuable conservation areas throughout the world and as a result, many countries are conducting wetland inventory studies to enable conservation authorities to manage those ecosystems within their boundaries. The following sub-sections document studies in the United States of America, India and Australia in order to understand global trends on wetland mapping.

3.2.1 UNITED STATES OF AMERICA (US)

Policy developments in terms of Section 404 of the 1972 Clean Air and Water Act have made the identification of wetlands a priority in the U.S (Mitsch and Crossink, 1993). According to this ruling, any development or land utilization must first take into consideration the protection of wetlands so that this resource is not compromised (Anderson and Herdin, 1992). The passing of certain legal frameworks in which wetlands became protected areas emphasised the need to map these areas according to institutional requirements. Many of the studies were done by individual organisations with a special interest in wetland areas, for example Ducks Unlimited (Caldwell and Koeln, 1988).

In case of Ducks Unlimited, wetland information became an increasingly critical resource, as the organization was keenly interested in duck populations and the influence of wetland areas on their behaviour. LANDSAT 3 MSS data was first utilized for inventory purposes but was found to have problems in terms of accuracy, mapping and cost (Caldwell and Koeln, 1988). In 1982, LANDSAT Thematic Mapper (TM) data was chosen to replace LANDSAT Multispectral Scanner (MSS) data, based on both its higher spectral (7 bands) and spatial (30 metres multispectral and 10m panchromatic) resolutions which were thought to provide an effective tool for mapping wetland areas (Caldwell and Koeln, 1988). Having experienced initial success with this remote sensing tool, the organization then set future goals of mapping all of the wetlands in areas of key interest. These mapping exercises have continued to date (Mitsch and Crossink, 1993).

Other mapping techniques focused on wetland delineation during the 1980's included the use of ortho-photoquads and 35mm aerial photographs (Mead and Crammon, 1982), the use of aircraft MSS data (Jensen *et al.,* 1987) and wetland mapping from digitised aerial photography (Scarpace *et al.,* 1981). The limitations within each of these studies were considerable given future intentions for wetlands in the United States of America. The need for inventory techniques covering large areas for constant inventorization and monitoring was considered vital (Caldwell and Koeln, 1988). Techniques utilizing aircraft platforms for capturing a remote image of wetlands experienced limitations in terms of photograph quality needed to cover wetlands areas, cost and time implications involved in processing this data and the requirement of long, perfectly parallel flight lines which was nearly impossible for large areas in which some wetlands were situated (Mead and Crammon, 1981; Scarpace *et al.,* 1981).

The improvement of satellite remote sensing technology led to the investigation of the practical usage of these systems. Dottavio (1984) provided one of the earliest studies that was conducted after the successful launch of LANDSAT 4 TM in 1982. The objectives of this study involved evaluating LANDSAT TM's spectral, spatial and radiometric characteristics for improved wetland-mapping accuracy in comparison to the capabilities of LANDSAT MSS data.

The study also examined the spectral characteristics of the LANDSAT TM for determining which wavelength bands would provide the greatest discriminatory power for two wetland plant communities. The results showed that the increased spectral capability of TM offered comparable benefits for mapping large homogenous areas compared to MSS data. The examination of LANDSAT TM showed that the infrared wavelength region had the greatest discriminatory power for the six land types examined (Dottavio, 1984).

Anderson and Herdin (1992) focused on the effectiveness of using high-altitude infrared photography for delineating wetland areas. The study was conducted in the spring of 1991. The interpretation of non-riparian wetlands from the available data proved to be difficult for the following reasons:

a) The scale of the photographs was too small to identify wetland areas and vegetation.
b) The season in which the photograph was taken did not fully represent all wetland sites.
c) Tree canopies in the area tended to mask the understorey, making wetlands difficult to detect (Anderson and Herdin, 1992).

The results showed that 61 per cent of the areas marked as "possible wetlands" from the infrared photograph interpretation in the laboratory, were delineated as wetlands after evaluations. Of the areas marked as likely wetlands in the laboratory, 94.5 per cent were delineated as wetlands following field verification. In areas where technicians identified potential wetlands, wetlands were discovered that had not been mapped during any of the other delineation stages. The overall results showed that field verification increased the quantitative data on wetlands. The study also allowed the existing National Wetland Inventory maps for the area to be assessed, since field verification was not part of the process when these maps were produced.

During the 1990 s the rapid decrease in wetland habitats prompted the establishment of various federal, state and local government agencies to formulate strategies to slow down or eliminate net wetland loss. As part of the National Wetland Inventory, the US Fish and Wildlife Service initiated a programme to map, inventorize and monitor the status and trends of wetlands throughout the United States of America on a 10-year reporting cycle (Kiraly *et al.,* 1990 in Lunetta and Balogh, 1999). In its early stages, this programme involved the use of national high-altitude photography and incorporated both photographic and photogrammetric techniques. Although effective, this photo-based process was limited by its time-consuming nature, its lack of cost effectiveness and the fact that the maps produced could not be rapidly updated (Lunetta and Balogh, 1999).

Researchers subsequently evaluated numerous advanced technologies in order to develop a more cost effective, rapid and reliable method to assist in the long-term monitoring of wetlands. The result was the application of multi-temporal LANDSAT 5 TM imagery for wetland identification in the States of Maryland and Delware. The methodology involved using two dates of TM imagery as single-date imagery could be improved upon by using an image scene from a seasonally wet period (Lunetta and Balogh, 1999). The hypothesis being tested was that classification accuracies of wetlands extracted from single-date imagery could be significantly improved by revision with information from the second date of LANDSAT TM data was selected to coincide with the seasonal period of wet soils (Lunetta and Balogh, 1999).

The methodology involved using two sets of LANDSAT TM images for the study area. The first image (11 June 1988) was used to develop an initial land cover map for the area. The second image (20 June 1986) was used to generate non-hydric and hydric soil data coverage. The June 1986 imagery corresponded to the "normal" seasonal wet period in that particular area. Ancillary data used in the study included historical precipitation and stream-flow records that occurred during the seasonal wet periods. Both coverages were then analysed using a GIS rule-based classification model in order to improve the classification accuracy of wetland classes.

The techniques used to identify wetland vegetation, soils and hydrology from satellite imagery are summarized in Table 3.1: according to Lunetta and Balogh (1999) below:

TABLE 3.1: TECHNIQUES USED TO MAP WETLANDS USING THREE WETLAND-RELATED PARAMETERS

IDENTIFICATION PARAMETER	MAPPING TECHNIQUE
1. VEGETATION	Vegetation coverage was produced from the single date 1985 LANDSAT TM image using an unsupervised classification approach. Visible bands 2 and 3 were selected to assist in the differentiation of saturated surfaces from that of other dark surfaces such as organic soils and asphalt. Band 4 was selected for sensitivity to foliar structure characteristics. Band 5 was used to differentiate soil moisture content. The unsupervised approach was used to identify signatures corresponding to unique spectral categories. This was followed by a maximum likelihood statistical classifier utilizing the statistics generated from the cluster analysis to assign each pixel in the image to a spectral category. Post classification into landcover categories was accomplished using stereoscopic interpretation of 1: 40 000 infrared photographs, soil maps and topographical sheets.
2. SOILS	Soil maps were used as ancillary data to identify areas that exhibit hydric soils.
3. HYDROLOGY	The image was divided into upland (non-hydric) and wetland (hydric) categories by applying a grey-level thresholding to the infrared bands of the LANDSAT TM image. Various density-slicing techniques were interpreted until a brightness threshold separating wetlands from uplands was found.

The GIS rule - based classification was implemented in a pixel-wise basis. Sader *et al.,* (1995) in Lunetta and Balogh (1999) found that rule based method for forest wetland classification was significantly better than unsupervised classification techniques. The outcome of the rule-based GIS classification was a new data coverage in which each pixel was re-coded based on vegetation type and hydric or non-hydric soil groups. The results of the single date LANDSAT TM classification showed significant confusion existed between wetland and upland forests, and wetland and upland agricultural classes. The overall accuracy of the single date seven class classifications was 68 per cent. The overall classification results of the multiple date seven-class classification were 83per cent. There were also significant improvements in the discrimination of wetland versus upland forests, as well as wetland surrounded by agricultural areas.

The overall results showed that classification accuracies of seasonally saturated wetlands could be improved when areas with wetland hydrology were merged with it. The overall results showed the applicability of using multi-temporal LANDSAT TM imagery to supplement existing wetland inventory maps for identifying the location and extent of wetlands in the United States of America. One of the most important limiting factors was that of the sensor spatial resolution (30 m). Many wetland areas smaller than 0.09 hectares had to be subjected to techniques that generalized the feature at that particular point.

Wetland inventory studies have been ongoing tasks of many organisations in the United States of America since these initial studies, with advances made in mapping techniques and the improvement of satellite sensor abilities (Jensen *et al.,* 1987; Roggeri, 1995; Lunetta and Elvidge, 1998; Elliot and Hektner, 2000). Improvements in using remote-sensed imagery include the use of colour infrared aerial photographs (Elliot and Hektner, 2000), the increased use of collateral data such as soil surveys, water resource data and digital elevation models (Lunetta and Elvidge 1998; Elliot and Hektner 2000). There has also been an increasing use of field reconnaissance prior to mapping and the employment of experienced field and conservation personnel used to validate the existing wetlands before mapping can take place in these areas.

An important initiative to collect information on the earth has been NASA's Earth Observing System (EOS), which comprises a series of satellites especially designed to study the complexities of natural resource mapping, for example, wetlands. Of relevance to wetland mapping is the ASTER sensor (Advanced Spaceborne Thermal Emission and Reflection Radiometer) on board the EOS Terra Spacecraft (NASA, 2001). The primary goal of the ASTER mission is to obtain high-resolution image data in 14 channels over targeted areas, as well as black and white stereo images. With a revisit time of between 4 and 16 days, ASTER will provide the capability for repeat coverages of changing areas on the earth's surface.

This high-resolution (between 15 and 90m) imagery acquired by the ASTER sensor is ideal for monitoring and studying the transitional environments between water and land such as wetlands, beaches, estuaries and rivers (NASA, 2001). As this data is not currently available in South Africa, it is therefore not an option for using it in local studies (SAC, 2001).

3.2.2 INDIA

In India, wetlands are mainly found in the cold zones of the high Himalayas and along the 7500 km of coastline. The relevant conservation authorities recognised the need to conserve these valuable and fragile ecosystems and constituted a National Wetland Committee. This body served to advise the national government on policy guidelines for implementing programmes of the conservation, management and research on wetlands (Rao *et al.,* 1999). Following the constitution of this body, sixteen wetland sites were identified for conservation and management on a priority basis. For nationwide mapping of wetlands using remote-sensing databases, a two-tier classification system has been developed. In this system, broad classes, namely inland wetlands and coastal wetlands, have been identified (Rao *et al.,* 1999).

Two recent studies highlight the need for reliable and accurate data on the extent and location of wetlands. The first was a project to delineate wetlands in part of the Sundarban Delta and its adjoining areas of West Bengal (Dwivedi and Rao, 1999). The primary conservation priority of these wetlands is the support of a rich and diverse variety of flora and fauna, and is used by the local community for aquaculture.

It is therefore imperative that precise information be collected on the nature and extent of these wetlands in order to ensure their optimal utilization. Due to the coastal location of the study site, cloud-free remote sensed data was not readily available. The study therefore aimed at evaluating the potential of the European Remote Sensing Satellite (ERS-1) and the Synthetic Aperture Radar (SAR) data for the detection and delineation of wetlands.

Microwave data was acquired for the study area in three seasonal periods, which included the dates, 1 October 1992, 29 April 1993 and 16 September 1993. Additional data collected either concurrently or close to the SAR overpass included: India Remote Sensing Satellite (IRS-IB) and Linear Imaging Self Scanning (LISS-II) data. Topographical maps (1: 250 000 and 1: 50 000) and other published reports and articles on wetlands in the area were also utilized.

The digital data processing techniques included:

a) Geo-rectifying the images
b) Extracting common wetlands areas from the microwave and optical data layers
c) Applying a linear-stretching technique and thereafter mapping wetlands through the density slicing approach by defining their range of Digital Numbers (DN) values (Rao *et al.*, 1999).

Visual interpretation techniques showed that wetlands could be delineated on the IRS-IB and LISS-II data layers, in conjunction with natural features extracted from a 1:250 000 topographical map. Following this process, a ground-truthing exercise was planned close to the ERS-I overpass of the area. Observations of hydrological conditions, vegetation type and soil characteristics were made. Wetlands identified during the field verification process was then identified and delineated on the different data layers.

The overall results showed that the sensitivity of microwave energy to moisture content of materials enabled the reliable delineation of wetlands along the coastal regions of India. The characteristic microwave response of open and calm water, behaving as a specular surface, and the mixed response of the water with varying vegetation cover provided a sound base for differentiating permanently waterlogged areas from seasonally saturated areas supporting paddy crops (Rao *et al.,* 1999)

3.2.3 AUSTRALIA

Australia is one the driest continents on earth in terms of the ratio of rainfall to runoff. Despite this fact, the continent has a large number of wetlands that are of various sizes and include a large number of ephemeral wetlands (Johnston and Berson, 1993). A study was initiated to develop simple remote-sensing techniques suitable for mapping and monitoring wetlands using LANDSAT TM data for inland wetland sites in Victoria and New South Wales. The study made use of wetland sites previously mapped by these departments in order to test and compare the results and types of information using different methods. The objectives of the study were twofold, namely:

a) To assess the usefulness of satellite data for mapping the extent and distribution of wetlands in selected areas
b) Assessing the use of satellite imagery for delineating vegetation communities.

According to the requirements of the regional mapping programme LANDSAT TM imagery was selected because of its high spatial resolution (30 m) (which was the limit of resolution required in the regional mapping programmes) and its useful range of spectral bands (seven bands including mid-infrared). According to Johnston and Berson (1993), the bands used for the study included:

a) TM 1 (visible blue) for information on water depth and turbidity. Blue radiation penetrates clear water to the depth of 50 m, so reflectance in this band is a function of water depth, substrate brightness and turbidity.

b) TM 3 (visible red) for information on soil colour and calculation of vegetation index.

c) TM 4 (near - infrared) for information on plant condition.

d) TM 5 (middle-infra-red) which is strongly absorbed by water, so that MIR (mid-infrared) response is very low from inundated areas or areas of high soil moisture.

The study took cognisance of the fact that wetlands in this area fill only seasonally, with resulting changes in vegetation. Two images were acquired for the three study areas. The images were rectified and registered to the map base for overlaying on a uniform platform. Topographical maps were used to collate the digital images to the study area. Digital image processing consisted of haze removal techniques to correct for atmospheric effects on individual bands (Johnston and Berson, 1993). Mapping the wetland areas required a simple classification into wetland and non-wetland areas. The assumption was that wetlands should be identified as areas inundated during the season of maximum rainfall. LANDSAT TM imagery from the late summer period (January/February 1988) was used to provide the maximum seasonal contrast. Simple density slicing of TM band 5 was used, in which all pixels below a given threshold were classified as "wet". These boundaries were then transferred from the image processing system to a GIS, for comparison with previously published data on the study sites. The resulting visual analysis showed:

a) Most of the water bodies on both sites could be easily distinguished in both spring and summer images.
b) There was a significant level of correlation in terms, of size and shape, between the remotely sensed data and previously published data.
c) Differences between the seasons were also apparent from the digital images.

The overall results showed that approximately 95 per cent of wetlands described as open water or marshes in other studies were similarly identified from the imagery using a density-slicing approach. Despite the above high correlation, only 50 per cent of freshwater meadows could be identified from the imagery. Seven areas greater than one hectare were identified using the satellite image but these areas were not identified in other published works. The study provides a method for wetland comparison in terms of wetland water status and vegetation productivity at different times or seasons. A limitation of the study was that wetland classifications were not verified in the field. Field verification would allow more useful wetland groupings to be defined as well as quantifying depth estimates or resolving whether depth estimates or turbidity was the influencing factor for the TM1 response (Johnston and Berson, 1993).

3.3 SOUTHERN AFRICA

A review of wetlands inventory programmes amongst the southern African countries showed the need for more co-ordinated collation of available information. There is a wealth of site-specific reports on wetland sites across southern Africa but very little has been done to integrate this information into suitable baseline products that can be used for strategic planning purposes (Taylor *et al.*, 1995). The author also reviews the wetland inventory status of selected countries in southern Africa (Table 3.2).

TABLE 3.2: WETLAND REVIEW SUMMARY (Source: Taylor *et. al* (1995).

COUNTRY	WETLAND DISTRIBUTION	INVENTORY STATUS	INTERNATIONAL DESIGNATION
1. Angola	Approximate wetland area: 4,750 kms². Most wetland types exist in Angola, including 70 000 ha of marine inter-tidal wetlands.	Due to many years of civil war, systematic inventory of wetlands has not been possible.	None.
2. Botswana	Approximate wetland area: 28 310 km². Most of the country's wetlands are associated with the Okavango and Zambezi Rivers. The country possesses few permanent wetlands, while there are widely scattered seasonal pans across the arid interior of the country.	Controlled photo-mosaic maps (1:100 000 and 1: 50 000) are available for the entire country. Ecological zoning maps of the Okovango Delta at scales of 1:100 000 and 1:250 000 show wetland location. No formal wetland inventory procedures exists, but wetland locations have been established.	None.
3. Lesotho	Total area of Lesotho: 30 344 km², Approximate wetland area: 200 km²	Studies include: ground surveys of mires on the central Thaba-Putsoa mountain range (Backeus 1988 in Taylor et. al 1995). An inventory using SPOT imagery was done on the Maluti/ Drakensberg Mountains (Schwabe, 1989; Schwabe and Nthabane, 1989 in Taylor *et al.*, 1995). Besides these selected studies, no formal wetland inventory has been completed.	None.
4. Swaziland	Total area of Swaziland; 17 365 km², approximate wetland area: no reliable estimate is available.	No systematic inventory has been conducted.	None.
5. Namibia	Approximate wetland area: 11807km². The country is predominately arid to semi-arid. The majority of wetland areas are made up of pans, fed by seasonal streams.	A complete set of 1:50 000 topographical maps is available with useful wetland information. A national wetland resource review was initiated by the Ministry of Wildlife, Conservation and Tourism. However, maps to delineate wetlands are lacking.	Namibia has applied to the Ramsar Convention to become a contracting party.
6. Mozambique	Approximate wetland area: 12 529 km². This total is an underestimate, considering Mozambique has extensive dambos, endorheic pans and swamps scattered across the country. There are extensive mangrove swamps along the coast and the coastal plain also has important wetlands, which are mostly riverine floodplains (Taylor *et al.*, 1995).	No national wetland inventory has been performed. A wide range of topographical maps, exists of variable age and quality.	None.
7. Zambia	Approximate area of large wetlands including shallow open waters: 38000km². The larger wetlands are associated mainly with the Zambezi River and its major tributaries.	No national inventory exists. There have been recommendations for an inventory to take place. This is further motivated by the fact that wetland areas support large wildlife communities.	Ramsar Convention: 2 sites (Kafue Flats and Bangweulu swamps.

8. Malawi	Approximate wetland area: 2730 km².	Mzembe, 1990 in Taylor *et al.*, 1995, describes the dambos of Malawi as covering 2.590-km. Most of this area is under traditional use. Complications regarding wetlands occur in view of the fact that different definitions are used in different publications concerning wetlands. It is *possible to arrive at a reliable estimate of* wetland type and distribution from published sources and available maps.	None
9. Zimbabwe	Total area of Zimbabwe: 390 310 km², approximate wetland area: 12800km².	Topographical maps and aerial photographs exist at various scales. Different views on type and distribution of wetlands of the area exists (Johnston *et al.*, 1995). With these differing views there is a need for a national wetland inventory to be conducted, for as yet, no national wetland map on Zimbabwe exists.	World Heritage Area designation sought for Mid-Zambezi Valley and Mana Pools
10.South Africa	Total area of South Africa: 1 184 825 km² Approximate natural wetland area: 2500km² Man made wetland: 2100km² Total: 0.39%	The country is well supplied with maps of all types and scales. This base information would allow an inventory to take place without major technical difficulties. Various wetland studies have been completed in different parts of the country, with Kwa-Zulu-Natal receiving the most attention. There is an indication of wetland losses in different parts of the country. The DEAT has announced an interest in a national wetland inventory, but a suitable methodology has not been agreed upon.	Ramsar Convention: 12 wetlands sites.

3.4 SOUTH AFRICA

South African wetlands are relatively small (in terms of size) compared to those of its neighbouring countries like Mozambique, but their distribution is widespread (Taylor et. al 1995). Although there are few large wetlands in South Africa, the present wetland areas play an important role in providing habitats for both plant and animal species. South Africa's wetland losses are expected to be high as a result of these areas being cleared and drained for agricultural purposes (Breen *et al.*, 1997). A detailed national wetland inventory for South Africa is still to be completed (Dini *et al.*, 1998). In terms of the requirements of the Ramsar Convention, South Africa has not yet fulfilled its obligations of designating wetland sites to be included on the list of protected wetland areas (Breen *et al.*, 1997).

The earliest studies focused on mapping the location of priority wetlands in KwaZulu-Natal (Begg 1986, 88, 89). The study was commissioned by the Natal Town and Regional Planning Commission in an effort to document and interpret the information available on wetland areas at that particular time. The project was initiated as a six - year research project, which began in 1984. The research was undertaken in four phases (as shown in Table 3.3), all of which focused on the wetlands in the province of Kwa Zulu- Natal.

TABLE 3.3: A SUMMARY OF THE FOUR PHASES OF THE RESEARCH ACCORDING TO Beeg (1989)

PHASE	YEAR	DESCRIPTION
PHASE ONE	June 1984 to December 1985	Aimed at producing a report on the extent, role and present status of wetlands in Natal.
PHASE TWO	January 1986 to June 1987	Aimed at conducting an inventory of wetlands in the Mfolozi Catchment (Beeg 1988).
PHASE THREE	July 1987 to March 1989	Aimed at describing the location, status and function of the priority wetlands in KwaZulu-Natal.
PHASE FOUR	April 1989 to March 1990	Aimed at the formulation of a wetland policy statement

Phase three of this study has relevance for this research investigation as it involves the processes of mapping wetland areas. Each wetland area was mapped according to its priority. An overall priority rating was derived by assigning numeric values to the rating of each user agency involved in wetland management (Begg, 1989). Priority wetlands were thus defined as those wetlands that were important as far as management and policy formulation is concerned. The methodology involved using black and white aerial photographs obtained from the Offices of the Surveyor-General and 1: 50 000 topographical maps. Areas identified as "wetland areas" had their boundaries delineated. The products of the study included a record of the delineated wetland area for management authorities directly involved.

Limitations of the study stem from the fact that it concentrated only on those wetlands that are classified as "priority" wetlands. The management and policy formulations regarding these wetland areas are unclear. The delineation methods used to identify "wetland areas" failed to take into account the dynamic nature of wetland ecosystems and seasonal period in which the aerial photographs were taken. The concentration on "priority" wetlands also prevented the inclusion of smaller wetland areas in the prescribed area (Begg, 1989). The study also utilized all the information that was available at that particular time and it was duly stressed that the findings needed to be expanded (Begg, 1989).

Two of the earliest studies to focus attention on wetland mapping through the use of remote-sensing techniques included Walmsley and Botten (1987) and Thompson (1994a,b). Walmsley and Botten (1987) focused on an evaluation of satellite imagery to assist in the inventory of wetlands. Apart from a practical example, the evaluation highlighted the need for a management policy for the rational utilization of wetlands as they were a diminishing resource. It also noted that wetlands are still severely threatened by man's activities (Walmsley and Botten, 1987). The pilot project included the use of LANDSAT MSS and TM data collected on different dates and years to detect existing wetlands in the Rietvlei and Natalspruit areas.

On the assumption that a wetland area would be the first to respond to rainfall, two images were obtained for MSS data (November 1972 and 1982). The LANDSAT TM data included an image collected in May 1984. Soil maps at 1:50 000 scale were used as reference data as no ground truth data existed. A minimum distance classification procedure was done on both MSS images, which produced wetland 'signatures' that fell within or around the area designated as wetland by the soil maps. Visual inspection of the classification indicated that some of the outlaying areas could have been wetlands but were not classed as such on the soil maps. Visual comparison of the 1972 and 1982 MSS imagery indicated a reduction in the extent of wetlands, due perhaps to the increase in irrigated lands and the fact that the area had experienced drought conditions.

The aim of investigating the potential of using TM imagery for detecting wetlands was not achieved as a drought was experienced in the area during the month in which the imagery was collected (May). The preliminary investigation brought to light the following issues regarding mapping wetlands using satellite imagery:

a) Distinguishing between irrigated lands, healthy vegetation and wetlands is a problem, which could be overcome by applying a more finely tuned classification procedure, multi-temporal imagery and reliable surface reference data.
b) The accuracy of soil maps can be questioned.
c) The aim should be to acquire imagery during a time or season when wetlands are evident and distinguishable from surrounding vegetation.
d) Drought is a complicating factor (Walmsley and Botten, 1987).

The second initiative was to evaluate the use of remote sensing technology for wetland mapping. The CSIR was contracted by the Department of Environment Affairs and Tourism to provide guidelines to resource managers on the use of satellite remote-sensing techniques to map and monitor wetlands in South Africa (Thompson, 1994a,b).

This evaluation sought to satisfy two objectives, namely:

a) Part one consisted of a guideline document with recommendations to resource managers on the application of remote-sensing technologies to specific wetland management problems.
b) Since both aerial photography and satellite imagery could be used in mapping wetlands, the decision on which one to use depended on the various capabilities of both technologies to best satisfy the requirements of the resource managers.

The importance of the guideline document was to inform decision makers and wetland environmental managers of the potential of using satellite imagery to delineate wetland areas. The above workshop was held as a mechanism for highlighting the important empirical issues of satellite sensor capabilities (as can be seen from Table 3.4) and in this way, apply knowledge of this technology to a wetland inventory for South Africa.

TABLE 3.4: A SUMMARY OF QUESTIONS CONTAINED IN THE GUIDELINE DOCUMENT (Thompson, 1994a).

QUESTION	SUGGESTED ANSWERS
1. What type of wetlands can be identified using satellite imagery?	The features identifiable on satellite imagery are dependent on two basic factors: (1) the size of the feature in relation to the minimum area that can be identified (2) the difference in 'spectral signature' between the feature and the surroundings. If a wetland 'type' is sufficiently different in either form or structure to its surroundings, then it should be visible. Wetlands that do not contain areas of open water may be more difficult to identify.
2. Can wetland conditions be inferred from satellite?	Physical factors affecting wetland condition can in general be mapped. Non-physical factors are more difficult to detect and must be inferred by indirect association.
3. Is the *final map* to be accurate in terms of scale and projection?	Satellite data has the advantage in that both the digital and hard copy products can be easily obtained in a geo-corrected format. This means that both the scale and mapping projection are accurate.
4. Is cost-effectiveness a key factor in your choice of data, rather than mapping accuracy?	Yes, it will typically be more cost-effective to use satellite imagery for areas larger than 20 x 20 km. In the case that high mapping accuracies and identification of the smallest wetland features are the key requirements, regardless of the cost, then small-scale aerial photography will always provide a more detailed picture.
5. Which spectral bands should be used if satellite imagery is chosen, in order to maximise information content.	LANDSAT TM imagery consists of seven spectral bands over the same ground area. Data recorded in the visible bands (i.e. 1 -blue, 2- green, & 3- red) will show internal detail within the water body (i.e. turbidity, depth and deposition features). Bands 4 (near-infrared), 5 (mid-infrared), or 7 (far infrared) will be good indicators of total water extent.
6. What are the minimum areas that can be reliably mapped from satellite imagery, in comparison to aerial photography?	LANDSAT TM 1 ha (i.e. 100 x 100 metres) SPOT XS 0.3 ha (i.e. 54.8 x 54.8 metres)
7. Is the area you intend to map larger than 20 x 20 Km?	**Yes** - *It will be more cost effective to use satellite imagery if the area is larger than 20 x20 Km,* especially if information on the surrounding land cover/ land use is required. **No** - It will typically be more cost effective to use aerial photography for an area less than 20 x 20 km.

8. What frequency of information is possible from satellite imagery?	Satellite imagery is recorded and archived on a regular basis, which makes it an ideal tool for long and short-term monitoring. LANDSAT TM is updated every 16 days (cloud permitting). SPOT data is capable of being undated approximately every 22 days, although not every overpass is recorded, unlike LANDSAT TM.
9. Mapping features smaller than 1 ha	Satellite imagery is able to provide a fairly accurate estimation of small wetlands, where the wetland consists primarily of open water. For small wetlands defined in terms of differences in vegetation or species, the satellite imagery will not be applicable. Actual wetland or water extent can be accurately achieved if the feature is both larger than the minimum area that can be mapped operationally. LANDSAT TM imagery is not able to map features with repeatable accuracies below one hectare. Although one hectare is equivalent to 100 x 100 metres, and LANDSAT TM has a spatial resolution of 30 x 30 metres, in reality the minimum area that can be mapped is approximately three to four times larger. For example, approximately 100 x 100 metres for LANDSAT TM (i.e. 1 ha). SPOT XS data has an approximate minimum mapping area for operational purposes of 60 x 60 metres (i.e. 0.3 ha). This is more suited for mapping smaller features. However, SPOT has limitations in terms of (1) coverage of a single image (2) inadequacy of differentiating vegetation or soil moisture information.
10. Mapping only features larger than 1 ha	All satellite imagery is ideally suited to mapping wetland features larger than one hectare in size. The appropriate data type to choose is dependent on the area to be mapped, and the minimum size of the wetlands of interest. For wetlands between 1 - 25 hectares in size, either SPOT or LANDSAT will be used cost effectively. For wetlands larger than 25 hectares it would be more appropriate to use LANDSAT TM.

The second part of the evaluation was a workshop forum where resource managers (both remote-sensing and nature conservation communities) discussed current technical capabilities and resource management requirements for wetland management. The workshop provided information on three levels, these included:

a. National, regional, local and community needs for wetland management were identified.
b. A review of current applications of remote-sensing technologies was done.
c. Future research requirements were identified.

Future research requirements, as identified by the workshop members, included:

a) Continued research to enhance the identification of terrain and vegetation.
b) A stronger emphasis on the application of remote sensing linked to GIS techniques for satellite data, with cost-effectiveness as an important factor.
b) Applications of new technologies such as video-grammetry for depth measurement in water bodies and effective wetland identification.

Following this workshop several studies were completed on wetland identification in KwaZulu-Natal. The first included a pilot project to compile an inventory of wetlands in the Natal Drakensberg Park (Dely *et al.*, 1995). An aim of the pilot project was to evaluate the effectiveness of using satellite imagery to determine the extent and location of wetlands in the area (Dely *et al.*, 1995). The Natal Drakensberg is important in terms of its catchment qualities, as it supplies water to both KwaZulu-Natal and Gauteng Provinces. The Drakensberg Park wetlands are also important in that they provide habitats for a variety of species within the area (Dely *et al.*, 1995). Recognising the importance of wetlands in the Drakensberg Park, the KZN Wildlife Service (previously Natal Parks Board) provided a motivation to the Department of Environmental Affairs and Tourism for the area to be designated to the List of Wetlands of International Importance under the Ramsar Convention.

This motivation required the compilation of an inventory of wetlands in the Drakensberg Park. This project also presented the opportunity to evaluate and test the mapping, classification and inventorization techniques on a small scale (Dely *et al.*, 1995). Three mapping techniques were explored:

a) Mapping wetlands using aerial photography;
b) Mapping wetlands using orthophotographs;
c) Mapping wetlands using satellite imagery and topographic analysis.

The techniques used to interpret the orthophotographs and aerial photographs involved observing colour, tone and textural patterns from the variable reflectance of the different vegetation types. The purpose of this was to derive a characteristic wetland signature to delineate wetlands throughout the study area. The differences in photographs exposure and the differences encountered in using colour and black and white media were overcome by evaluating morphological criteria such as size and shape of the land, to help delineate wetlands. Landmarks were identified and used as reference points from which wetlands could be mapped. Areas that were shadowed and could possibly obstruct the identification of wetlands were demarcated for field investigation. Following the evaluation of aerial and orthophotographs, three different types of satellite imagery were evaluated for the identification of wetlands:

a) SPOT imagery;
b) LANDSAT TM imagery;
c) Russian Satellite imagery.

LANDSAT TM imagery was given preference and chosen for the study area. The other two sources of satellite data proved inadequate for the requirements of the study, primarily because of limited coverage of the area (SPOT) and a limited spectral resolution for the mapping of wetlands (SPOT and Russian Satellite imagery). LANDSAT TM data could also be purchased in a processed, geometrically corrected format (Dely *et. al* 1995). The selection of satellite imagery was done in accordance with the period of the year in which the best climatic conditions for wetland identification occurred.

An assessment of the monthly rainfall data for the two years prior to the time the study was to be conducted was done in order to derive information on the seasonally 'wet' period of the year. This confirmed that wetlands are best mapped during a seasonally wet time of the year, when maximum differentiation occurred between the colours of stream-bank vegetation, non-wetland vegetation and riparian grasslands.

Methods used to analyse the data consisted of both unsupervised and supervised classification techniques. The topographic analysis involved constructing a digital terrain model (DTM) of the Natal Drakensberg Park. This enabled the analysis of the topography of the area in order to increase the identification of potential wetlands. The findings revealed the following factors concerning the mapping of wetlands within the study site from satellite imagery:

a) Satellite imagery did not allow wetland areas to be sufficiently distinguished from riparian vegetation and grasslands.
b) Satellite imagery was not able to detect the majority of wetlands given that the size-class distribution of wetlands in the study area was frequently less than or equal to 1 ha (Dely *et al.*, 1995).

Despite these shortcomings, the pilot project demonstrated the advantages of using satellite imagery for coarse mapping of wetlands, both in terms of cost-effectiveness, data integration and data manipulation techniques. The study also highlighted the relative efficiency of using satellite remotely sensed imagery for mapping wetlands in inaccessible areas of the Drakensberg Park.

During August 1995, the Town and Regional Planning Commission contracted an independent GIS organisation to compile an inventory of the wetlands in the Mkomazi Catchment. According to the terms of reference, the objective of the exercise was to map all wetlands within the Mkomazi Catchment greater than 10 hectares in extent, using digital analysis of satellite imagery. The data used for the project included:

a) LANDSAT TM satellite imagery;
b) Aerial photography;
c) Orthorectified aerial products at a scale of 1:10 000.

A LANDSAT TM image was acquired for the study area. The analysis of the satellite image involved the selection of three spectral channels (band 3-visible red, band 4 – near-infra red and band 5–mid-infrared) as the most appropriate spectral bands from which wetlands could be delineated (Whyte and Shepard, 1995). The spectral bands were chosen based on previous research both in South Africa and abroad (Whyte and Shepard, 1995; Johnston and Benson, 1993). Different image processing techniques were then applied to the chosen image in order to ascertain the best possible method of delineating wetlands. These techniques included:

a) Using single-band properties to derive a characteristic wetland signature
b) Multi-spectral analysis
c) Band ratios
d) Automated and supervised classification techniques

According to Whyte and Shepard (1995), these intensive analysis techniques were unsuccessful for delineating wetlands in the study area. Although positive identification of wetland sites was made with certain analysis techniques, no single process was able to accurately highlight wetland areas for the full catchment area. The insufficient nature of satellite imagery to map wetlands in the study area led to a change in methodology of the study. This involved using finer resolution aerial photography and orthophotgraphs. An extensive networking strategy followed which required field officers working in the area to assist in the identification of wetlands. This study highlighted several limitations in using satellite imagery to delineate wetlands:

a) The difficulty in establishing set criteria for mapping wetlands.
b) Limited use was made of the satellite imagery, given the different parameters that relate to wetland areas.
c) Cost seemed to be a factor in determining the strategies used for wetland mapping. Had this not been the case, a possibility exists that alternative strategies of using the data could be found.

In light of the above, Taylor *et al.* (1995) provides useful guidelines for those authorities attempting wetland inventories which includes:

a) Wetland areas can be best detected through their infra-red spectral reflectance, which detects vegetation and soil moisture related features.
b) LANDSAT TM bands 4,5 and 7 are the infra-red bands but most wetlands discrimination studies has used LANDSAT TM band 5, however band 1 can be used to detect open water, and the use of TM bands 1 and 5 can discriminate wetland vegetation from open water.
c) There is a preference to use imagery from seasons when wetland areas are moist (spring and early summer), while surrounding land is dry.
d) Manual visual interpretation of aerial photographs is currently unbeatable for defining wetland boundaries. However, the date or season of these photograph will affect recognition of seasonal wetlands and their boundaries.
e) Aerial photographic interpretation is time-consuming and therefore an expensive task.
f) In contrast to topographic maps, soils maps showing hydromorphic soils areas are comparatively useful sources of information.
g) It is incorrect to dismiss the use of existing topographic maps. They show drainage patterns, contours and altitude and are useful in providing framework for inventory information.

3.5 AN ASSESSMENT OF REVIEWED WETLAND STUDIES USING REMOTELY SENSED DATA

The reviewed literature highlights many important factors regarding the importance of wetlands, different techniques for mapping these areas from satellite imagery and results and limitations. In addition to the actual mapping procedures described, there seems to be a consensus in all the studies that wetlands are important areas worthy of conservation and management. In this regard, inventories within these countries form the basis of action towards effectively managing these fragile ecosystems. Wetland delineation techniques seem to vary between countries. This is largely as a result of differences in technical expertise, knowledge and the objectives of the studies in particular countries. Developing countries (like South Africa) have initiated studies that are orientated towards evaluating different available technologies and methods of data integration. Countries (like the US) have moved away from evaluation strategies and are using remote-sensing technology and advanced software applications for various other environmental applications associated with wetland environments. Divergent trends in different countries have created disparities in terms of wetland inventory progress. There is an urgent need for developing countries with limited technological expertise to perform wetland inventory studies for vast areas in an efficient manner. Satellite imagery holds much promise in this regard, as it is able to aid wetland mapping by providing coverages of vast areas, in different seasons and within an affordable level of acquisition.

This study seeks to address these issues by evaluating the use of multi-temporal multispectral LANDSAT ETM+ imagery to map wetlands using different image processing techniques. Multi-temporal imagery is used to highlight the optimum period of the year to map wetlands. Multispectral imagery will be used to evaluate the ability of the different spectral bands of LANDSAT ETM+ satellite imagery to highlight the different wetland characteristics. Ancillary data (topographical 1:50 000 maps) will be used as well as evaluated for consistency in identifying wetland areas. Several different classification techniques will be used to map wetlands after which a field verification exercise will attempt to confirm results of the highest classification.

CHAPTER FOUR: MATERIALS AND METHODS

4.1 INTRODUCTION

This chapter deals with the data sources and methods undertaken in this research. Many of the steps used in various sections of processing the data are adopted and improved upon from the reviewed studies (Chapter Three). There are five parts: data acquisition, digital image processing, data generalization, accuracy assessment and field verification.

4.2 INPUT DATA ACQUISITION

4.2.1 SATELLITE DATA ACQUISITION

This study concentrated on the use of remotely sensed data obtained from a multispectral sensor on an orbiting space platform. The imagery used was LANDSAT Enhanced Thematic Mapper Plus (ETM+). Attributes of the acquired satellite imagery are described in Table 4.1.

TABLE 4.1: IMAGERY OBTAINED FOR THE RESEARCH INVESTIGATION

SATELLITE SENSOR	DATE OF CAPTURE	PATH/ ROW	CLOUD COVER	BAND CHARACTERISTICS
1. LANDSAT 7 ETM+ L721168080_0801990712	1999/7/12 (winter)	168-0-80	0	**WINTER IMAGERY** **9** bands in total – Bands 1,2,3,4,5,7 (28.5m spatial resolution) Bands **6.1** and **6.2** –Thermal bands (60m spatial resolution) [1]Band **8**- Panchromatic Band (15 m Spatial resolution)
2. LANDSAT 7 ETM+ L721168080_0802000120	2000/1/20 (Summer)	168-0-80	0	**SUMMER IMAGERY** **9** bands in total – Bands 1,2,3,4,5,7 (28.5m spatial resolution) Bands **6.1** and **6.2** –Thermal bands (60m spatial resolution) * Band **8**- Panchromatic Band (15 m Spatial resolution)

[1] Band 8 (panchromatic band) was subjected to a different image processing technique due to its higher spatial resolution (15 meters), which would make identifying smaller wetlands problematic.

The imagery was purchased from the United States Geological Survey (USGS) at a processing level of *nine. Figures 4.1 and 4.2 show both the summer and winter LANDSAT ETM+ images (in false-colour composite), which were acquired for the research. The COMPOSITE Module produces a colour composite image from three bands of byte binary image. A twenty-four (24) and eight (8) bit composites can be produced. The former is used for display and visual analysis (ERDAS, 1997).

4.2.2 GEOGRAPHIC INFORMATION SYSTEM (GIS)

As satellite images are captured on a pixel-by-pixel basis, both a raster-based GIS (IDRISI) and a vector-based GIS (ArcView 3.2) were applied. Both raster and vector-based systems were selectively used while the main image processing software included ERDAS Imagine 8.4. As an example, the vector-based GIS (ArcView 3.2) was applied when infrastructural data such as roads and rivers had to be analysed.

4.2.3 SCENE CONSIDERATIONS

Both LANDSAT 7 ETM + scenes were chosen according to specific seasonal times in their respective years. To achieve a maximum contrast of wet and dry conditions for the identification of wetlands (Johnston and Berson, 1995). An evaluation of rainfall data was done from December 1999 to January 2000 from all weather stations within the study area. The analysis of means for the rainfall data within the period December 1999 and January 2000 is highlighted in table 4.2.

* Level 9: Radiometrically corrected. Geometric corrections are applied in both along- scan and across-scan direction using GCP's. The scene is corrected and aligned to a map projection.

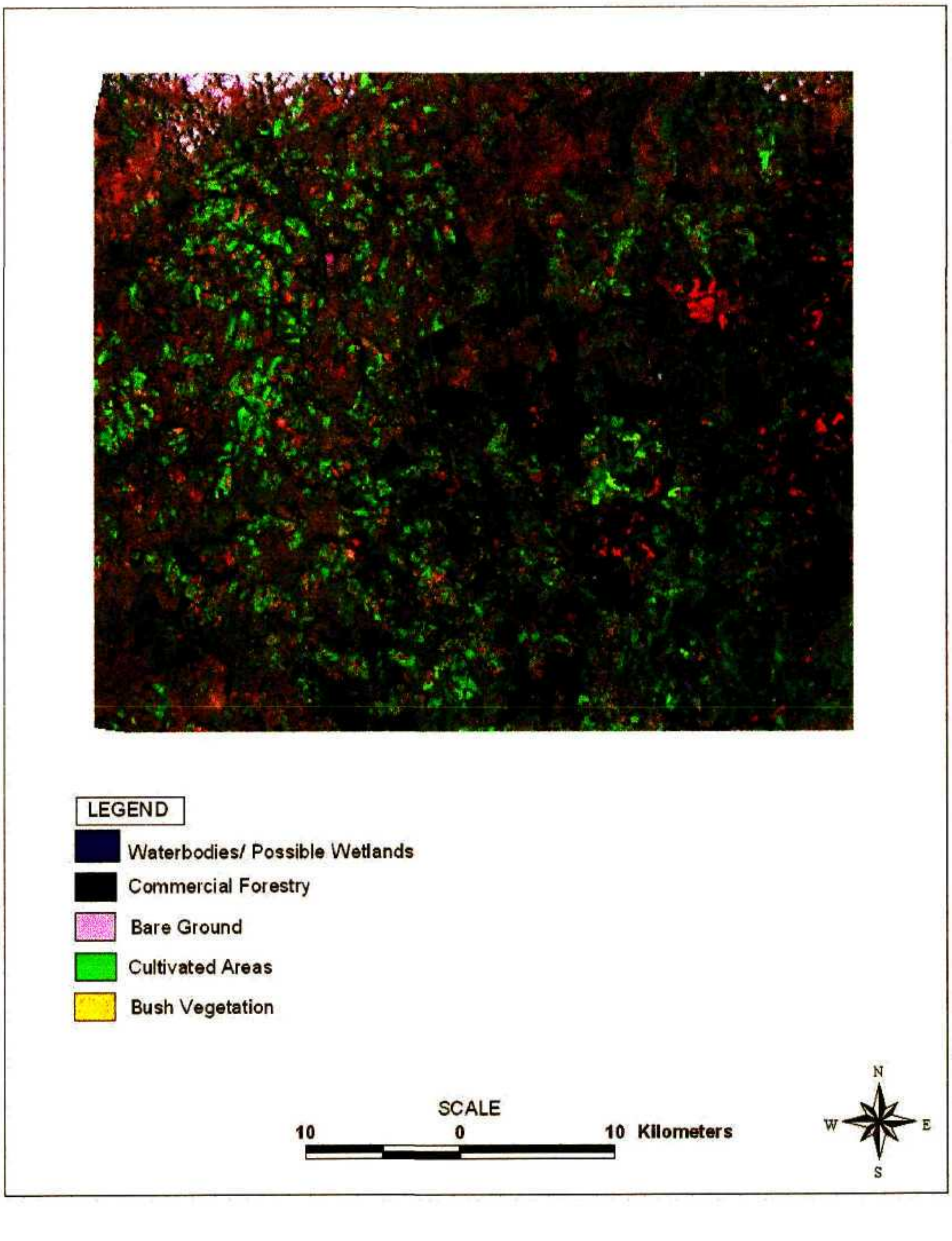


FIGURE 4.1: FALSE COLOUR COMPOSITE (FCC) of LANDSAT ETM+ SUMMER IMAGE.

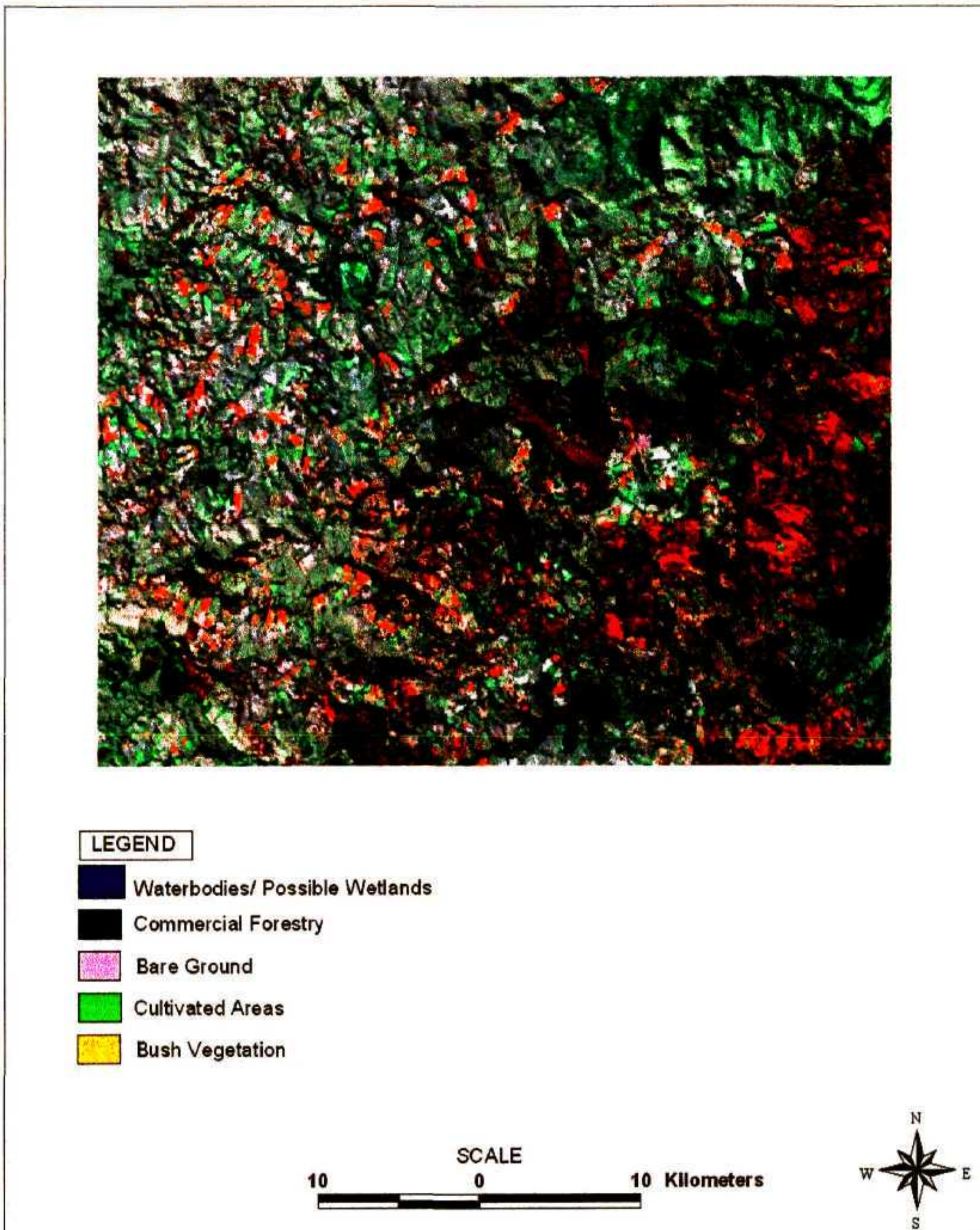


FIGURE 4.2: FALSE COLOUR COMPOSITE (FCC) OF LANDSAT ETM + WINTER IMAGE

4.2.4 ANCILLARY DATA SOURCES

4.2.4.1 TOPOGRAPHIC MAPS

Sixteen 1: 50 000 topographic maps (15' S by 15' E) cover the study area: 2930AA, 2930AB, 2930AC, 2930 AD, 2930BA, 2930BB, 2930BC, 2930BD, 2930CA, 2930CB, 2930CC, 2930CD, 2930 DA, 2930DB, 2930DC, 2930DD. These topographical maps were used in digital format during the visual interpretation stages of image processing to obtain the following information:

a) Detect the large wetland areas mapped on the topographical sheet compared to the spectral information available after the classification process.
b) Distinguishing between different types of land use.
c) Detecting shadows of certain elevated areas so that this information can be used in the classification processes.
d) Determining hydrological characteristics such as rivers and farm dams.

4.2.4.2 RAINFALL DATA

Rainfall data acquired from the Computing Centre for Water Research (CCWR), Pietermaritzburg, was used to determine the months from which the satellite data could be chosen (as shown in Table 4.3).

4.2.4.3 WETLAND VERIFIED DATA FOR THE STUDY AREA

The results of the image classification were initially compared to existing wetland data collected in the Mgeni catchment. The data was collected initially by Scotney (1970) as part of a research into soil characteristics and land use planning in the Howick area which encompasses the current study area. Scotney (1970) determined wetland areas in terms of soil profiles and the use of aerial photographs at a scale of 1:250 000. This data was updated in 1996 with attribute information (Kotze, D. Pers comm.)

TABLE 4.3: RAINFALL DATA USED TO SELECT THE SATELLITE DATA

1. OBSERVED DATA	MONTH	MEAN	STATION NAME
a. Wettest	January	212.7 mm	Hancock J. Howick
b. Driest	July	2.4 mm	Aberdeen Angus Stud
2. *Observed and Patched data	**Month**	**Mean**	**Station Name**
a. Wettest	January	208.5 mm	Fannim A Dargle
b. Driest	July	2.4 mm	Aberdeen Angus Stud

(Source: CCWR, 2001)

4.3 DIGITAL IMAGE PRE-PROCESSING AND PROCESSING METHODS

Prior to image processing, all datasets were loaded onto a Silicon Graphics (Model 02) computer running on IRIX 6.5.7, which supports ERDAS Imagine Professional 8.4 software. This also included all ancillary data (topographical layers, hydrological data, verified wetlands data). This data was then re-projected according to the satellite image projection, i.e. Transverse Mercator (Spheriod), WGS84 (Datum), with a central meridian of 31 degrees. All datasets were checked for 'fit' by super-imposition onto the summer imagery.

The CLUSTER module in IDRISI (Eastman,1997) was used to perform a histogram peak-cluster analysis. A peak is defined as a value with a greater frequency than its neighbours on either side. Once peaks have been identified, all possible values area assigned to the nearest peak and all the divisions between classes fall at midpoints between peaks. The CLUSTER procedure is fast and effective in uncovering the basic landcover structure of the image by determining the number of classes into which the image can be classified (Eastman, 1997). In this investigation, a broad classification was used in which a class is determined by containing a higher frequency than all of its non-diagonal neighbours.

* Observed and patched data includes data (readings) that was missing for a particular weather station and therefore an estimation needed to be made for that particular weather station.

4.3.1 UNSUPERVISED CLASSIFICATION

The unsupervised classification was achieved by producing a standard false-colour composite image, being a cross-classification of three bands (Bands 4,3,2) of LANDSAT Enhanced Thematic Mapper Plus (ETM+). False-colour composites appear similar to an infrared photograph where objects do not have the same colours or contrasts as they would naturally. False-colour composites have been used successfully for providing a maximum contrast of water and upland areas for wetland mapping purposes (Johnston and Berson, 1995). This band combination allows easy recognition of the contrast of vegetation (red) and water (blue or black). A broad generalization retaining all the clusters from the false-colour composite was chosen and the image was classified according to 20 main classes, which were the number of class categories emerging after the CLUSTER analysis. It was also decided to perform an additional classification step in which the images were divided into the maximum number of classes according to their digital number values. An unsupervised classification with 255 classes was also performed. This step enabled the researcher to apply pattern recognition techniques (ERDAS, 1997) by dividing the image into its maximum number of classes. This division would spectrally enhance the image for the human eye to sort certain textures, patterns and colours into categories (ERDAS, 1997). Unsupervised classifications such as the 20-class classification and the pixel-based classification (255 classes) have been also used in other wetland studies (Lunetta and Balogh, 1999).

4.3.2 SUPERVISED CLASSIFICATION

Through an interactive examination (using the INQUIRE modules) of the unsupervised classification procedures in ERDAS, topographical map sheets and the available hydrological data, the researcher was able to recognise the classes that most likely represent wetlands. Specific large wetland areas were identified based on the previous unsupervised classification and the topographical analysis, and these were selected as training sample sites.

The seed pixel tool is preferred for the process of supervised classification as it automatically generates homogenous pixels (in terms of spectral characteristics) to form polygons that can be used as training sites. It can, however, sometimes overestimate class variance (ERDAS, 1997). The Seed Pixel method proved adequate for the specified tasks, as the researcher was able to choose training samples that were represented by single pixels, which could be used as a model pixel against which other pixels contiguous pixels are compared. With a set of reliable signatures that represents wetland areas created and evaluated, a classification was performed on both summer and winter images using a Maximum Likelihood decision rule (ERDAS, 1997). The Maximum Likelihood classifier considers not only the cluster centres but also its shape, size and orientation. This is achieved by calculating the statistical distance based on the mean values and covariance matrix of the clusters. The statistical distance is a probability value and a pixel is assigned to a class (cluster) to which it has the highest probability (Janssen, 2000).

4.3.3 LEVEL SLICING (PANCHROMATIC IMAGES)

A level-slice procedure is done using panchromatic bands (15 metre resolution) and is similar to a histogram equalisation in that it divides the data into equal amount (levels). The effect on the data is that spectral values are grouped together at regular intervals into a discrete number of levels, each with one output brightness value (ERDAS, 1997). The motivation behind a level-slice approach being used in this research investigation is to maximize the recognition of wetlands using a 15 metre resolution (panchromatic bands) and also using the spectral classes from the already classified images (20 and 255 class) as a guide. Both summer and winter images were subjected to a level-slicing approach. Identifying the spectral class groupings that indicated 'wetlands' in both supervised and unsupervised images aided identification of wetlands on the panchromatic images. Spectral levels that represented wetlands were then given a specific "signature" which were then evaluated in terms of the previous procedures.

4.4 DATA GENERALIZATION

The primary focus of the investigation was the mapping of wetlands in the study area. Time constraints did not allow a detailed landcover classification to be completed and as a result, only wetland-related features were targeted. In instances where spectral confusion were noticed between different landcover classes, for example: grassland and bush vegetation, the researcher based the final decision of that class by inspecting other areas with the similiar spectral response.

4.5 ACCURACY ASSESSMENT

An accuracy assessment was done using Arc View 3.2 (ESRI 1996). Each visually interpreted classification (unsupervised/ supervised and level-sliced classifications) was converted to binary images using the RECODE module in ERDAS (ERDAS Field Guide 1997). Binary images are images consisting of two numerical values (zero's and one's). The zeros represented non-wetland areas and the ones represented wetland areas as per classified image. These binary images were then subjected to cleaning of vector layers and building of vector topology using the VECTOR module in ERDAS, after which they were converted into shape file format (.shp). Classified and mapped wetlands were then shown in polygons representing the location of the 'extent of each wetland'.

Both data layers (verified wetland comparison data) and classified mapped wetland images were then superimposed. A verified random sample of 100 wetland polygons was chosen from the attribute table of the wetland data layer and this checked against the classified mapped wetland images. Accuracy of these classified mapped wetland images was determined in term of proximity and shape of the classified polygons in relation to the wetland verified data layer.

On completion of the accuracy assessment procedure, it was decided that a field verification exercise was needed. Forty random wetland sites were selected along the R103 for ease of access. Each site was located using a (Global Positioning System) GPS and a detailed map of the wetlands. The extent of each site was roughly determined and the site was inspected for the presence/ absence of a wetland.

4.6 SUMMARY

A wide variety of techniques, specifically designed for delineating wetland areas and patterns, has been employed in this study (Figure 4.3). They include image-processing techniques, field-verification data and accuracy-testing techniques. By combining all these processes and data sets, it was possible to derive spatially significant information regarding wetland size and position. Ancillary data was used as independent data sources for testing and evaluating the image classification stages. This research investigation used image classification techniques from known studies to highlight wetland areas. Multi temporal satellite imagery, seasonal considerations, pixelwise and broad classification techniques as well as field verification exercises have been used before with a high degree of success (Anderson and Herdin, 1992; Lunetta and Balogh, 1999; Rao *et al.,* 1999; Johnston and Berson, 1995; Walmsley and Botten, 1987).

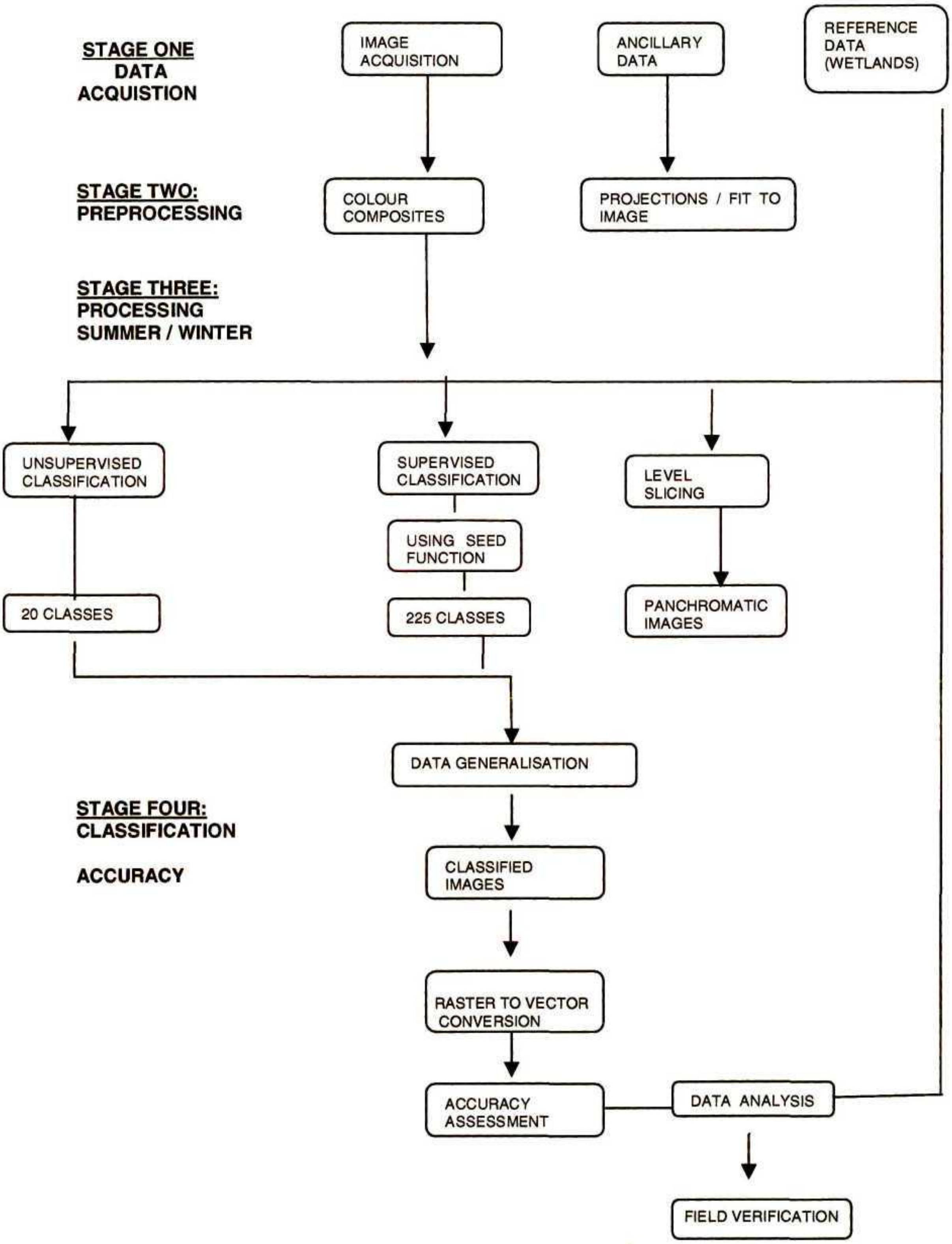


FIGURE 4.3: MAIN STAGES OF THE RESEARCH INVESTIGATION.

CHAPTER FIVE: RESULTS AND DISCUSSIONS

5.1 UNSUPERVISED CLASSIFICATION

5.1.1 TWENTY CLASSES

The unsupervised classification using 20 classes enabled the researcher to establish a maximum set number of divisible classes for the image in order to get an overview of the different land cover classes. Lunetta and Balogh (1999) also used this technique to uncover broad landcover classes. This technique also enabled the researcher to gain an understanding of the position and extent of the larger wetlands and the large water bodies. Both summer and winter images were classified and the results showed different land cover classes that included wetlands and water bodies, especially in the summer image.

The classification of the summer image was done with relative ease as the main classes were easily identifiable, since the topographical maps were used as an interactively tool to guide the identification of the main classes, such as cultivated lands, forestry, rivers (both perennial and non perennial) and dams (both farm dams and natural dams). Wetlands and water bodies were identified in the summer image by their spectral response (blue), their proximity to perennial rivers and their similar identification on the topographical sheets.

The winter image proved difficult to classify, as there seemed to be no distinct spectral signature for wetlands and waterbodies, except large waterbodies such as the Midmar Dam. The topographical maps were limited for this task as there was a tendency to highlight distinct smaller areas whilst the classification using 20 classes tended to group smaller areas into larger areas. For example, the difference between grasslands and bush vegetation was difficult to detect as both shared the same spectral response. Large wetland areas identified on the summer-classified images were selected and subjected to a quick field verification to gain an understanding of their positions, as stated on the classified image.

Ancillary data in the form of topographical maps were used in this field verification exercise to determine positional coordinates (latitude and longitude). The differences between the summer and winter images using this classification technique produced the following results:

a) Large wetland areas could be detected on the summer image (Subscene 5.3 A).
b) Similar areas on the winter scene are classified as grassland vegetation, fire scars and bare ground (Subset 5.3 B).
b) There is considerable spectral overlap between forestry shadows, wetlands and burnt areas in the winter scene (Subset 5.3 B).
c) The summer classified scene highlights wetland areas around rivers (Subscene 5.3 A).

An evaluation of the classification indicated that the smallest identifiable wetland was between 6-8 pixels, which is a ground area of approximately 180 metres. This was also observed in the first field verification exercise done soon after the classification. The classification as confirmed in the field verification exercise, seemed to capture large open water bodies and wetland areas while smaller wetland areas remained undetected. Figure 5.3 (A) highlights one of these large wetland areas near the Midmar Dam mouth. The unsupervised classification (summer and winter images) using 20 classes produced low classification accuracies for both images. The overall summer classification accuracy (polygons with a wetland signature) was 55%. The winter image classification revealed an accuracy of 39% (Figure 5.1). The low classification accuracies for both images resulted from two main factors:

a) Using a broad classification parameter (20 classes) implied a loss of spatially insignificant classes that could be vital to decision makers (for example, smaller wetland sites and certain wetlands systems found along rivers) (Eastman, 1997).
b) The comparison wetland data (Scotney 1970) identified wetland areas that were inconsistent with the classified image. According to the field verification and the analysis of the classification, these areas had either changed in land use or the original wetland area had been drained.

PLATE 5.1: AN EXAMPLE OF A WETLAND AREA THAT WAS DRAINED FOR AGRICULTURAL PURPOSES.

PLATE 5.2: COMMUNITIES BENEFITTING FROM WETLAND AREA NEAR MOOI RIVER

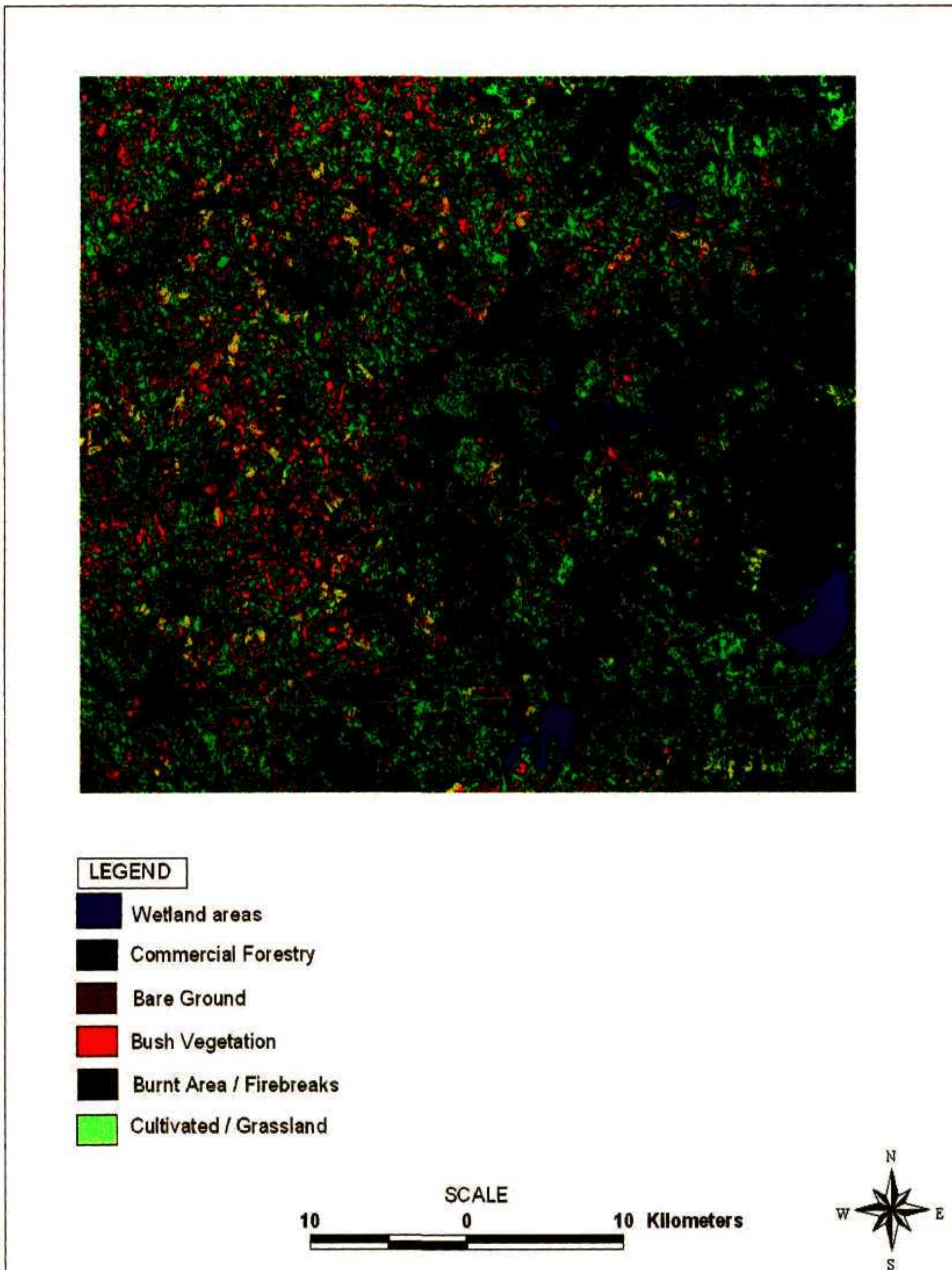


FIGURE 5.1: UNSUPERVISED CLASSIFICATION: WINTER IMAGE (20 CLASSES)

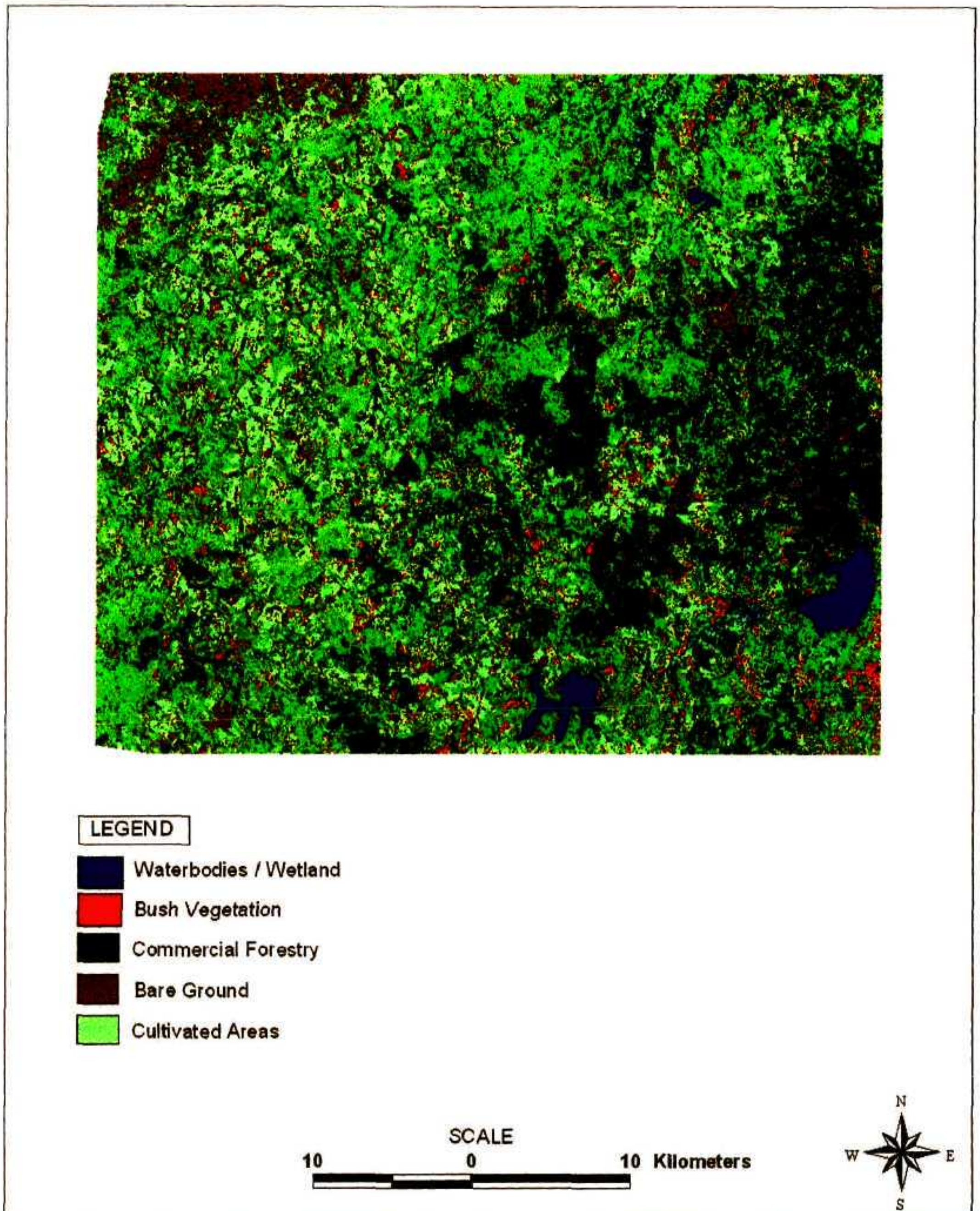


FIGURE 5.2: UNSUPERVISED CLASSIFICATION: SUMMER IMAGE (20 CLASSES)

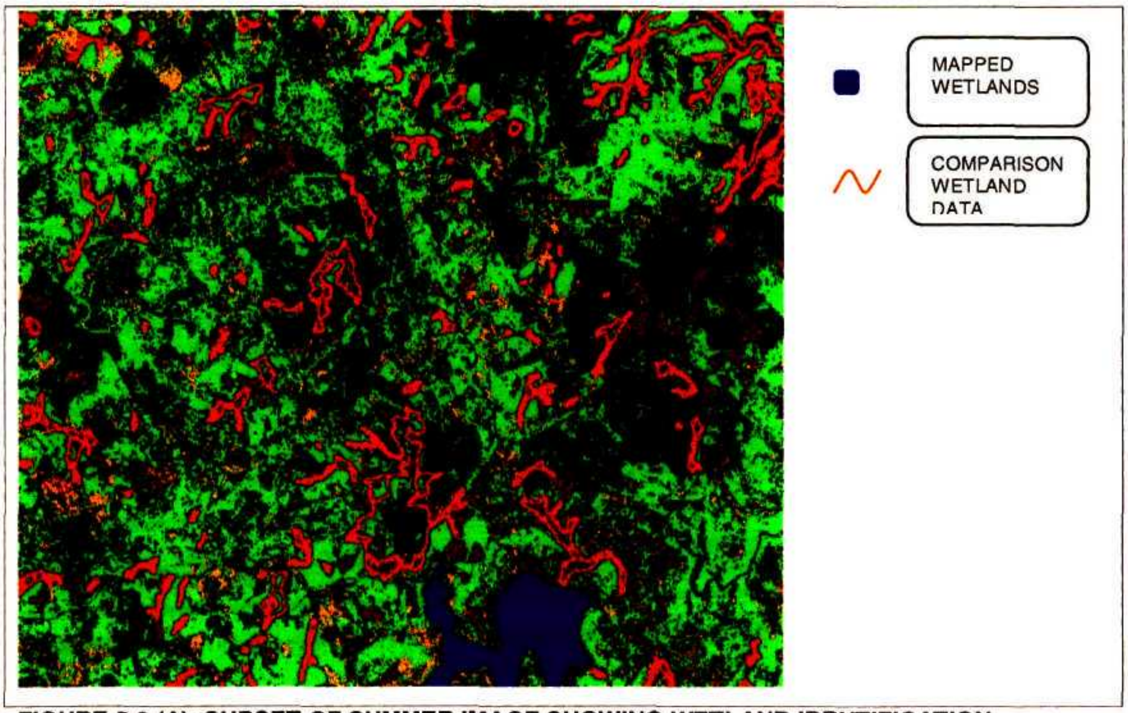


FIGURE 5.3 (A): SUBSET OF SUMMER IMAGE SHOWING WETLAND IDENTIFICATION.

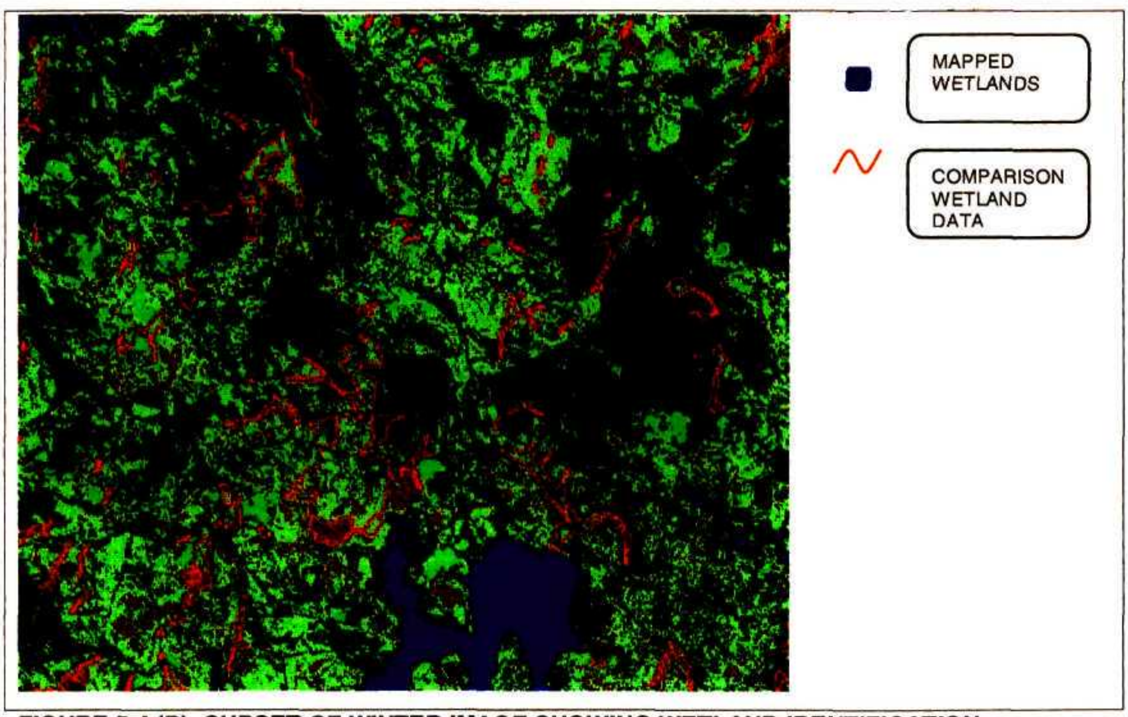


FIGURE 5.4 (B): SUBSET OF WINTER IMAGE SHOWING WETLAND IDENTIFICATION

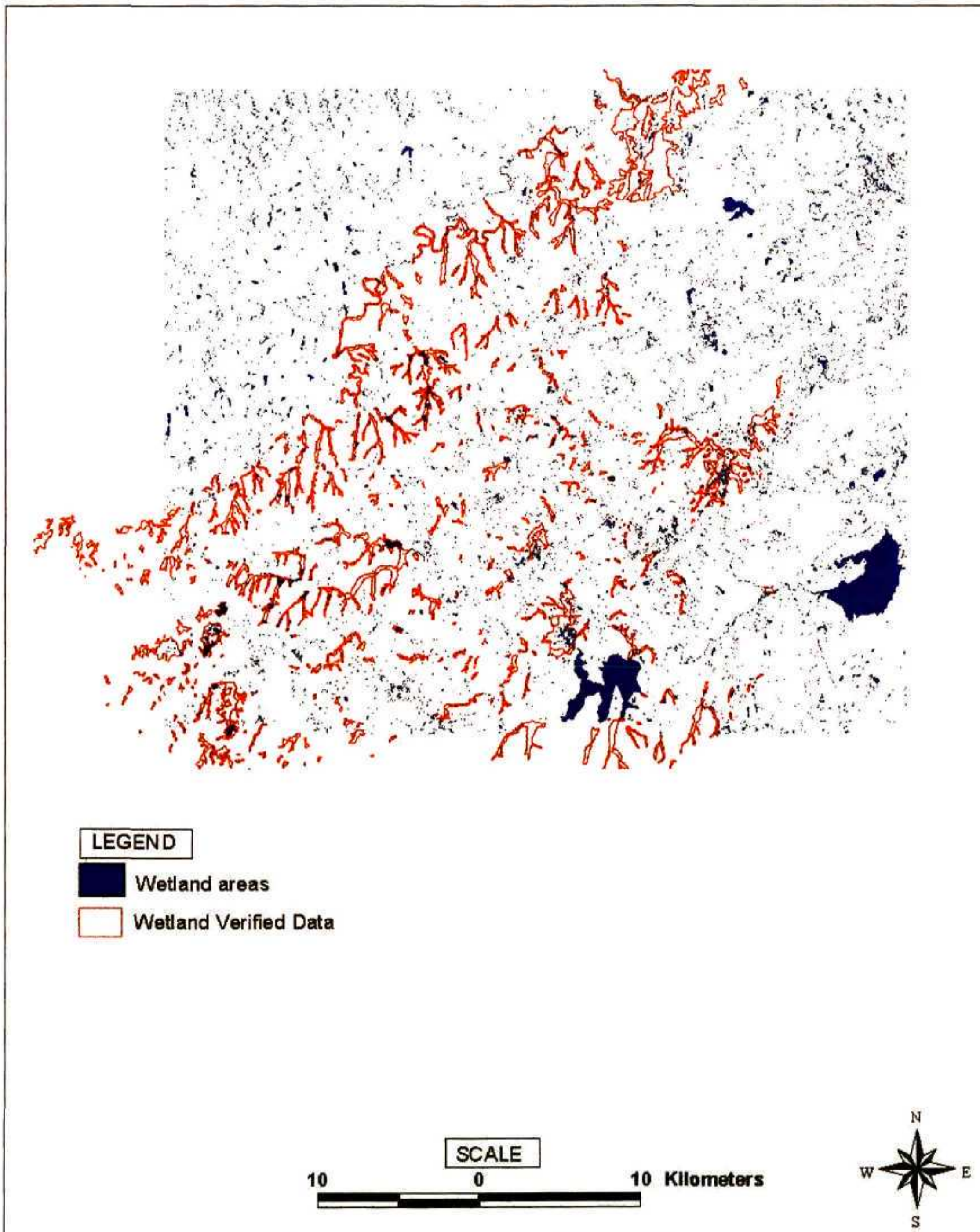


FIGURE 5.4: BINARY IMAGE: SUMMER (20 CLASSES)

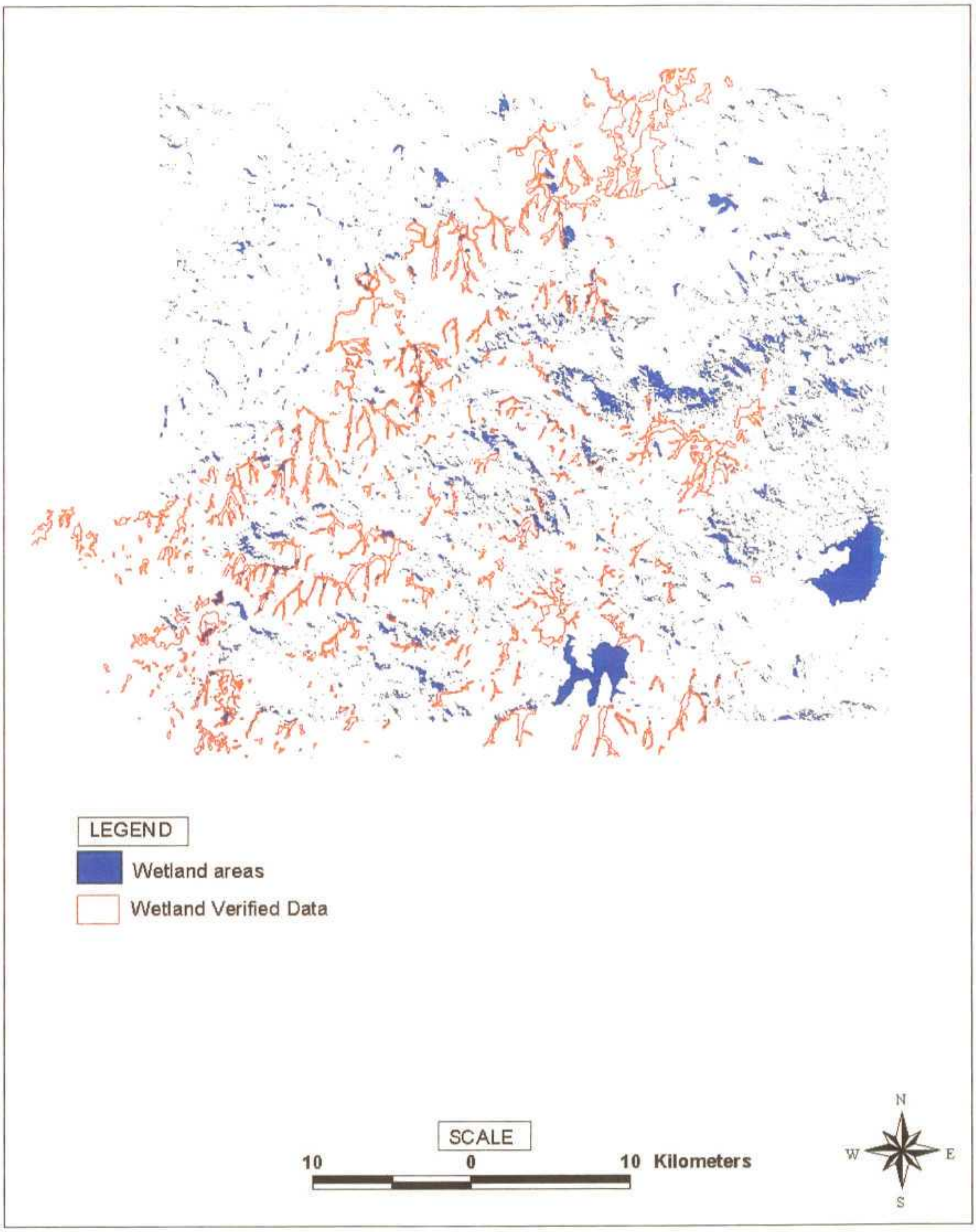


FIGURE 5.5: BINARY IMAGE: WINTER (20 CLASSES)

5.1.2 255 CLASSES

Stemming from the results of the 20 class classification procedure described earlier, a need arose to derive more conclusive results from an additional finer classification procedure (Walmsley and Botten, 1987). It was decided that the images (summer and winter) would be divided into their full range of spectral values (0-255) and a manual interpretation classification procedure would be applied. The images were classified according to 255 classes that were grey-scale pixel values. Individual large wetlands were then identified on the topographical sheets and from information gathered on the previous field verification exercise (20 class classification). The procedure of assigning a 'wetland' value to each pixel involved the following steps:

a) Once the large wetlands were identified, these sites then acted as training sites for the classification of other areas with the same spectral signature throughout the image.
b) Each grey pixel within the identified wetland was then coded (red), - which resulted in all other pixels with the same grey value was then coloured in red.
c) The researcher would then manually check the image. If this colour (red) was not related to a water feature or a wetland area, it was excluded.

This procedure allowed a level of pattern recognition to take place in the data (ERDAS, 1997) in which one distinct colour only was used to evaluate wetland areas while automatically masking out all other land-use categories. Topographical maps were used as this added value to this procedure by helping to distinguish water areas such as farm dams, perennial rivers and flow patterns, with the use of the contour lines. The summer image proved relatively easy to classify as wetland patterns throughout the image became evident as each land use category was masked out. The classification of the winter image proved problematic because of the constant spectral confusion between wetland areas, burnt areas, firebreaks and shadows of trees and slopes (Lunetta and Balogh, 1999). The verified wetland data was used to perform an accuracy assessment on the classified images. Classified and mapped wetland pixels were overlaid onto the verified data.

A random sample was selected and checked against the verified data. The summer scene produced a relatively high accuracy level of 71 per cent whilst the winter image produced an accuracy of 47 per cent (Figure 5.1). This being a fine classification procedure, produced a considerable number of pixels over classified (Eastman, 1997) as can be seen on Figure 5.7. A visual analysis of the classified summer and winter images indicated the following differences and similarities:

a) The classified image produced wetland areas that were also evident on the verified data. The only difference was the actual extent and size of the classified wetlands which differed considerably from the verified data.
b) The summer classified image showed both large and small open water areas and wetlands. Smaller open water areas were checked against the topographical maps in order to distinguish between farm dams, reservoirs, and wetland area.
c) *The winter classified image indicated spectral confusion between wetland areas/ open water areas and shadows within forested areas, shadows of steep slopes, clouds and burnt areas (Figure 5.6 A).*

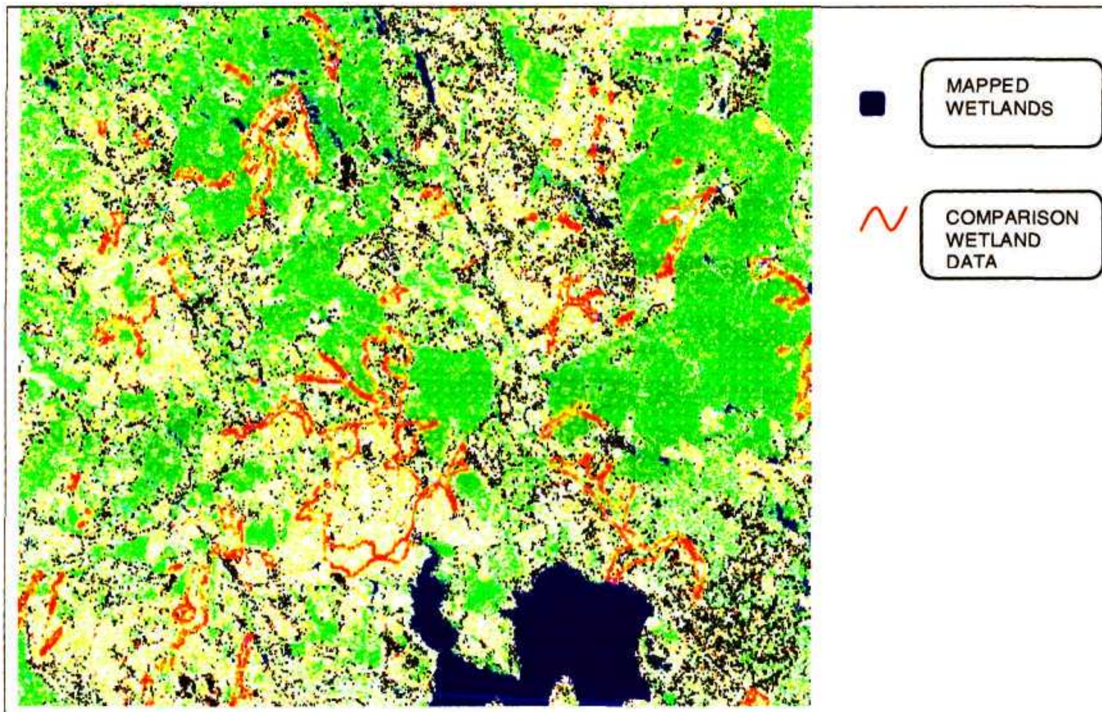


FIGURE 5.6 (A): SUBSET OF WINTER IMAGE SHOWING WETLAND IDENTIFICATION

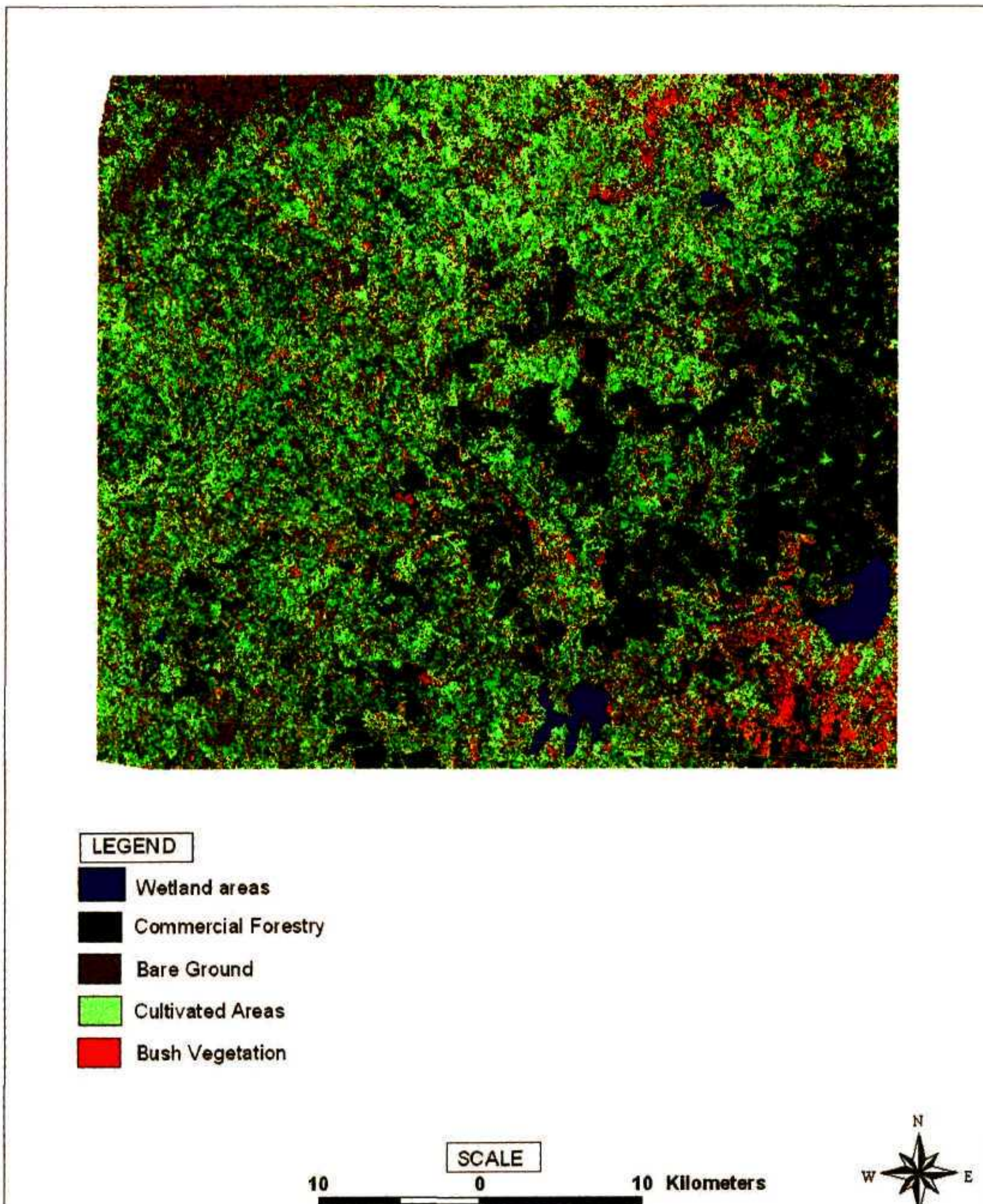


FIGURE 5.7: UNSUPERVISED CLASSIFICATION: SUMMER (255 CLASSES)

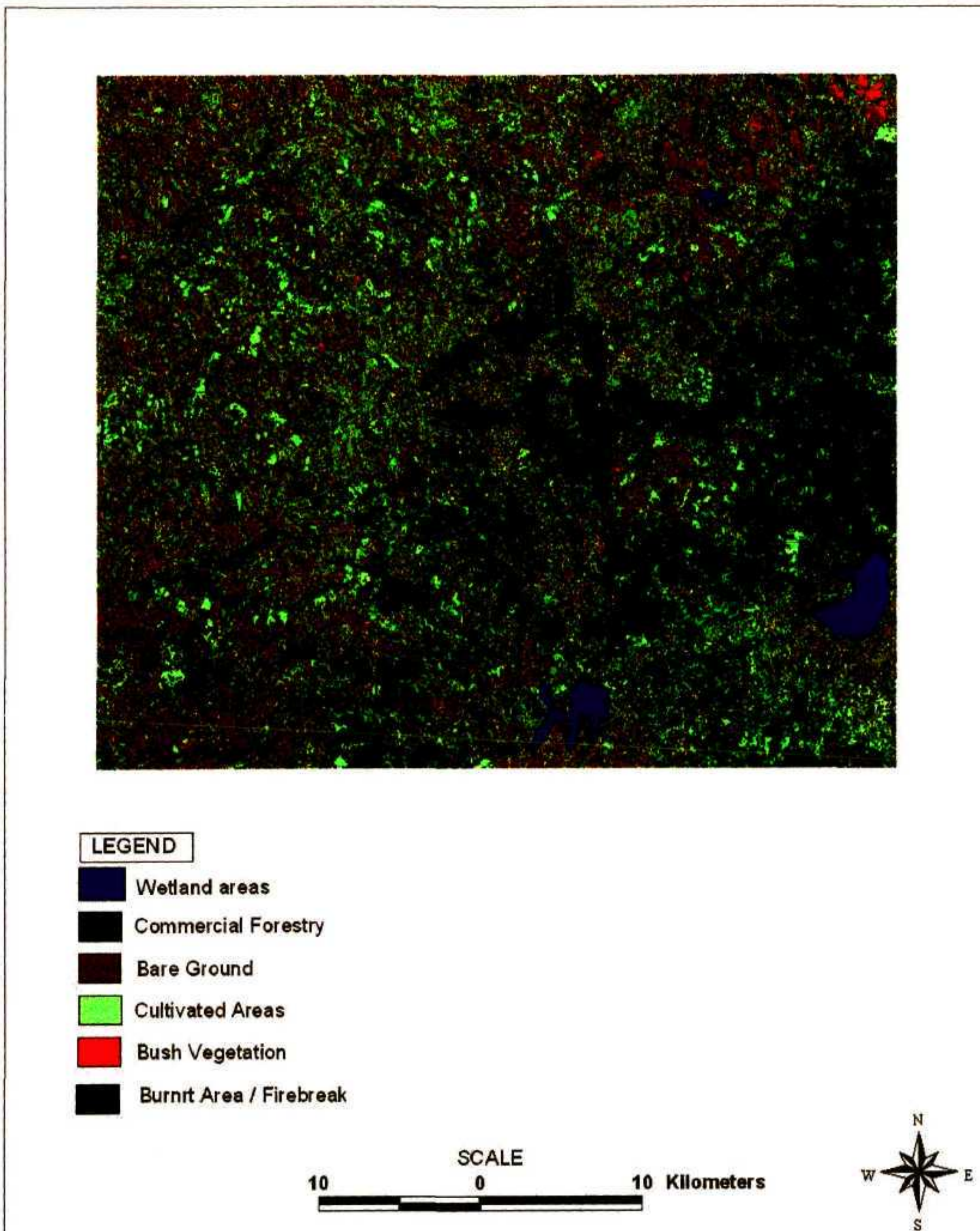


FIGURE 5.8: UNSUPERVISED CLASSIFICATION: WINTER (255 CLASSES)

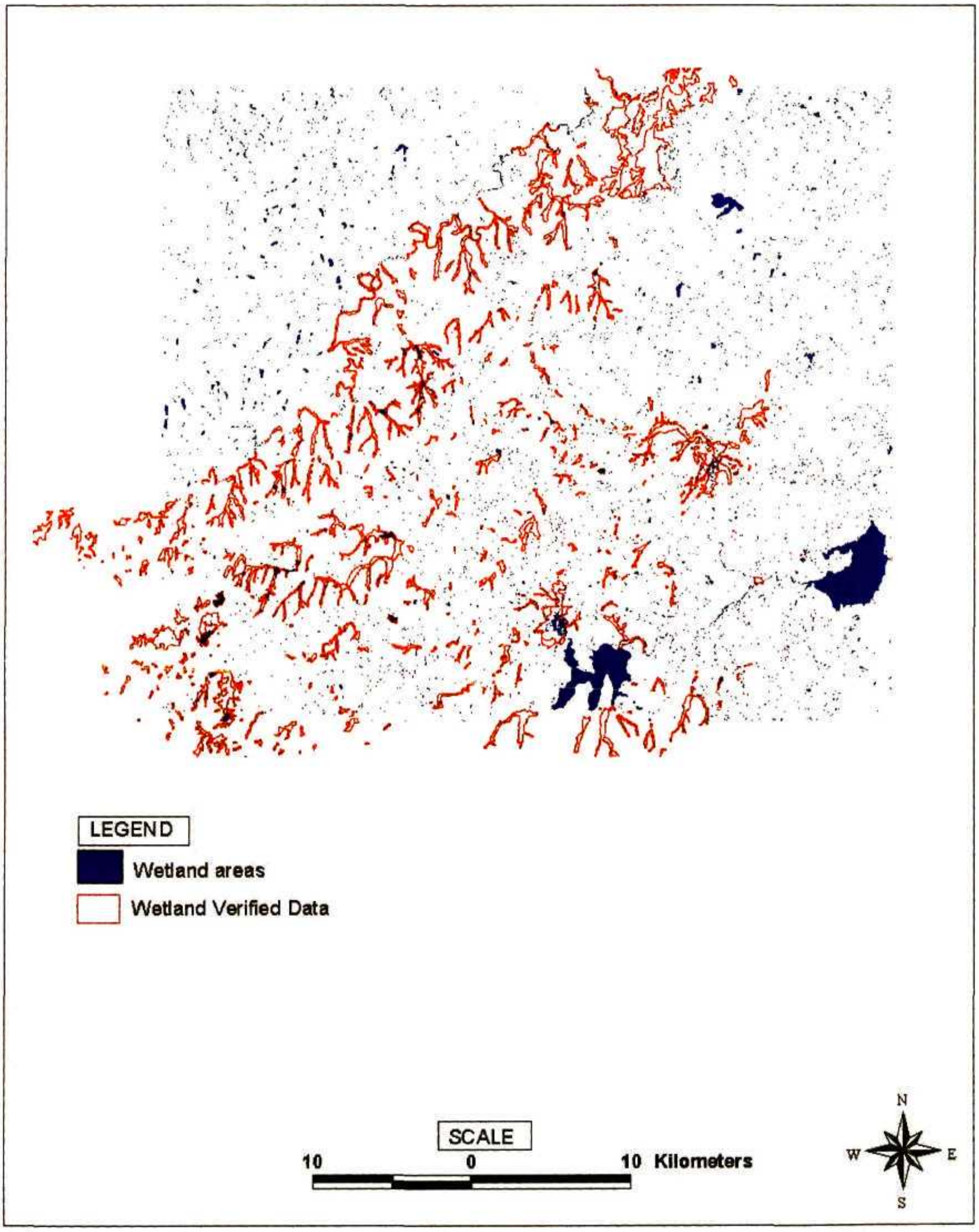


FIGURE 5.9: BINARY SUMMER IMAGE (255 CLASSES)

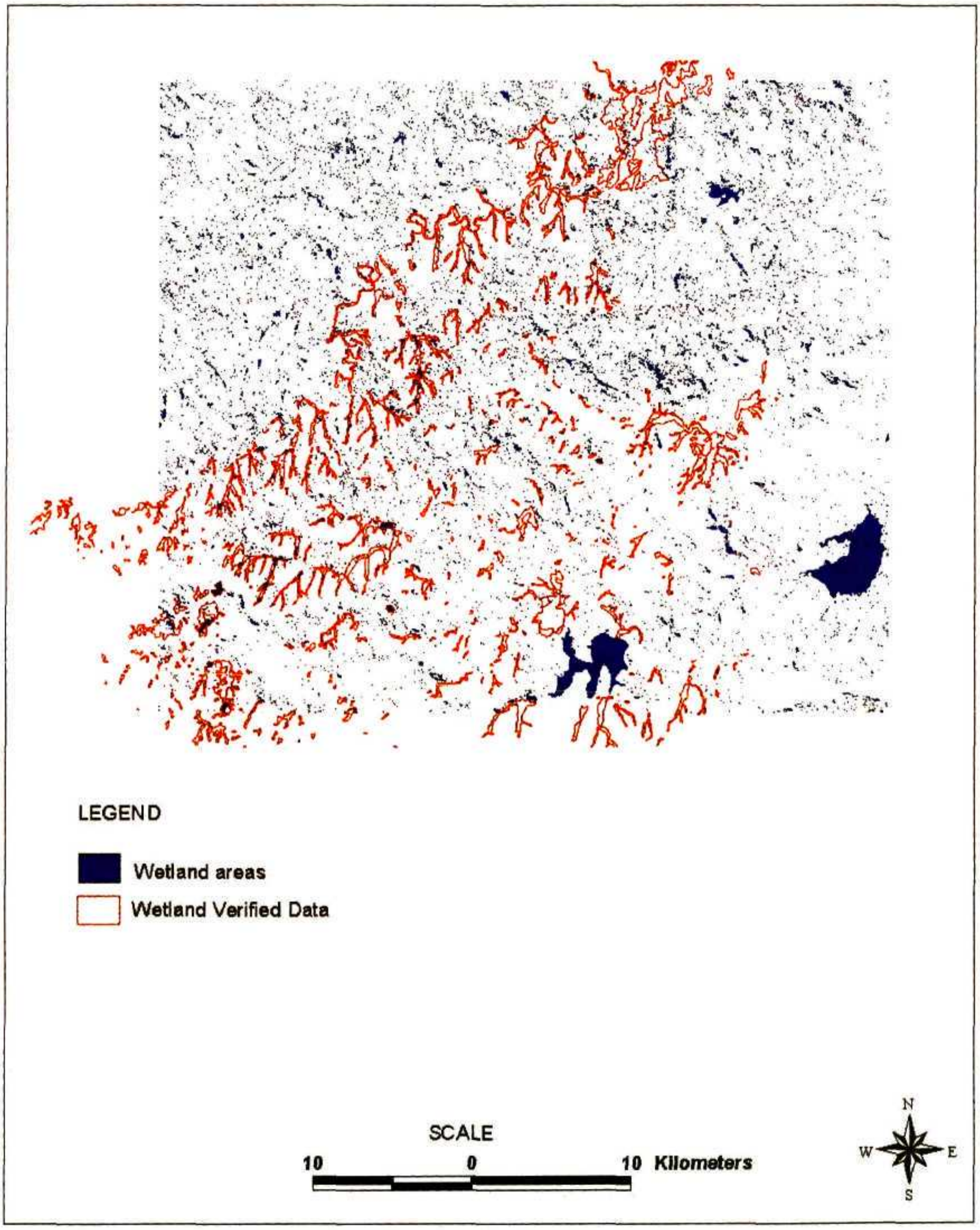


FIGURE 5.10: BINARY IMAGE: WINTER (255 CLASSES

5.1.3 THE DIFFERENCE BETWEEN THE 20-CLASS AND 255-CLASS CLASSIFIED IMAGES

The 20-class classification of both the summer and winter images was intended to uncover a broad generalized picture of the main categories of land cover and to locate the larger wetland bodies in the images. The summer image was the most useful for achieving these objectives as it highlighted the large wetland areas that were used in the 255-class classification.

The differences between both classifications is that while the summer images in both classifications highlighted similar wetland areas, the 255-class classification was able to classify small wetlands (6-8 pixels) compared to the mainly large wetland areas that could be identified in the 20-class classification. The closest 'fit' of the wetland verified data was with the summer classification (255 classes). Whilst the 20-class classification of the summer image revealed limited details regarding wetlands, it was useful as it highlighted larger wetland areas that were used as training sites for the 255-summer classification.

The winter images of both classifications (20 and 255 classes) revealed limited information regarding wetland areas. The spectral confusion created between burnt areas, shadows and the extensive areas of bare ground complicated the detection of wetlands. Both classification procedures of the winter (20 and 255 classes) showed no significant contribution in highlighting wetland areas except by highlighting a few large wetlands and open water bodies.

5.2 SUPERVISED CLASSIFICATION

The supervised classification was done by selecting sample areas within both the winter and summer images using the SEED generating function in ERDAS (ERDAS, 1997). The researcher at this stage was familiar with the larger wetland areas especially in light of the previous classification procedures (20 and 255 classes). The wetland training sites were selected from the false colour composite images of both winter and summer.

An additional step of increasing the contrast of the images was undertaken to ensure that wetland areas are highly visible. In both the summer and winter images three large training sites were chosen in which ERDAS automatically generated polygons The ERDAS software was unable to include the boundaries of each wetland site as the images were processed using a cubic convolution method that resulted in fuzzy boundaries being created between water edges and the boundary vegetation.

The final classified images included all areas with the same spectral signature as the three training sites. The final classified images with all mapped wetlands are shown in figure 5.12. The accuracy of each final image was determined by superimposing the verified data and thereafter selecting random samples. The supervised classification for both winter and summer images showed an improved classification accuracy for the summer image. The total percentage of wetlands correctly classified for summer was 65 per cent and winter was 41 per cent, as shown in Figure 5.1. A visual interpretation of both the summer and winter supervised revealed the following:

a) Although the accuracy of the summer classification differed to that of the summer classification using 255 classes, the supervised classification showed both large and smaller wetland bodies with an accurate 'fit' when compared to the verified data.
b) The supervised classification also showed distinct wetlands around river tributaries (Subset 5.13 A).
c) Wetland areas within commercial forested areas were also evident (Subset 5.13 A) despite some spectral confusion between wetlands and shadows.
d) Although there exists a considerable degree of over-classification, distinct wetland patterns could be seen in many areas.
e) The mapped wetlands in the winter classification did not show the full extent when compared to the verified data (Subset 5.13 B).
f) Compared to the summer classification, only a limited number of small wetlands could be identified.

5.3 DIFFERENCES BETWEEN THE SUPERVISED AND UNSUPERVISED CLASSIFICATION PROCEDURES

The different results obtained from both the supervised and unsupervised classification procedure resulted mainly from of the different techniques used to process these images. The summer images of both classifications produced relatively high accuracy results, compared to the winter classified images. The pixel-based approach adopted for the summer image classification resulted in both large and small wetland areas being classified. The manual interpretation of the summer image using 255 classes was actually a 'reverse' supervised classification in which all other non-wetland areas were progressively excluded. The high accuracy level generated by similar techniques has been documented in other studies (Taylor *et al.*, 1995; Lunetta and Balogh, 1999; Rao *et al.*, 1999) except for the fact that aerial photographs were used instead of remotely sensed imagery. The 20-class classification produced poor results as it highlighted significant areas that could be classified as wetland in nature. This classification was intended at uncovering a broad generalized indication of landcover. The supervised classification was successful at mainly identifying large wetland and open water areas, which included those within forested areas and along river channels.

The winter images for both the unsupervised and supervised classification produced poor results as the spectral confusion created with wetland/ water areas and burnt scars, shadows and bare ground. The over-classification within each classification procedure (supervised and unsupervised) was considerable and therefore did not warrant a field verification exercise.

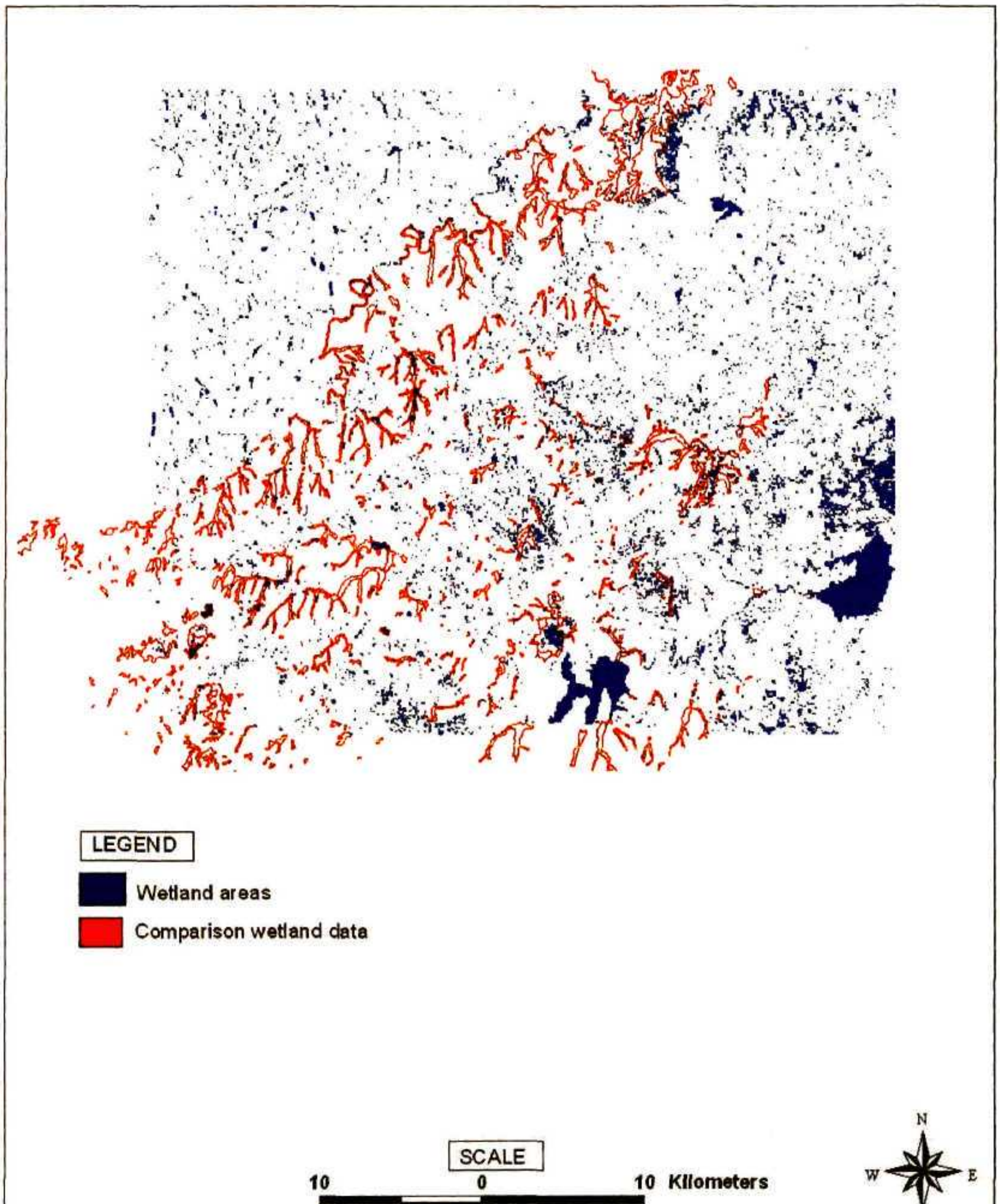


FIGURE 5.11: SUPERVISED CLASSIFICATION: SUMMER

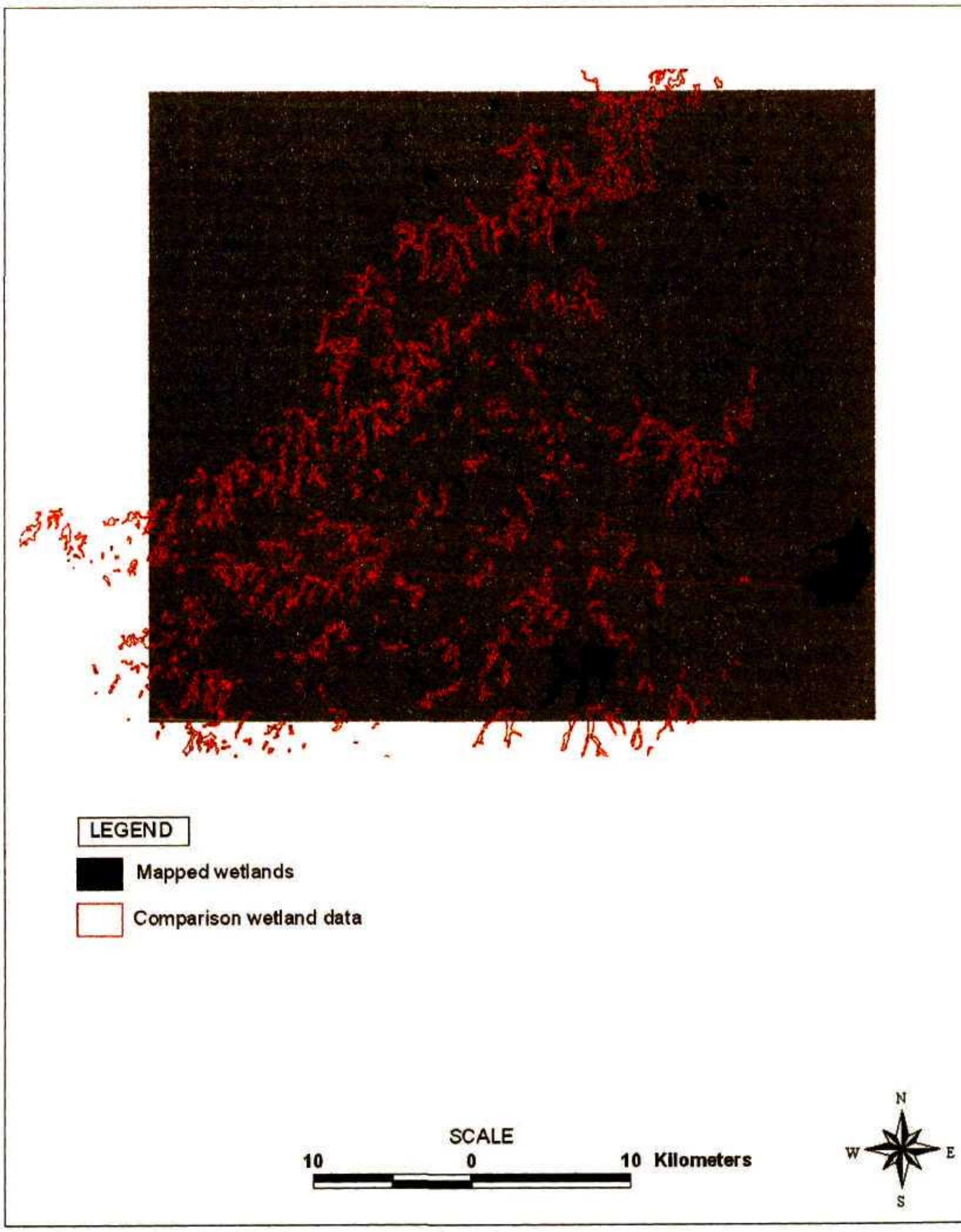


FIGURE 5.12: SUPERVISED CLASSIFICATION: WINTER

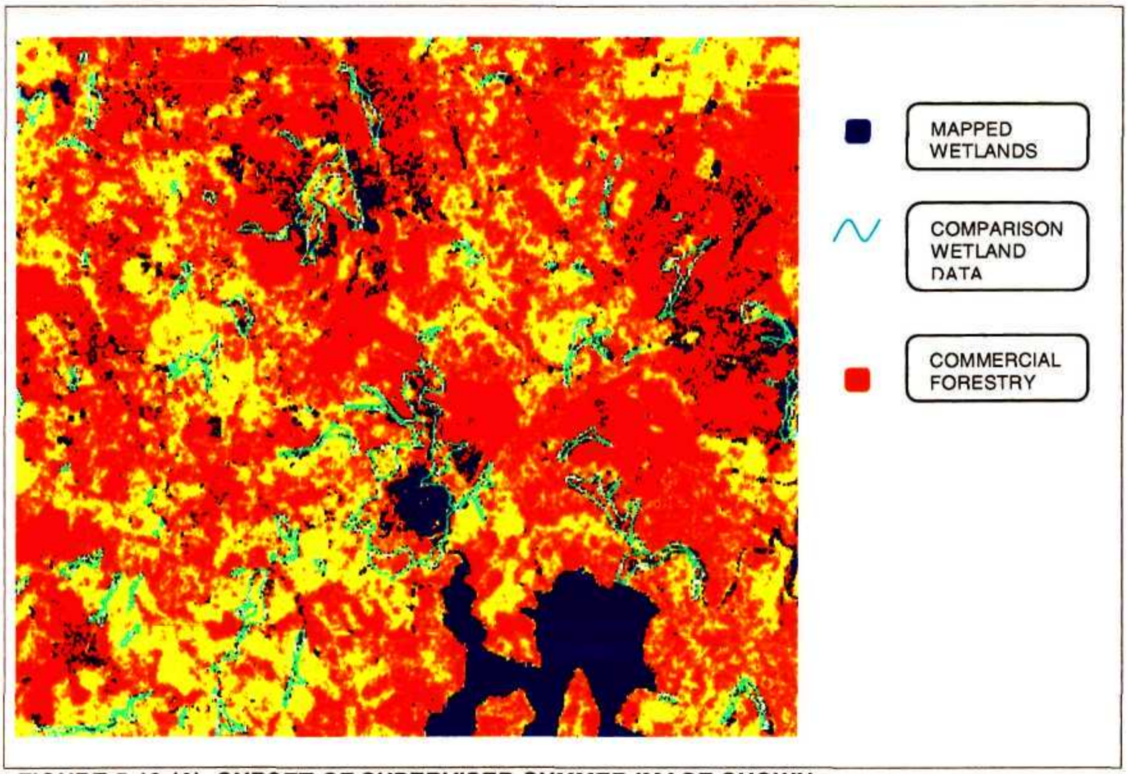


FIGURE 5.13 (A): SUBSET OF SUPERVISED SUMMER IMAGE SHOWN WETLAND IDENTIFICATION.

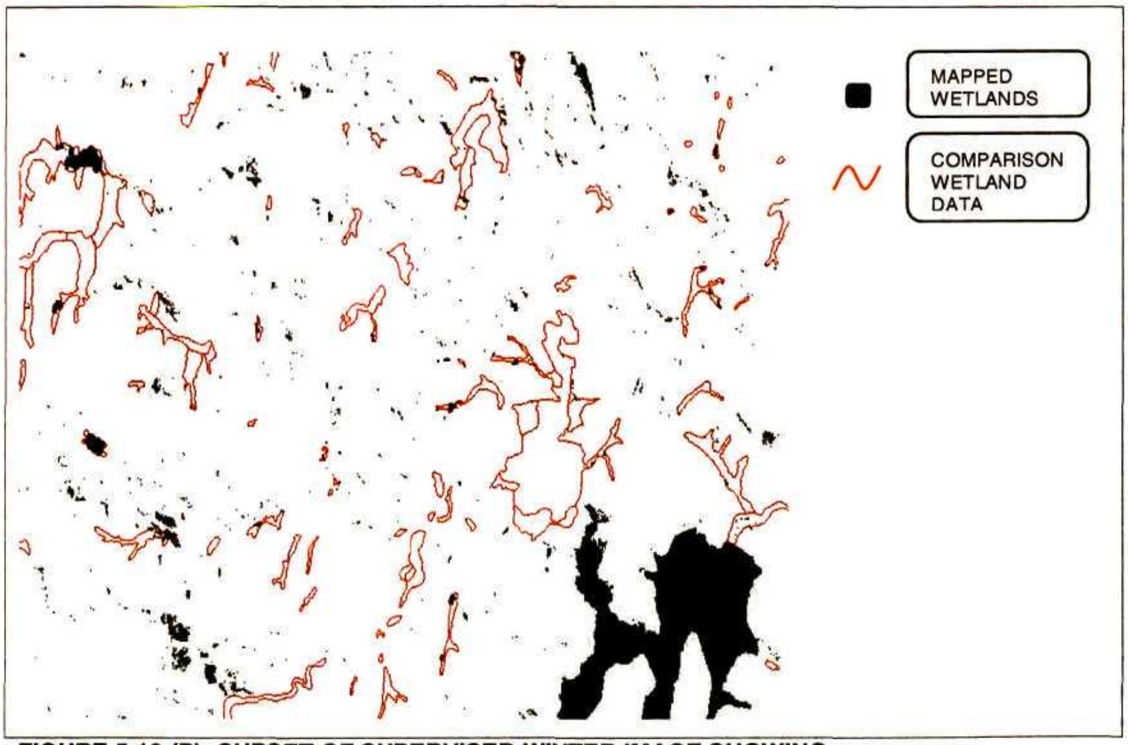


FIGURE 5.13 (B): SUBSET OF SUPERVISED WINTER IMAGE SHOWING WETLAND IDENTIFICATION

5.4 LEVEL-SLICING CLASSIFICATION

The decision to utilize the panchromatic bands for the purposes of wetland identification in both the images was primarily related to their spatial resolution of 15 metres. The spatial resolution of the panchromatic bands was previously used in other studies to indicate wetland area (Johnston and Berson, 1995; Lunetta and Balogh, 1999). Both panchromatic bands (winter and summer) were subjected to the same procedure of identifying large wetlands areas within each image and then masking the other spectral characteristics out using different colours.

The summer image was level-sliced first as there had been significantly more accurate results from previous classification processes. Three land-cover categories were decided upon and used: forestry, wetlands and open water. It was shown (in the supervised summer classification) that wetland areas existed within forestry plantations and therefore the decision to use and classify commercial forestry in the level slicing approach. The summer image produced a relatively high level of accuracy (65 per cent) in terms of locating open water bodies, wetland areas and wetlands within forestry plantations, as can be seen in Figure 5.16. The use of the verified wetland data to perform and thereafter evaluate the results showed that the classified image (summer) produced a good estimation of both small and large wetland areas.

The difference in spatial resolution of the panchromatic bands made little difference to the recognition of wetlands during winter. There were similar spectral confusions (slope shadows, burnt areas and fire breaks) in the post-evaluation analysis. The winter classification produced an accuracy of 45% as compared to the wetland verified data. A short field verification exercise was planned to check the results of the summer classification exercise. The results of the exercise revealed the usefulness of using the panchromatic bands to identify large open water wetlands (Subset 5.14) and the ability of the panchromatic bands to highlight wetland vegetation.

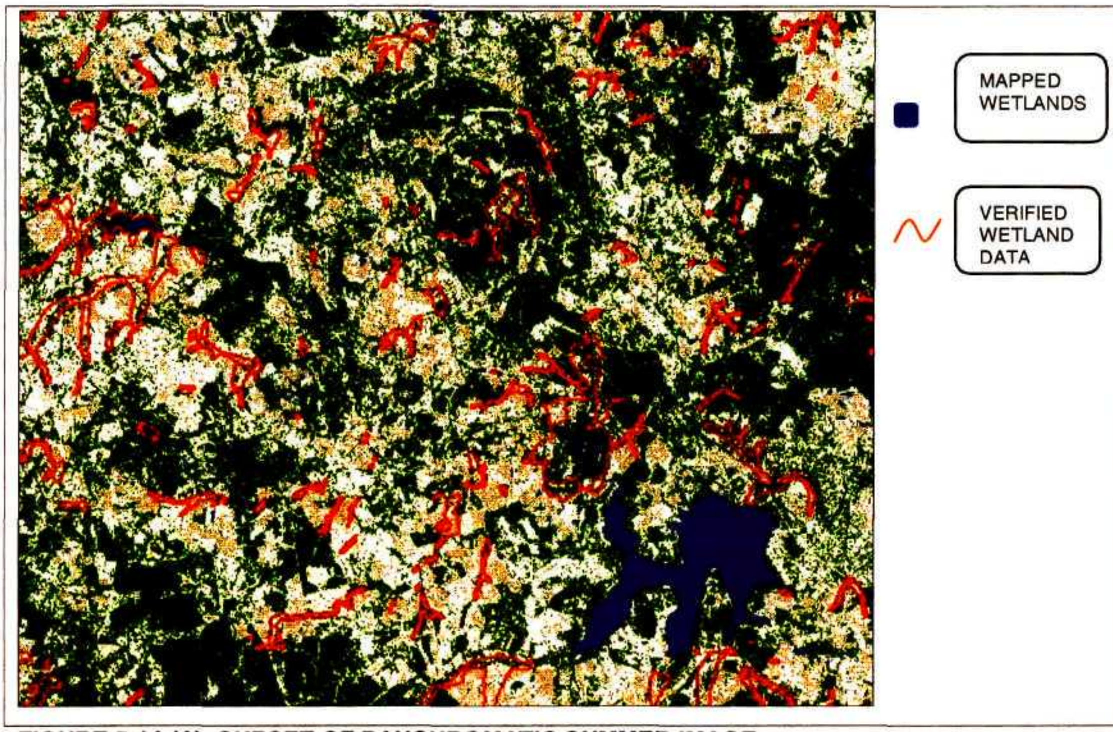


FIGURE 5.14 (A): SUBSET OF PANCHROMATIC SUMMER IMAGE SHOWING WETLAND IDENTIFICATION.

PLATE 5.3: PART OF THE LARGE WETLAND AREA DELINEATED USING THE PANCHROMATIC SUMMER BAND

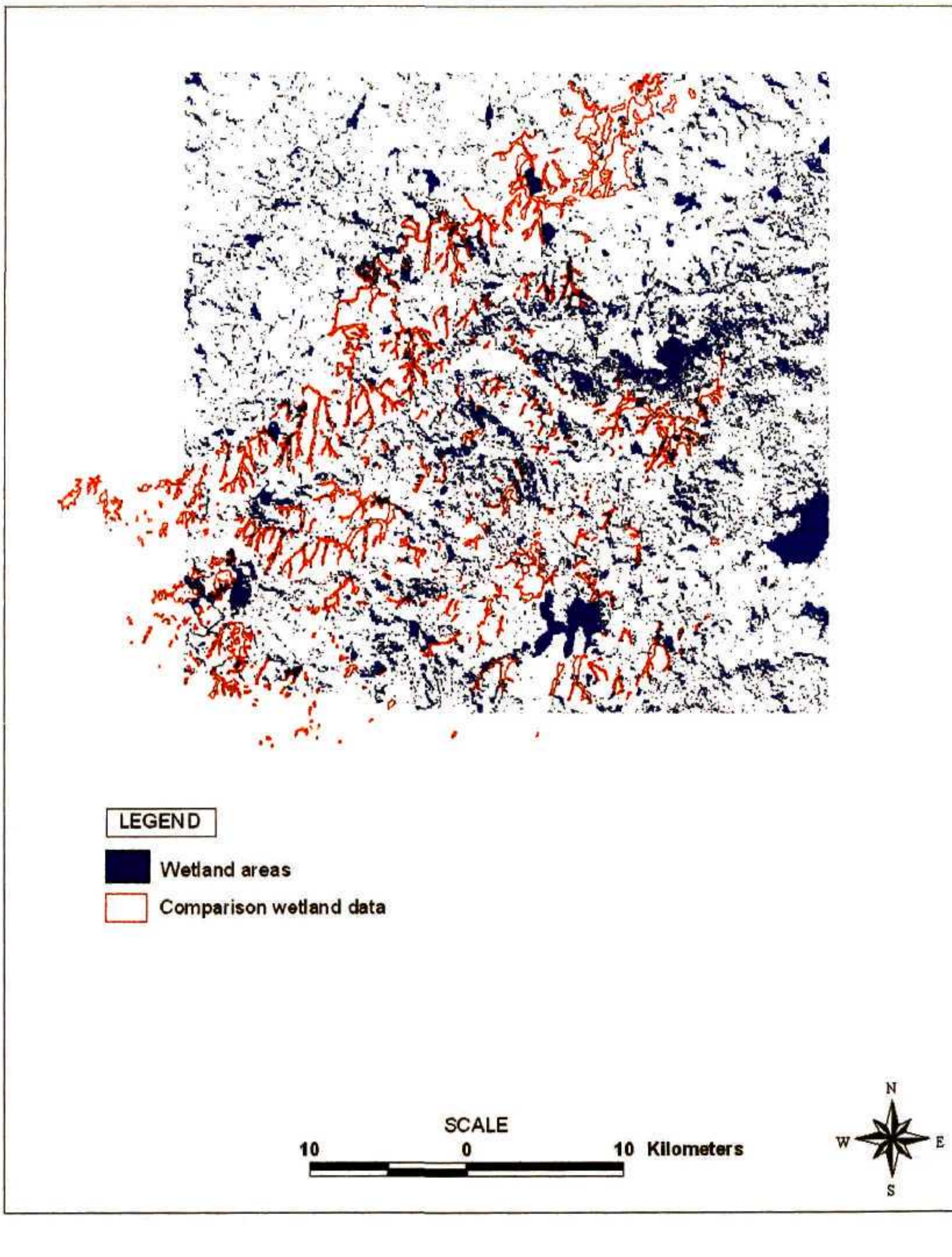


FIGURE 5.15: LEVEL SLICED WINTER IMAGE

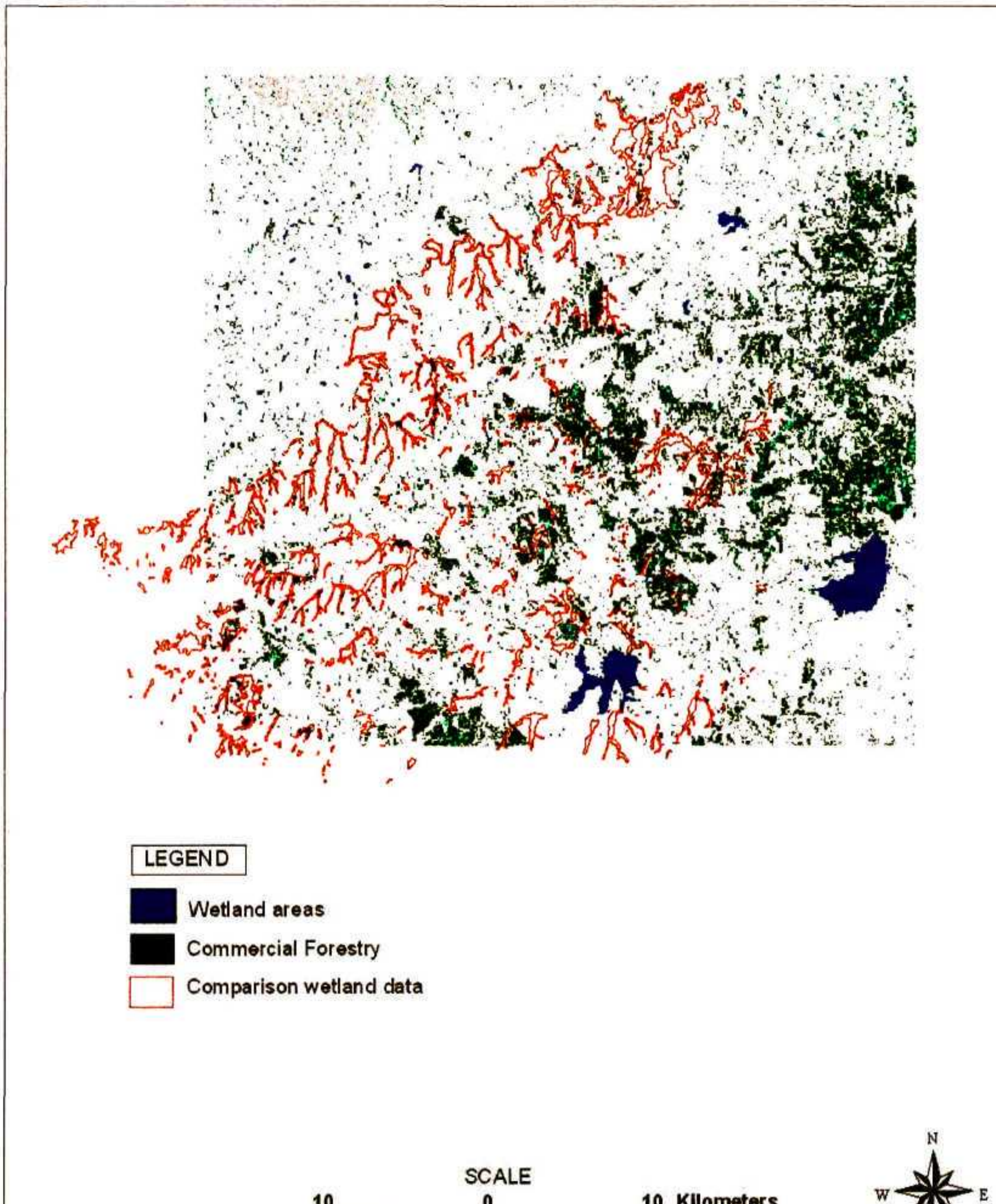


FIGURE 5.16: LEVEL SLICED SUMMER IMAGE

5.5 FIELD VERIFICATION.

The field verification exercise was done by selecting main roads along which mapped wetland areas could be visually verified. The most accurate classification (summer-255 classes) was chosen for the field verification exercise. The primary motivation for the field verification exercise was based on two factors:

a) The classified summer (255 classes) showed large open water bodies that could be wetland associated as these areas were not include as wetlands on the verified data. Therefore the comparison verified data had to be validated.

b) The above classification also identified small wetlands that were not included in the comparison verified data. These smaller areas needed to be verified to evaluate the success of the satellite image classification to capture both large and small wetland areas.

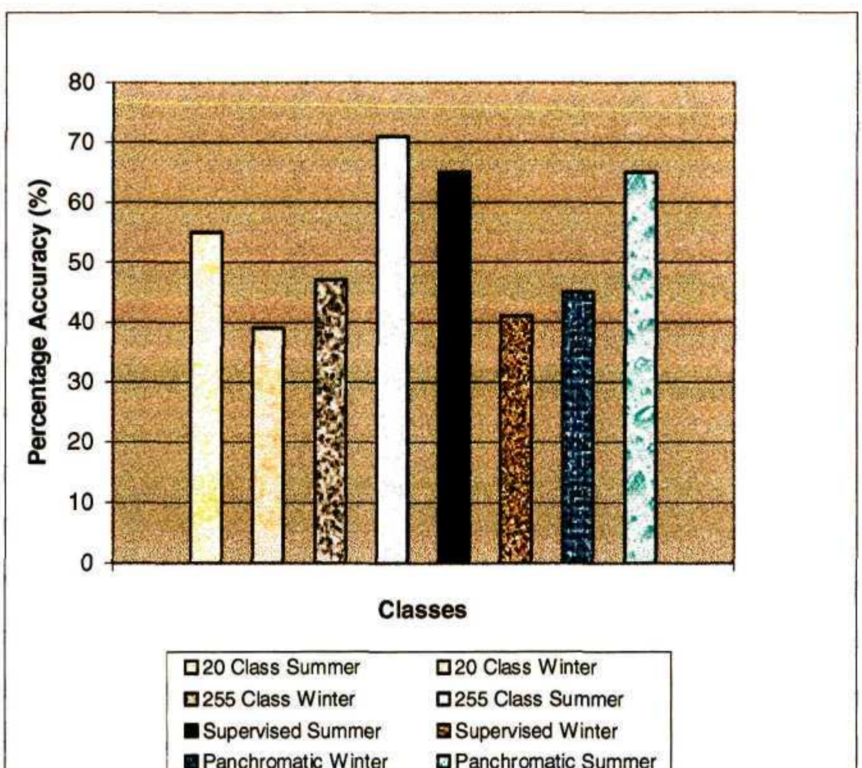


FIGURE 5.1: SUMMARY OF CLASSIFICATION RESULTS

This route enabled the researcher to identify and verify both large and small areas classified as wetlands. The verification exercise was effective and successful, not only in terms of identify areas that were mapped as wetlands but not included on the verified data, but also in getting accustomed with the level of development affecting these natural habitats in the area and the benefits of these areas to the surrounding community (Plate 5.2). Forty sites were chosen along an accessible route (R103) which included both large and small areas classified as wetlands. The results showed that 37 sites were confirmed as wetland sites whilst only three sites where not confirmed as wetland sites. This indicates an overall sample accuracy of 93 %. The confirmed sites showed different wetland characteristics that aided in their identification, such as wetland-related vegetation, soils and biodiversity aspects. Table 5.2 tabulates the results of the field verification sites.

TABLE 5.2: FIELD VERIFICATION RESULTS

TEST SITE	FIELD VERIFICATION	CHARCTERISTICS	APPENDIX A
SITE 1 A	YES	Consisted of 10 single pixels in the shape of a horse - shoe. Field verification shows that it is a wetland approximately 40 metres wide. Not indicated as wetland area on comparison data. (Figure 5.1).	None
SITE 1 B	YES	This site is close to the Midmar Dam Falls and is part of the Mgeni River (Figure 5.1). Identified by the wetland vegetation compared to surrounding grassland. Correctly indicated in the comparison data.	None
SITE 1 C	YES	Located on the opposite side of the N1 after the Midmar Dam wall. Large wetland area indicated on the classification as a group of 16 individual pixels (Figure 5.1). It was correctly mapped in the comparison data.	None
SITE 2	YES	Located adjacent to the Mgeni River and was identified by the vegetation and high levels of soil moisture.	Plate 5.1
SITE 3	NO	Was not identified as a wetland. Consisted of large trees.	None
SITE 4	\NO	Unconfirmed as a wetland.	None
SITE 5	YES	Smaller wetland that seemed to have been drained as plate 5.2 indicates. Cultivation occurrs on the edges of the wetland.	Appendix A
SITE 6 A 6 B	YES	Confirmed as a wetland.	None
SITE 6 C 7	YES	Correctly mapped in the comparison data but the extent seemed to differ. Indicated as a group of six pixels in a linear order, which seemed to have been a larger wetland previously but was drained for pastoral land purposes.	None
SITE 8 9 A	YES	These three areas seemed to belong to one wetland system that links to the large Lions River wetland. A railway line	None

SITE 9 B			runs through the area and on the opposite side an informal settlement is developing.	
SITE 10	YES		The pixel shape indicates a dam, which is what the site actually is but the pixels around it indicate a wetland feature. The area has been correctly mapped in the comparison data.	None
SITE 11	YES		Confirmed as a wetland area leading into a dam (Figure 5.1).	None
SITE 12 **13**	YES		Part of a large wetland that forms part of the Ligetton Falls. Extensive areas of moist soils and wetland vegetation.	Appendix A
SITE 14	YES		Area near Curry's post showing large open water wetland site near residential land use.	Appendix A
SITE 15	YES		Wetland area is part of the Balgowan Dam. This is also indicated in the comparison data.	None
SITE 16	YES		Large wetland area near the Glen Eagles Farm, which is also captured by the comparison data	Appendix A
SITE 17	YES		Field verification shows that it is a wetland part of which is also correctly mapped in the comparison data	None
SITE 18	YES		Confirmed as wetland area and correctly mapped in the comparison data.	None
SITE 19	YES		Located near Rawdons Hotel and part of a larger wetland (as pixels indicate). Incorrectly mapped in the comparison data.	None
SITE 20	YES		Large wetland area that was drained for agricultural purposes. The extent of this wetland in the comparison data is incorrect.	None
SITE 21 **22** **23**	1.1	YES	Three large wetland areas just outside the town of Nottingham Road. Only a small part is mapped in the comparison data.	None
SITE 24 **25**	1.2	YES	Wetland areas that runs parallel to the road (R103). This wetland seems to have been part of an extensive continuous wetland before it was drained for cattle farming purposes. Areas of wetland-related vegetation are still evident	Appendix A
SITE 26 **27** **28** **29** **30**	YES		Smaller wetland areas that form part of the Mooi River wetland system. Clearly visible from the road. The linear arrangement of the pixels following the shape of the river flow provided the researcher with the indication of the wetland.	None

Figures 5.17 to 5.20 are field verification site maps in ascending order from the site 1a to site 40. The figures are displayed in the following order:

1) Figure 5.1 shows sites 1a to 13 a
2) Figure 5.2 shows sites 13a to 20
3) Figure 5.3 shows sites 21a to 26
4) Figure 5.4 shows sites 26 to 40

Each field verification map follows in sequence from the first test site (1a) to the last test site (40), which are all along the main road (R108). The field verification exercise showed that small wetlands indicated by single pixels in a certain geometric shapes (site 1a) were identified positively in the field. Other small pixels areas, such as site 3, 4 and 12, were also identified as wetlands. The field verification also indicated certain inconsistencies within verified wetland data that was used to perform the accuracy assessment. In certain wetland sites the full extent/ size of the wetland differed from the comparison verified data. An example from Figure 5.1 includes test site 10. In this test site the actual wetland area is approximately equal to that on the figure while the verified wetland data indicated a larger area.

Conclusions from the field observation are the following:

a) The classification (255 class-summer) identified both large and small wetland sites which were positively identified during the field verification exercise.
b) Many wetland sites identified using satellite imagery differed in size and extent when compared to the verified comparison wetland data that was originally collected using aerial photography (Scotney 1970).
c) Many wetlands sites in the study area have been drained and therefore do not appear in the classified image.
d) The larger wetland areas have also been drained and therefore appear smaller on the classified image.
e) Some wetlands were identified on the classified imagery but are not visible on the verified data used to calculate the accuracy of each classification. Examples include test site 1a, 3, and 4.

The field verification exercise indicated that many of the wetlands have been partly or completely drained and replaced by agricultural activities and pasturelands. Compared to the initial verified data, it is clear that the overall area of wetlands have been reduced. Discussions with certain landowners also confirmed this fact.

5.6 SUMMARY

The image processing of winter and summer LANDSAT ETM+ imagery for the identification and mapping of wetlands revealed the following:

a) The winter imagery was unsuitable for mapping wetlands; as considerable spectral confusion exists between wetlands, burn scars, firebreaks and shadows.
b) The winter image also produced more wetland areas that were over-classified with the different classification processes, taking more time to complete, compared to the summer image classifications.
c) The summer imagery with its different classification procedures was successful in highlighting both large and small wetland areas and revealed other potential wetlands that were not indicated on the comparison data.
d) The accuracies from the classification suggest that the summer image is superior to the winter imagery in portraying information about wetlands.
e) The field verification revealed a high level of consistency between the summer classification and subsequent identification of wetlands and the actual wetland sites on the ground.

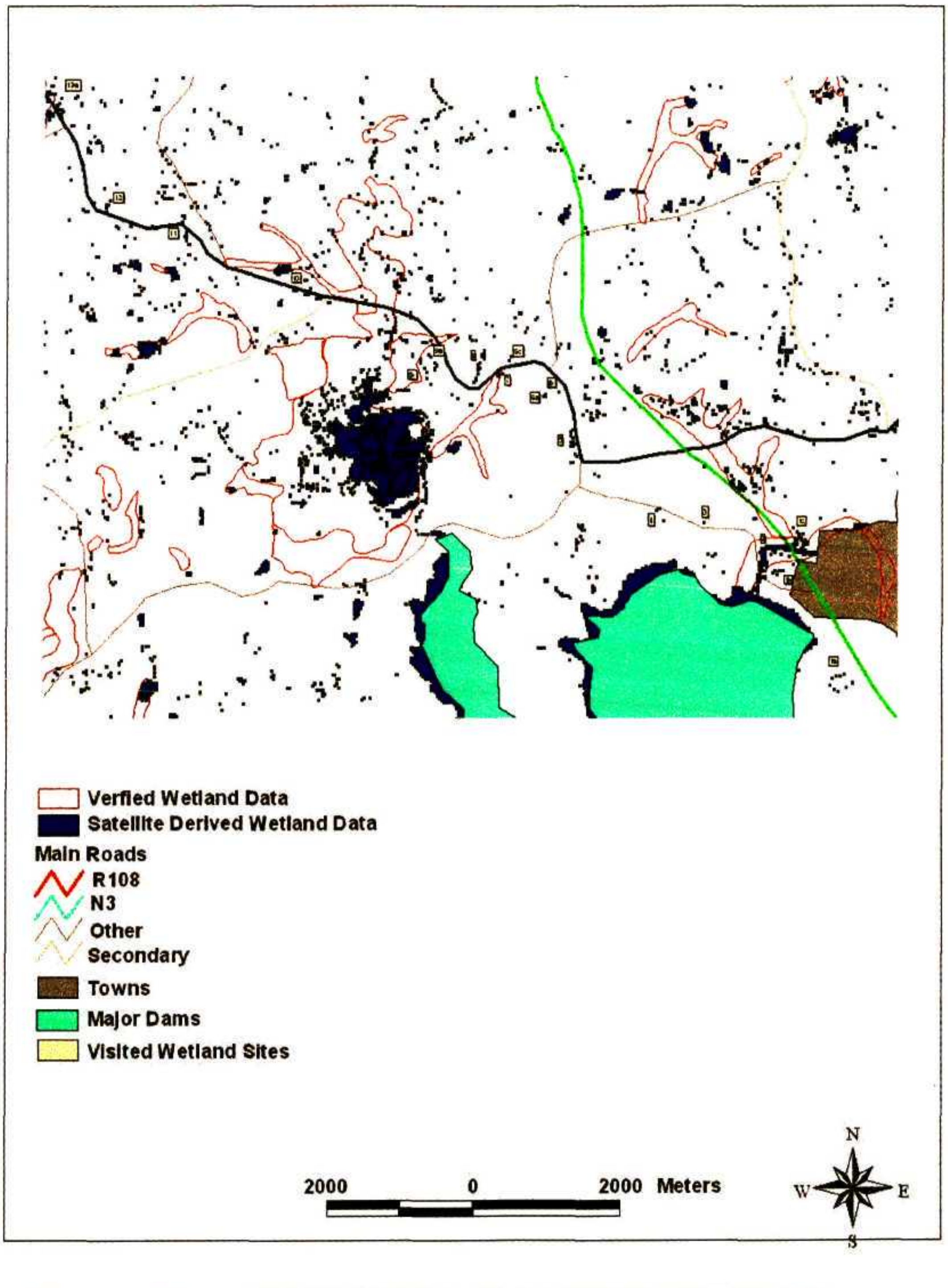


FIGURE 5.17: FIELD VERIFICATION SITES (1a TO 13a) DERIVED FROM SUMMER CLASSIFICATION (255-CLASSES)

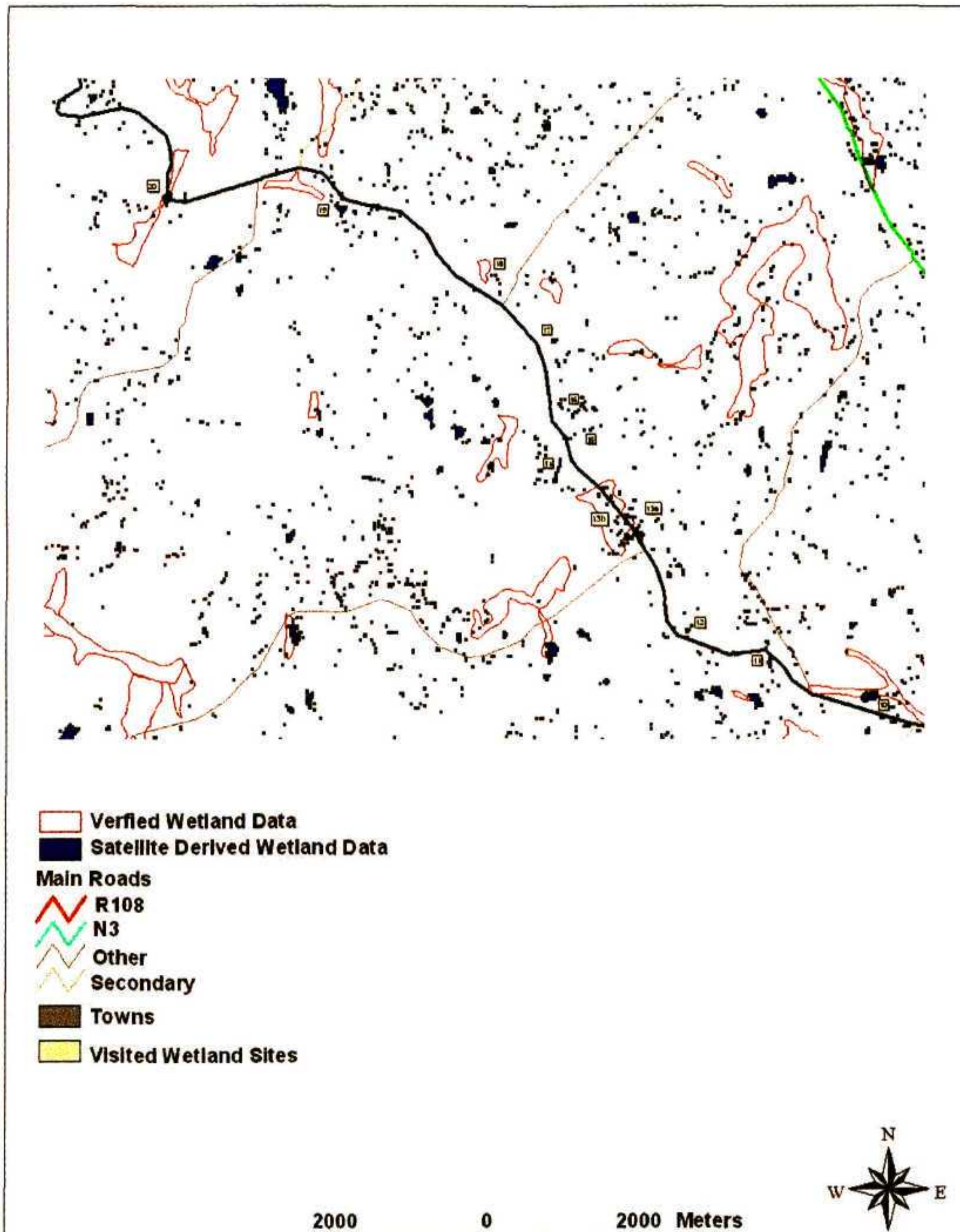


FIGURE 5.18: FIELD VERIFICATION SITES (13a TO 20) DERIVED FROM SUMMER CLASSIFICATION (255-CLASSES)

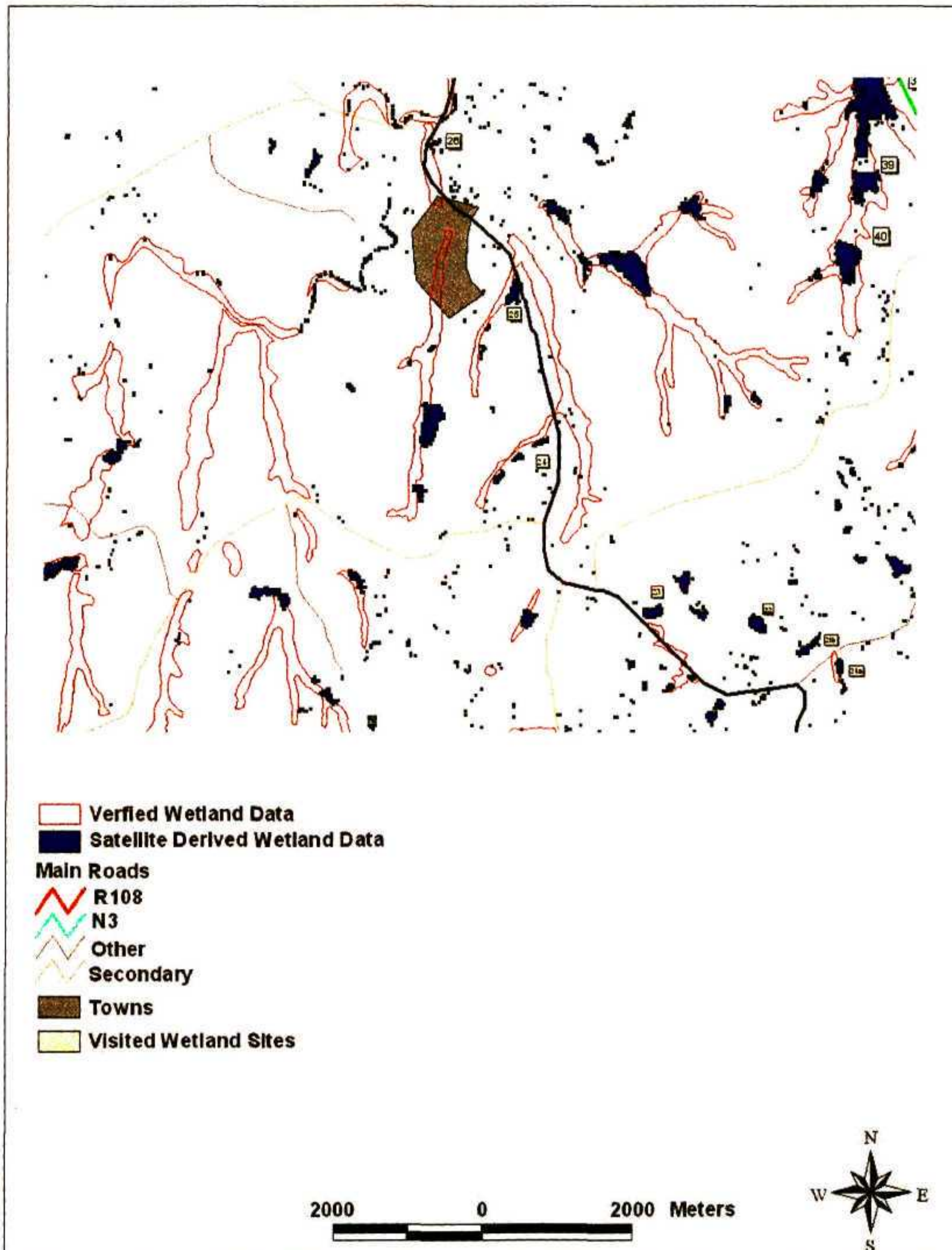


FIGURE 5.19: FIELD VERIFICATION SITES (21a TO 26) DERIVED FROM SUMMER CLASSIFICATION (255 CLASSES)

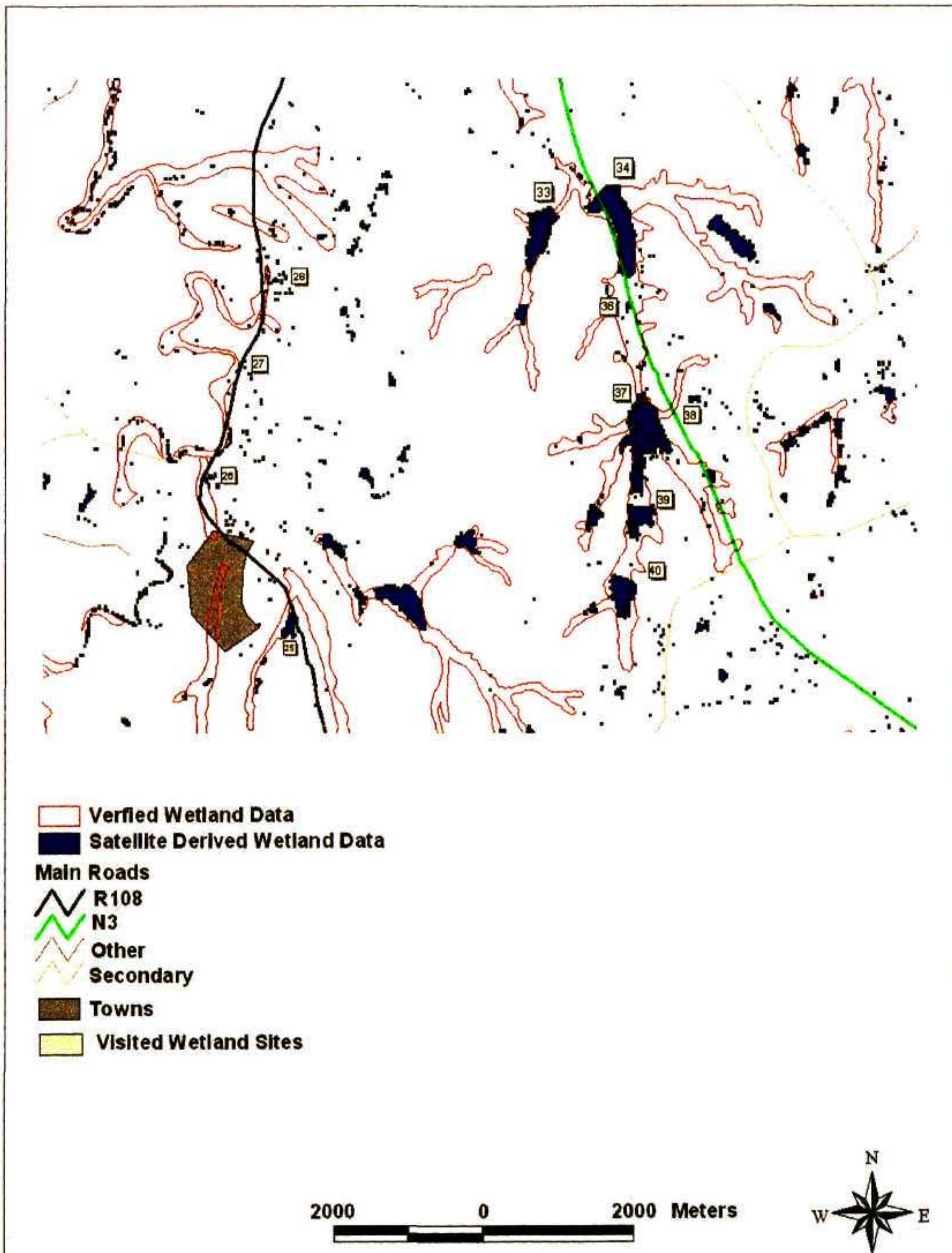


FIGURE 5.20: FIELD VERIFICATION SITES (26 TO 40) DERIVED FROM SUMMER CLASSIFICATION (255 CLASSES)

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

The use of satellite remote sensing and GIS techniques to interpret and map wetlands in the study area was motivated by the following factors:

a) To test the effectiveness of using satellite imagery for mapping both large and small wetland areas.

b) To evaluate the accuracy and relevance of aerial photography compared to satellite imagery for the purposes of wetland mapping.

In this chapter, these concerns are addressed and future recommendations are described.

6.2 MAPPING WETLANDS FROM SATELLITE IMAGERY

This research investigation showed the relevance and applicability of using LANDSAT ETM+ imagery to map wetland areas. This investigation utilized two images in different seasons (summer and winter) in order to evaluate the effectiveness of satellite imagery to map the seasonal contrasts in wetland areas. Different image processing techniques were used to differentiate wetland areas from other land cover classes in accordance with evaluated studies done elswhere. These techniques were shown to be effective at delineating wetland areas. Each image was processed separately using the different image processing techniques. The broad classification (unsupervised 20 classes) of each image resulted in a general land cover assessment of the study area and helped locate the large wetland areas and open water bodies (Lunetta and Balogh, 1999). A manual interpreted classification (255 classification) produced accurate results when compared to the verified data, and was eventually used in the field verification exercise (Walmsley and Botten, 1987).

Supervised classification techniques followed by large wetland areas were identified. The level-slicing procedure of the images led to the identification of small wetlands but failed to highlight geometric shapes of the wetland bodies. The accuracy results of each classification indicated the usefulness of summer imagery in the mapping of wetlands from satellite imagery. The summer classified images produced high levels of accuracy (Figure 5.1) with the exception of the summer image classification (20 classes) which was intended for a land cover spectral estimate within the study area. The winter image classification produced low accuracies as a result of the different spectral confusions created between burnt areas, fire- breaks, and shadows.

In addition to the observations done during the field verification exercise the high classification results indicate the viability and usefulness of using LANDSAT ETM+ imagery for wetland delineation purposes. The investigation has also been successful in achieving the specific objectives stated in Chapter Two. This exercise confirms the applicability of satellite imagery for wetland and open water mapping in South Africa as used in countries like Australia (Johnston and Berson, 1995), U.S.A (Jensen *et al.,* 1987) and southern Africa (Taylor *et al.*,1995).

6.2.1 SEASONALITY

The use of winter imagery for delineating wetland areas proved unsuccessful (Figure 5.1) due to the spectral confusion created during the classification process by areas with fire scars, firebreaks and slope shadows. The study area falls within the boundaries were extensive commercial forestry and cultivation occur and burning practices seemed to be a yearly activity during the winter months (June and July) (Tarboton and Schule, 1992). The extensive areas of bare soil and rock surfaces complicated the task of identifying wetland areas from the winter scene. This type of spectral confusion has also occurred in other wetland mapping studies (Walmsley and Botten, 1987). Fire scars and firebreaks possess the same spectral signature of water in the winter scene, thereby producing an over-classification of wetland areas. The summer imagery produced a reliable distinction of wetlands, open water areas, grasslands, forestry and cultivated lands.

6.2.2 MAPPING TECHNIQUES

Different imagery processing techniques were explored in this research investigation in order to optimally recognise wetland areas. Two unsupervised classification were done which included a classification using 20 classes thereafter using 255 classes. The 20-class classification was intended to show general land cover classes and would be recommended in areas where landcover such as bush vegetation would complicate the identification of wetlands. The 255-class classification produced a high level of accuracy as the wetland areas were manually interpreted and thereafter assigned spectral characteristics accordingly. The only drawback of such a classification is it's time consuming nature. It is therefore not applicable for use in projects aimed at a rapid evaluation and mapping of wetland areas.

The supervised classification using the summer image also produced a high accuracy level compared to the data that was used to verify each wetland. It did not however identify the range of smaller wetlands in the study area as compared to other classifications such as the level-sliced approach and the unsupervised 255 classifications. The winter classified images showed poor results because of the spectral confusions created by the different landcover classes. The winter image showed extensive areas of dry and bare ground within which there will be a possibility of seasonal wetlands occurring.

The use of ancillary data such as topographical maps of 1: 50 000 scale assisted with selected aspects of wetlands identification such as drainage, aspect, relief, identification of farm dams and only a small portion of wetlands. The wetland areas evident from the classified images, topographical maps and the comparison wetland data show large discrepancies in wetland size and extent. Many of the wetlands captured on the topographical 1: 50 000 sheets were different in terms actual wetland area. Other ancillary data sources that were limited in quantity but useful included the hydrology data (dams and rivers) as it identified drainage patterns, perennial and non-perennial rivers.

6.2.3 VERIFIED DATA

The verified wetland data assisted the research investigation in two specific ways, despite certain limitations discovered after the field verification exercise. Firstly, this dataset provides information on the position of each wetland in the study area. During the field verification exercise it provided an estimation of the wetland area lost and indicated areas where wetlands had not been captured. The dataset identifies larger wetland areas compared to the classified images. The field verification exercise revealed that most wetland areas had in fact been drained for other land-use practices. Many wetlands mapped from the classified images were not included on the comparison wetland data.

6.3 RECOMMENDATIONS

This research investigation shows the applicability of using satellite imagery for both delineating wetland areas and for updating and verifying wetland-related spatial information collected using different resources. The research investigation was, however, only an evaluation of a particular satellite sensor (LANDSAT ETM+) for mapping wetlands in the light of emerging satellite technologies and image-processing techniques (SAC, 2001, Verhoeye, 2000). The investigation provides the basis for future developments regarding satellite imagery and its use for both wetland mapping and other natural resource studies. The following are recommendations for future studies:

a) *The successful identification of wetland areas from satellite imagery* is highly dependent on the time of the year (season) in which the imagery is captured. This research shows that wetland mapping from winter imagery is complicated and produces low accuracy levels due to the spectral confusions created with other categories. Mapping wetlands from satellite imagery should rather concentrate on summer imagery, especially late spring or early summer (Thompson, 1994a,b; Johnston and Berson, 1995).

b) Different image processing techniques should be evaluated depending on the mapping objectives to ensure the maximum identification of wetlands. Recent research has shown the viability of using both 'hard' and 'soft' classification processes to map wetlands (Verhoeye, 2000). The division of the image into its maximum range of spectral classes (255) was successful for identying wetlands but only after a general classification (20 classes) was done. In addition, other classification processes (supervised and level-slicing techniques) were also used as these additional processes increased the identification of wetlands.

c) A general classification of landcover using techniques (20-classes unsupervised classification in this investigation) that takes into account the spectral peaks within the data is necessary as it helps in delineating areas of interest. A national land-cover database at the appropriate scale should be incorporated into resource mapping of this nature. Topographical modelling is also recommended for wetland identification as it assists in the differentiation of bare ground, slope shadows and the actual wetland site.

d) Manually interpreting the pixels in an area of interest is useful as it leads to a focused classification of an image (255-class unsupervised).

e) The use of ancillary data should be subjected to quality checks before it is used to evaluate results of any classification. The most recent ancillary data regarding those particular phenomena should always be used.

e) Field verification exercises are crucial to wetland mapping as it is a reliable confirmation of the classification accuracies especially if other ancillary data is being used. Field verifications exercises should include an initial transect verification process as well as further, more detailed exercises should be planned.

f) Different satellite sensors should be evaluated in order to complete different phases of wetland mapping. High-resolution satellite sensors such as SPOT and ASTER, are useful for monitoring purposes while LANDSAT satellite imagery can be used for mapping purposes.

g) Radar sensors are useful for detecting soil moisture (wetlands) levels as the dielectric constant for water is at least 10 times that of dry soil. The presences of water in the top few centimetres of soil can be easily detected (Lillesand and Kiefer, 1994).

h) Finally, wetland mapping studies and monitoring must constitute 'living documents' in which constant evaluation and improvements are sought.

This research investigation shows the usefulness of satellite remote sensing for mapping wetlands areas as it covers extensive areas not usually captured using aerial photographs. The relative cost-effectiveness of acquiring satellite imagery is an advantage for large-scale mapping projects, especially for large-scale inventory studies like that, which is to be done in South Africa (Dini *et al.*, 1998). The emergence of new satellite sensors and improved image processing technology will allow greater identification levels of areas such as wetlands (Verhoeye, 2000).

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