A Brief Review of Remote Sensing Data and Techniques for Wetlands Identification

M. Ritchie[1], S. Das[2]
1. Modelling and Digital Science, Council for Scientific and Industrial Research and Department of Statistics; Nelson Mandela Metropolitan University, South Africa, mbeckley@csir.co.za
2. Modelling and Digital Science, Council for Scientific and Industrial Research and Department of Statistics, Nelson Mandela Metropolitan University, South Africa, sdas@csir.co.za

BIOGRAPHY

Ritchie is currently a doctoral student (Statistics) at the Nelson Mandela Metropolitan University. She completed her MSc (Applied Sciences – Mechanics) at the University of Pretoria in 2014.

Das is a principal researcher at the Council for Scientific and Industrial Researcher and a research associate at Nelson Mandela Metropolitan University.

SUMMARY

This paper reviews some data issues and associated techniques which have been implemented in the field of remote sensing for the identification of wetlands. Wetlands are found in diverse geographic areas, however *in situ* measurements from wetlands may often be hard to obtain. A review of some data sources and associated techniques revealed that satellite data is a good means of identifying wetlands. Further, various data sources may be complimentary in nature, and by combining data from various sources (including ancillary data), better identification of wetlands can be achieved.

While multi-temporal imageries aid in the detection wetlands, the date(s) of imagery could have a large effect on the accuracy of the classification of wetlands. Various techniques for wetland identification exist, some of which are statistically based while others may be rule-based or machine learning based. Hybrid techniques combining unsupervised and supervised classification are gaining popularity along with rule-based methods due to their higher accuracies in classification.

Remote sensing, wetland identification, remote sensing classification techniques,

INTRODUCTION

Wetlands are areas saturated or inundated by surface- or ground-water which has vegetation adapted to living under those soil conditions [Everglades Forever Glossary 2011]. They are crucial to the ecosystem as they perform key functions, such as providing critical habitats to plants and wildlife that depend on them, as well as providing protection from storms, waves and floods to the areas inland [Klemas 2011]. Wetlands also play a crucial role in the recharging of aquifers and improvement of water quality by the filtering of waste [Klemas 2011, Rundquist et al. 2001]. As such they are referred to as the kidneys of the landscape' because of the hydrological and chemical functions which take place within them [Rundquist et al. 2001]. Further, the standing waters in the wetlands provide sites for many biogeochemical processes including the fixation of carbon and nitrogen and the production of gases such as methane and nitrous oxide [Rundquist et al. 2001].

The importance of wetlands was, however, only recognised relatively recently. Previously, wetlands were filled in, drained or were altered to make them more useful to society [Rundquist et al. 2001], and there is still concern regarding human induced stresses such as pollutant run-off and fragmentation by roads [Klemas 2011]. Besides human stresses on wetlands, there is also the stress caused by climate change [Klemas 2011]. In the United States, it is estimated that about 33 230 acres of wetland were lost between 1998-2004 [Klemas 2011], with a majority of this loss being due to coastal salt marsh being converted to open saltwater [Klemas 2011], suggesting that rising sea levels could be problematic for wetlands as most of them are not far above sea-level. In South Africa, for example, it is estimated that 58% of the wetland area of the 'Mfolozi catchment of Natal' was lost by the middle of the 1980s [Taylor et al. 1995].

Remote sensing has been used for mapping and classifying wetlands for over 40 years [Rundquist et al. 2001]. Data obtained from remote sensing appears to be both practical and attractive for monitoring [Klemas 2011] as wetlands are found in diverse geographic areas, and *in situ* measurements are often difficult to obtain [Rundquist et al. 2001].

METHOD AND RESULTS

The purpose of this review is to present a brief overview of some of the available remote sensing data sources and some of the methods and techniques used in the analysis of such data for identifying wetlands.

Data Sources

Aerial Photography

Aerial photography is has been preferred for detailed wetland mapping, especially when mapping many different types of vegetation [Ozesmi and Bauer 2002]. The U.S. Fish and Wildlife service has made use of natural colour and infrared colour aerial photography [Klemas 2011], while Seher and Tuller (1973) used both natural colour and infrared colour aerial photography to map marsh vegetation in four wildlife reserves in Nevada. It was determined that not only were aerial photography useful, but that the scale of the images was also important.

For identifying and mapping wetlands, aerial photography was used by McEwan et al. (1976), Klemas et al. (1974), Stewart et al. (1980) and Carter et al. (1979), while Hardisky et al. (1986) used colour infrared aerial photography along with appropriate ground measurements to quantify the biomass and productivity of large wetlands.

Satellite Data

Another source of remote sensing data is multi-spectral satellite data that are available at varying spatial resolutions. Multi-spectral sensors have less than a dozen spectral bands [Klemas 2011]. In general, medium resolution refers to a resolutions of 10-30m, while high resolution refers to resolutions of 1-4m. Low resolution satellite systems have resolutions of 30m+. Some of the available sources for satellite imagery are given in Table 1.

Resolution	Satellite Systems
Low	Landsat MSS; IRS-1B LISS II
Medium	Landsat 4-, 5- TM; SPOT-1,2,3,4
High	IKONOS; QuickBird; OrbView-3; WorldView-1,2; GeoEye-1; AVHRR

Table 1: Some sources of multi-spectral satellite data

High resolution images come at a higher cost than medium resolution ones, which implies that under budgetary constraints, medium resolution imagery may still be the preferred imagery. Low resolution imagery is generally no longer used in identification as medium resolution data are readily available.

Satellite data has many advantages in wetland identification research because of they allow for:
- repeat coverage which is of advantage if multi-temporal data is used for improved classification accuracy or in the case of change detection;
- classifying the upland areas which can influence the wetland;
- digital format of the data which allows for easy integration into Geographic Information Systems;
- coverage of large areas;
- cheaper alternative to aerial photography when a large area is considered.

However, there are also limitations to satellite classification which include issues related to:
- fluctuating water levels changing spectral reflectance of vegetation causing confusion;
- visible scars from fires which are often confused with water;
- pixel size whereby mixed pixels can cause problems for classification and smaller wetlands may not be identified.

Some studies for wetland identification making use of satellite data include Turner and Rundquist (1981), Jensen et al. (1993), Gluck et al. (1996), Haper and Ross (1982), Hewitt (1990). Singh et al. (2013) used multi-temporal Landsat images to appraise the land use of mangrove forests in India.

Radar Data

Radar systems are those which transmit and receive radiation in the microwave portion of the electromagnetic spectrum [Ozesmi and Bauer 2002]. Radar has the advantages that it can penetrate cloud cover, it can be collected under any solar illumination conditions and the radar reflections provide different information to optical sensors [Rundquist et al. 2001; Ozesmi and Bauer 2002]. Radar data has been found to be able to detect the presence and extent of flooding, even under plant canopy [Ozesmi and Bauer 2002].

Previously the use of radar in wetland studies was limited due to poor availability of radar data [Rundquist et al. 2001]. However, following the launch of RadarSat (1995), ERS-1(1991) and JERS-1(1992), it has become possible to make use of such data [Rundquist et al. 2001; Ozesmi and Bauer 2002].

Wetland studies using radar data include Hess et al. (1990), Kasischke and Bourgeau-Chavez (1997) and Henderson (1995). Radar data has also been used in conjunction multi-spectral data. Some such studies (some for general land cover analysis) include Rundquist et al. (1997), Schistad Solberg et al. 1994, Bruzzone et al. (1999) and Townsend and Walsh (1998). Separately, Kushwaha et al. (2000) made use of multi-temporal radar imaging data in order to identify mangrove wetlands in a coastal region of India – using multi-temporal imagery that included pre-monsoon, monsoon and post-monsoon images.

Ancillary Data

Ancillary data which can be used for wetland identification include topographic data, soil data, elevation data or digital elevation models, socio-economic data, forest cover maps, hydrography data, point measurements of atmospheric and surface variables [Goodenough et al. 1995] and other geophysical data [Schistad Solberg et al. 1994].

In general, studies have found that the use of ancillary data improves classification accuracy of wetlands and other land cover classes [Ozesmi and Bauer 2002], and often studies use such data whenever it is available [Klemas 2011].

Wetland Identification Techniques

Various types of techniques have been used in wetlands identification and mapping studies. Broad classes for these methods include visual interpretation, unsupervised classification, supervised classification, hybrid classification and rule-based classification. Each of these classes will be considered below.

Visual Interpretation

Visual interpretation was used in early works of wetland identification and mapping [Seevers et al. 1974; Johnston and Barson, 1993]. This method while accurate, requires a large amount of the analyst's time [Ozesmi and Bauer 2002]. In order to reduce the amount of analyst's time required, classification for the identification of wetlands has transitioned into computerised classification [Ozesmi and Bauer 2002]. These computerised classification techniques are briefly considered below.

Unsupervised Classification

The first of the computerised classification were unsupervised classification techniques. These techniques make use of similar spectral values of pixels to group them into clusters, which are the then identified and labelled by an analyst. In general, a large number of clusters are translate to better accuracy [Ozesmi and Bauer 2002]. Kempka et al. (1992) used more than 230 clusters. On the other hand, often cluster busting is used to reduce the number of clusters [Ozesmi and Bauer 2002].

Unsupervised classification has been used by Gluck et al. (1996), Lee and Marsh (1995), Park et al. (1993) and Ramsey et al. (1998) amongst others for identification or mapping of wetlands.

Unsupervised classification requires no training data and there is no expensive training phase in the classification process, only an analyst's time is required to classify the clusters. However, it is possible that this method may not produce spectral groupings that match the classes of interest.

Supervised Classification

Supervised classification techniques, unlike unsupervised classification, makes use of training data to classify the image. The training data consists of areas of pixels of known classifications. These techniques may require computationally expensive training periods for the classification but do not require much of the analyst's time. These methods also allow for the creation of classes matching those of interest.

Some supervised classification techniques include:
- Maximum Likelihood Classification (Butera 1983, Lee and Park 1992, Yi et al. 1994);
- Discriminant Function Analysis (Franklin et al. 1994);
- Minimum Distance to Means (Huguenin et al. 1997);
- Parallelpiped (Hines et al. 1993);
- Support Vector Machine (Singh et al. 2013);
- Bayesian formulation based classification (Schistad Solberg et al. 1994);
- Bayesian formulation and neural network based classification (Bruzzone et al. 1999)

Hybrid Classification

In order to improve classification accuracy, researchers have combined unsupervised and supervised classification techniques, referred to as hybrid classification techniques. Results using hybrid classification are generally more accurate than those of either of the technique used by themselves.

Hinson et al. (1994) made use of a hybrid technique to identify coastal wetlands in Texas, while Hodgson et al. (1987) used a hybrid technique known as guided clustering to identify wood stork habitats (which coincide with wetlands).

Rule-based Classification

Another class of techniques was generated to improve accuracy, these techniques are referred to as rule-based methods. Rule-based classification techniques use training data to develop rules upon which pixels are classified. These methods often use ancillary data and do require more of the analyst's time. The results are comparable with hybrid techniques.

Some rule-based classification studies for the identification of wetlands include Sadar et al. (1995), who made use of data including hydric soil data, National Wetland Inventory maps, a digital elevation model and hydrography in addition to Landsat TM data, and Bolstad and Lillesand (1992) who used topographic position and soil texture data in addition to Landsat TM data.

CONCLUSIONS

While various data sources are available for the purpose of wetland classification, they generally tend to be complimentary. Additionally, the use of multiple data types, including ancillary data, tends to improve classification accuracy. Multi-temporal data also, in general, improves classification accuracy.

Among the various types of classification techniques available, hybrid and rule-based classification techniques give the best classification accuracies.

As such, for a specific wetland classification research, one thus needs to consider available data types and sources in conjunction with budgetary and computational time constraints in order to determine the best data sources and methods to be used for the specific purpose.

REFERENCES

Bolstad, P.V. and Lillesand, T.M., 1992, Rule-based classification models: flexible integration of satellite imagery and thematic spatial data, Photogrammetric Engineering and Remote Sensing, 58, 965-971.

Bruzzone, L., Prieto, D.F. and Serpico, B. , 1999, A neural-statistical approach to multitemporal and multisource remote-sensing image classification, IEEE Transactions on Geoscience and Remote Sensing, 37(3), 1350-1359.

Butera, M.K., 1983, Remote sensing of wetlands, IEEE Transactions on Geoscience and Remote Sensing, GE21, 383-392.

Carter, V., Malone, D.L. and Burbank, J.H. , 1979, Wetland Classification and mapping in Western Tennessee, Photogrammetric Engineering and Remote Sensing, 45, 273-284.

Everglades Forever Glossary, 2011, www.dep.state.fl.us/evergladesforver/about/glossary.htm#w, Last accessed: 25 April 2015

Franklin, S.E., Gillespie, R.T., Titus, B.D. and Pike, D.B., 1994, Aerial and satellite sensor detection of *Kalmia angustifolia* at forest regeneration sites in central Newfoundland, International Journal of Remote Sensing, 15, 2553-2557.

Gluck, M., Rempel, R. and Uhlig, P.W.C. , 1996, An evaluation of remote sensing for regional wetland mapping applications, Forest Research Report No.137, Ontario Forest Research Institute, Sault Ste Marie, Ontario, Canada.

Goodenough, D.G., Bhogal, P., Charlebois, D., Matwin, S. and Niemann, O., 1995, Intelligent data fusion for environmental monitoring, IEEE, 2157-2160.

Hardisky, M.A., Gross, M.F. and Klemas, V., 1986, Remote Sensing of Coastal Wetlands, Bioscience, 36(7), 453-460.

Henderson, F., 1995, Environmental factors and the detection of open surface water areas with X-band radar imagery, International Journal of Remote Sensing, 16, 2423-2437.

Hess, L.L., Melack, J.M. and Simonett, D.S., 1990, Radar detection of flooding beneath the forest canopy: a review, International Journal of Remote Sensing, 11, 1313-1325.

Hewitt, M.J. III, 1990, Synoptic inventory of riparian ecosystems: the utility of Landsat Theumatic Mapper data, Forest Ecology and Management, 33/34, 605-620.

Hines, M.E., Pelletier, R.E. and Crill, P.M., 1993, Emission of sulfur gases from marine and freshwater wetlands of the Florida Everglades: rates and extrapolation using remote sensing, Journal of Geophysical research, 98, 8991-8999.

Hinson, J.M., German, C.D. and Pulich, W. Jr, 1994, Accuracy assessment and validation of classified satellite imagery of Texas coastal wetlands, Marine Technology Society Journal, 28, 4-9.

Hodgson, M.E., Jensen, J.R., Mackey, H.E. Jr and Coulter, M.C., 1987, Remote sensing of wetland habitat: a wood stork example, Photgrammetric Engineering and Remote Sensing, 53, 1075-1080.

Huguenin, R.L, Karaska, M.A., Blaricom, D.V. and Jensen,J .R., 1997, Subpixel classification of blad cypress and tupelo gum trees in Thematic Mapper imagery, Photogrammetric Engineering and Remote Sensing, 63, 717-725.

Jensen, J.R., Cowen, D., Althausen, J., Narumalani, S. And Weatherbee, O., 1993, An evaluation of the Coast Watch change detection protocol in South Carolina, Photogrammetric Engineering and Remote Sensing, 59, 1039-1046.

Johnston, R.M. and Barson, M.M., 1993, Remote sensing of Australian wetlands: an evaluation of Landsat TM data for inventory and classification, Australian Journal of Marine and Freshwater Resources, 44, 235-252.

Kasischke, E.S. and Bourgeau-Chavez, L.L., 1997, Monitoring south Florida wetlands using ERS-1 SAR imagery, Photogrammetric Engineering and Remote Sensing, 63, 281-291.

Kempka, R.J., Kollasch, R.P. and Koelen, G.T., 1992, Using GIS to preserve the Pacific flyway's wetland resource, GIS World, 5, 46-52.

Klemas, V., 2011, Remote Sensing of Wetlands: Case Studies Comparing Practical Techniques, Journal of Coastal Research, 20(4), 518-527.

Klemas, V., Daiber, F., Bartlett, D., Crichton, O. and Fornes, A., 1974, Inventory of Delaware's Wetlands, Photogrammetric Engineering, 40, 433-439.

Kushwaha, S.P.S., Dwivedi, R.S. and Rao, B.R.M. , 2000, Evaluation of various digital image processing techniques for detection of coastal wetlands using ERS-1 SAR data, International Journal of Remote Sensing, 21, 565-579.

Lee, C.T. and Marsh, S.E., 1995, The use of archival Landsat MSS and ancillary data in a GIS environment to map historical change in an urban riparian habitat, Photogrammetric Engineering and Remote Sensing, 61, 999-1008.

Lee, J.K. and Park, R.A., 1992, Application of geoprocessing and simulation modeling to estimate impacts of sea level rise on the northeast coast of Florida, Photogrammetric Engineering and Remote Sensing, 58, 1579-1586.

McEwan, R., Kosco, W. and Carter, V., 1976, Coastal Wetland Mapping, Photogrammetric Engineering and Remote Sensing, 42, 221-232.

Ozesmi, S.L., Bauer, M.E., 2002, Satellite remote sensing of wetlands, Wetlands Ecology and Management, 10, 381-402.

Park, R.A., Lee, J.K. and Canning, D.J., 1993, Potential effects of sea-level rise on Puget Sound wetlands, Geocarto International, 4, 99-110.

Ramsey, E.W. III, Chappell, D.K., Jacobs, D., Sapkota, S.K. and Baldwin, D.G., 1998, Resource management of forested wetlands: hurricane impact and recovery mapping by combining Landsat TM and NOAA AVHRR data, Photogrammetric Engineering and Remote Sensing, 64, 733-738.

Rundquist, D., Leavitt, B., Payton, S. and Narayanan, R. , 1997, Using ERS-1 data to measure and map selected conditions related to the production of methane in a wetland environment: the Nebraska Sandhills, USA, Proceedings Third ERS Symposium, 197-202.

Rundquist, D.C, Narumalani, S. and Narayanan,R.M., 2001, A review of wetlands remote sensing and defining new considerations, Remote Sensing Reviews 20(4), 207-226.

Sadar, S.A., Ahl, D. And Liou, W.-S, 1995, Accuracy of Landsat TM and GIS rule-based methods for forest wetland classification in Maine, Remote Sensing of Environment, 53, 133-144.

Schistad Solberg, A.H., Jain, A.K. and Taxt, T., 1994, Multisource Classification of Remotely Sensed Data: Fusion of Landsat TM and SAR images, IEEE transactions on geoscience and remote sensing, 32(4), 768-778.

Seevers, P., Mahoney, R., Maroney, R. and Rundquist, D., 1974, An inventory of Nebraska Wetlands with the use of Imagery from the Earth Resources Technology Satellite,Proceedings: Fourth Annual Remote Sensing of Earth Resources Conference, University of Tennessee Space Institute, 281-292.

Seher, J. and Tuller, P., 1973, Color Aerial Photos for Marshland, Photogrammetric Engineering, 39, 489-499.

Singh, S.K., Srivastava, P.K., Gupta, M., Thakur, J.K. and Mukherjee, S., 2013, Appraisal of land use/land cover of mangrove forest ecosystem using support vector machine, Eviron Earth Sci, 71, 2245-2255.

Stewart, W., Carter, V. and Brooks, P., 1980, Inland (Non-Tidal) Wetland mapping, Photogrammetric Engineering and Remote Sensing, 46, 617-628.

Taylor, A.R.D., Howard, G.W. and Begg, G.W., 1995, Developing wetland inventories in Southern Africa: A review, Vegetatio, 118, 57-79.

Townsend, P.A. and Walsh, S.J., 1998, Modeling floodplain inundation using integrated GIS with radar and optical remote sensing, Geomorphology, 21, 295-312.

Turner, J. and Rundquist, D., 1981, Wetlands Inventory of the Omaha District, U.S. Army Corps of Engineers, 110.

Yi, G.-C., Risley, D., Koneff, M. and Davis, C., 1994, Development of Ohio's GIS-based wetland inventory, Journal of Soil and Water Conservation, 49, 23-28.