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Understanding riverine wetland-catchment processes using remote sensing data and modelling

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Abstract:

Many wetlands are dependent on river basin processes, and at the same time, scientists have recognised the important role of wetlands in the river basin: they are important zones for groundwater recharge, they temper high flows and are therefore very important to limit flooding. By purifying the water, wetlands also play a very important role for water quality. However, the underlying processes are often not very well known or are poorly quantified. This is especially true for many wetland rich basins in Africa that are poorly gauged or even ungauged. In this study we analyse to what extend remote sensing data can be of use to analyse and model ungauged or poorly gauged wetland rich river basins, taking the Kagera river basin as a case study by using existing maps with information on the basis of soil water of the toplayer, evapotranspiration maps, DEM and land use maps and satellite born rainfall estimates. A river basin model is built using the "Soil and Water Assessment Tool". The freely available GIS maps for DEM, Soil Maps and land use maps are very useful for setting up catchment models but they are not very helpful for wetland characterisation. The satellite rainfall data are still not well replacing ground data to model the rainfall-runoff processes. The generated maps for daily soil water values are promising to derive information on the dynamics of remote riverine wetlands. With this information, a better integration of wetland and catchment models should be obtained.

Keywords: Wetlands; catchments; remote sensing; SWAT

1. INTRODUCTION

Wetlands are buffer zones between water and land that play important roles in controlling flooding, reducing pollution, providing habitats for fauna and biota and maintaining livelihoods. Wetlands constitute only around 1% of Africa's total surface area, (excluding the smaller seasonal wetlands), and relatively little scientific investigation has been undertaken in comparison to other ecosystems such as forest or to wetlands in other parts of the world (in America and some part of Asia). Africa's many wetland types support a great diversity of plants and animals, and livelihoods.

But, wetlands suffer from over-extraction of fresh water, overuse of their resources, drainage and pollution. They are blocked by dams or turned into agricultural land. Already 50% of the world's wetlands have been lost in the past century (van den Bergh et al., 2004). Also Rwanda's largest population (80%) lives in wetland reclaimed areas. Actually, it is needed to make a serious attention on the remaining ones. In order to increase understanding of the role of wetlands for humans and nature, and in order to follow the wetland area in the world, global identification and characterisation techniques are needed.

Many wetlands are dependent on river basin processes, and in the same time, scientists have recognised the important role of wetlands in the river basin: they are important zones for groundwater recharge, they temper high flows and are therefore very important to limit flooding. By purifying the water, wetlands also play a very important for river water quality. However, the underlying processes are often not very well known or are poorly quantified. This is especially true for many wetland rich basins in Africa that are poorly or ungauged basins. Therefore we aim to analyse to what extend remote sensing data can be of use to analyse and model ungauged or poorly gauged wetland rich river basins, taking the Kagera river basin as a case study by using existing maps with information on the basis of soil water of the toplayer, DEM and land use maps and satellite born rainfall estimates.

2. THE KAGERA CATCHMENT AND WETLANDS

The Kagera River basin is distributed in four countries: Burundi, Rwanda, Tanzania and Uganda The study area covers an area of approximately 58,000 km². The Kagera River is the largest of the 23 rivers that drain into Lake Victoria and it is the most remote head stream of Nile River. It is formed at the confluence of two rivers: Nyabarongo (Rwanda) and Ruvubu (Burundi). The elevation in the basin varies from around 1,100 m above mean sea level in east to 4500 m in the Northern-west.

Rainfall varies from less than 1000mm over the eastern part of the basin up to 1,800 mm and above in the west, where most of the runoff is generated. There are two rainfall seasons, with the longer south-easterly monsoon bringing rain between about February and May, and the shorter north-easterly monsoon from about September to November. The runoff responds to the rainfall with a higher peak in May and a smaller peak in November. However, the river flows are attenuated by a number of lakes, and wetlands and associated lakes (Holmberg et al., 2003). Heavy rainfall during rainfall seasons and steep slopes cause erosion hence degradation of ecosystem. On the other hand, there are also droughts during prolonged dry seasons. Moreover, Kagera Basin faces problems related to water resources management of trans-boundary watersheds. Wetlands have a significant influence on hydrologic processes in Kagera River basin and they occupy in average 6% of Burundi and Rwanda surface area (FAO-SAFR, 1998).

3. REMOTE SENSING AND GIS DATA

The following data have been used:

Digital Elevation Model (DEM)

- HYDRO1k: the U.S. Geological Survey's (USGS) public domain geographic database HYDRO1k (http://edc.usgs.gov/products/elevation/gtopo30/hydro/index.html), which is derived from their 30 arc-second digital elevation model of the world GTOPO30. HYDRO1k has a consistent coverage of topography at a resolution of 1 kilometre.

- SRTM (Shuttle Radar Topography Mission) is a joint project between NASA and NGA (National Geospatial-Intelligence Agency) to map the world in three dimensions (http://www2.jpl.nasa.gov/srtm/index.html). The SRTM digital elevation data has a spatial resolution of 3 arc-second for Global coverage of latitude and longitude (approximately 90 meters). The SRTM "finished" data meet the absolute horizontal and vertical accuracies of 20 meters and 16 meters respectively.

Digital stream network (DSN):

- HYDRO1k: The USGS' HYDRO1k database is derived from the flow accumulation layer for areas with an upstream drainage area greater than 1000 km2.

Soil map:

- FAO: Food and Agriculture Organization of the United Nations (FAO, 1995) provides almost 5000 soil types at a spatial resolution of 10 kilometres with soil properties for two layers (0-30 cm and 30-100 cm depth). Further soil properties (e.g. particle-size distribution, bulk density, organic carbon content, available water capacity, and saturated hydraulic conductivity) were obtained from Reynolds et al. (1999) or by using pedotransfer functions implemented in the model Rosetta (http://www.ars.usda.gov/Services/docs.htm?docid=8953).

Landuse map

- GLCC: the USGS Global Land Cover Characterization (GLCC) database (http://edcsns17.cr.usgs.gov/glcc/glcc.html) has a spatial resolution of 1 kilometre and 24 landuse classes. The parameterization of these classes (e.g. leaf area index, maximum stomatal conductance, maximum root depth, optimal and minimum temperature for plant growth) is based on the available SWAT landuse classes and literature research.

Weather data

- TRMM (Tropical Rainfall Measuring Mission). TRMM is joint project of NASA and National Space Development Agency of Japan, which objectives are observing and understand the tropical rainfall and how this rainfall affects the global climate. TRRM is interested in tropical rainfall because most of the rainfall is found in tropical zones and have a significant influence on the global climate change. Daily accumulated rainfall or rain rate data are available for the period from 1998 to present, with a spatial resolution varying from 0.25 degree to 5.0 degree resolution. (http://disc2.nascom.nasa.gov/Giovanni/tovas/TRMM_V6.3B42_daily.shtml)

- NCEP/NCAR: The NCEP/NCAR Reanalysis Project is a joint project between the National Center for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR). The NCEP/NCAR Reanalysis data are divided into 6 different sections: pressure level, surface, surface fluxes, tropause sections, derived data and spectral coefficients. Precipitation data are in surface fluxes section. This section comprises 4-times daily, daily and monthly time series from January 1st, 1948 to present. The data sets spatial coverage is T62 Gaussian grid with 192x94 points. Other climate variables available through this dataset are air temperature, surface lifted index, pressure, relative humidity, and wind velocity. The levels of measurement are surface or near the surface, or entire atmosphere. (http://www.cdc.noaa.gov)

Wetlands data:

- WETLANDS-FAO: information on wetlands is gathered at the site http://www.fao.org/DOCREP/003/X6611E/x6611e00.htm#TopOfPage

Soil Water data

Figure 1 shows the daily Soil Water content map with grids of a resolution of 0.25 degree that containes soil water content in percentage as well as identifiers for grids with water surface > 5% of the area (Owe et al., 2008). As can been seen in the area that zooms in onto the Kagera basin, some pixels referring to water surface or the areas that contain wetlands. Each day contains strips of missing data as can be seen in Figure 1 but those strips shift. Around 30-40% of the values of the constructed time series for the Kagera basin are missing data.

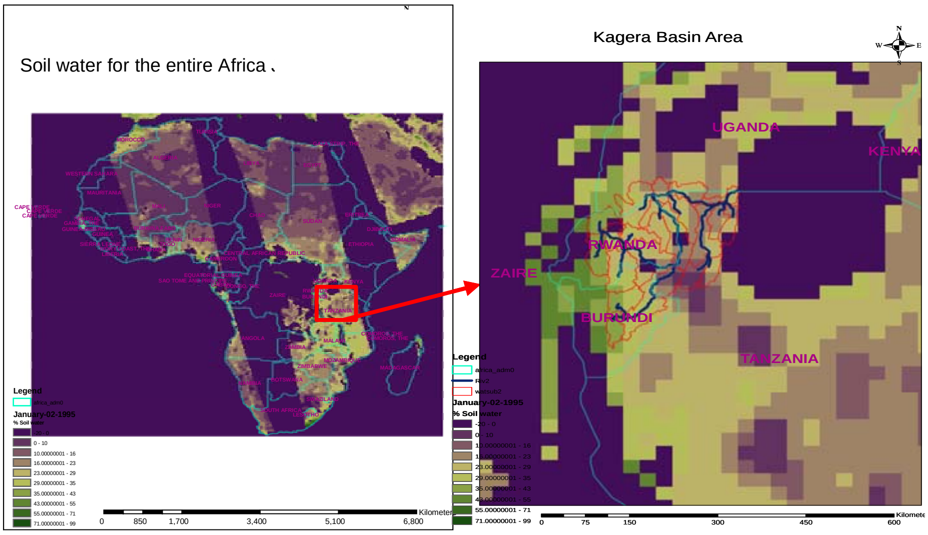

Figure 1 Soil water content map for entire Africa and for Kagera

4. CATCHMENT MODEL

Wetlands play a very important role in the catchment hydrology. Since catchments contain wetlands and not vice versa, the catchment model SWAT (Soil and Water Assessment Tool) (Arnold et al., 1998) was chosen for this study.

SWAT

SWAT is a conceptual model that operates on a daily time step. The objectives in model development were to predict the impact of management on water, sediment and agricultural chemical yields in large basins. To satisfy these objectives, the model (a) uses readily available inputs for large areas; (b) is computationally efficient to operate on large basins in a reasonable time, and (c) is capable of simulating long periods for computing the effects of management changes.

Model set-up

The watershed delineation of Kagera River basin was done using a DEM of spatial resolution of around 90m x 90m from SRTM, and the basin was subdivided into 12 sub-catchments, whose surface areas range from 11,900 to 16,745 km². The other data used are soil map of 1km x 1km resolution produced by FAO and land use map from Global 2000 land cover with a resolution of 1km x 1km. Monthly discharge from “The Global River Discharge Database” for 5 gauging stations was used for model evaluation. Several sources of weather data were compared.

The model calibration period was from 1974 to 1979. The following period up to 1985 was used to validate the calibrated model. The calibration process was done in three phases: resizing of subbasins channels, specification of wetlands, modification of ground water flow parameters and then auto-calibration with sensitive parameters. An automated base flow separation filter (Arnold, 1995) was used to determine the recession constant and ground water delay for the subbasins from stream flow data.

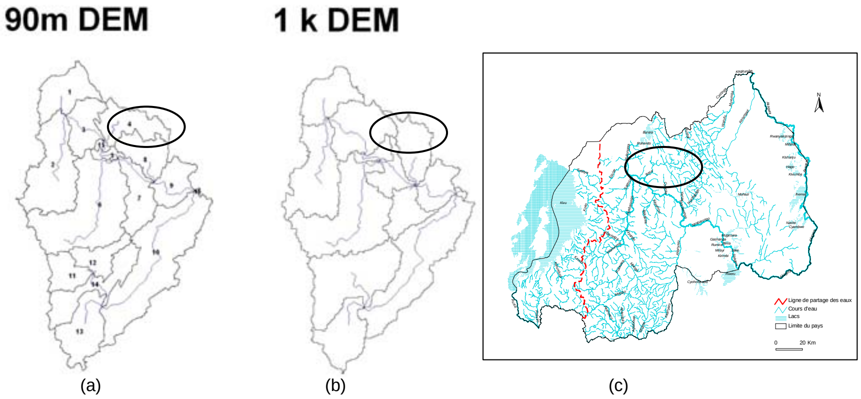

Figure 2 Delineation of Nyabarongo and Rubuvu catchement using 90m DEM (a) and 1 kilomter DEM (b) and the hydrological map of Rwanda (c)

DEM evaluation

A SWAT model was built for the Nyabarongo and Ruvubu sub-catchments that are located in the South–West of the Kagera basin, within the countries of Rwanda and Burundi. In Figure 3, it is clear that the difference of DEM resolution is mainly apparent at smaller scales. The shape of the watershed is very much alike, but several defined subbasins, like sub-basin 4 get a very different shape. Due to this, the runoff water generated in the circeled area of Figure 2 will enter the Nyabarongo river at different locations. From the hydrological map of Rwanda it can be concluded that the 90 m DEM produces the right delineation. Also very clear differences are apparent in the calculated slope that are 4 times higher in the mountaineous subbasin 2 when using the 90 m DEM compared to the 1 k DEM.

Rainfall input evaluation

Different sources of rainfall derived from remote sensing data are compared to groundwater data (Haguma, 2007). The evaluation is based on the coefficient of determination (R^2), Nash-Sutcliffe efficiency coefficient (Ns) and Deviation of stream flow volume (Dv) to measure the model performance.

The simulated stream flow using TRMM gave an underestimation, where the best simulation gave only 18% of the total volume. Due to underestimation of precipitation, the simulated stream flow was very low so that no calibration was done, except manual adjustment of ground water parameters. A calibration and validation was performed for the CRU/dGen and the NCEP/NCAR giving reasonable results, but poor results for predictions of the validation period (Table 1).

Table 1. Performance of the Kagera model for different sources of rainfall data (Ns=Nash-Sutcliffe efficiency, R^2= coefficient of determination, RMSE=Root mean squared error)

	CRU/dGen		NCEP/NCAR		Ground data	
	Calibration (1974-1979)	Validation (1980-1985)	Calibration (1974-1979)	Validation (1980-1984)	Calibration (1974-1979)	Validation (1980-1985)
Ns	0.41	0.01	0.43	-21.03	0.63	-1.36
R2	0.48	0.26	0.45	0.03	0.65	0.08
Dv	-7.67%	-10.83%	-6.96%	39.49%	-7.31%	11.24%

Wetland incorporation

Wetlands were included on the basis of the previously described FAO site. The poor validation results can be related to the lack of information on the wetland hydrology in the model. Promising results were obtained for the Nyarabongo watershed at Kigali station that does not contain large wetlands (Figure 3). The Nash-Sutcliffe efficiencies of the calibration and validation were 0.65 and 0.78 respectively.

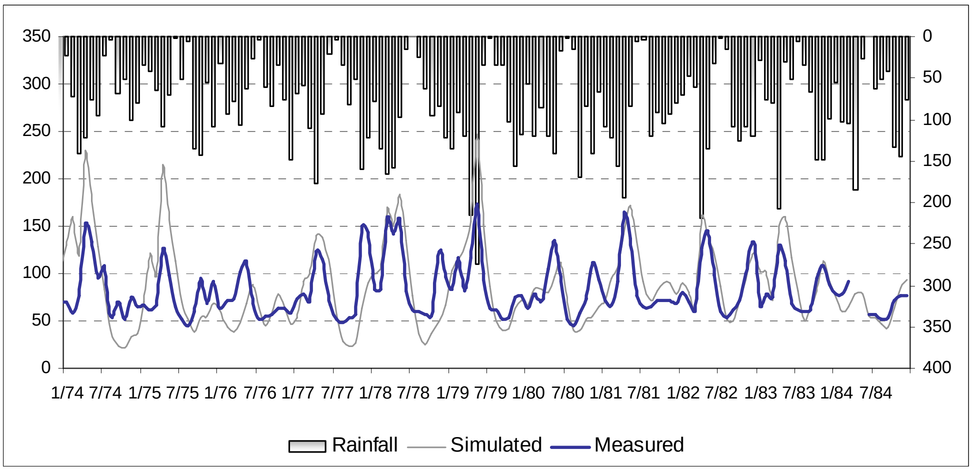

Figure 3 Simulations for the Nyarabongo watershed, validation period using (Kigali station)

4. WETLAND IDENDTIFICATION AND CHARACTERISATION

For the cells 6 (wetland area) and 18 (agricultural area) of Figure 4, time series have been computed (Figure 5) based on the daily soil water data maps for the year 2005.

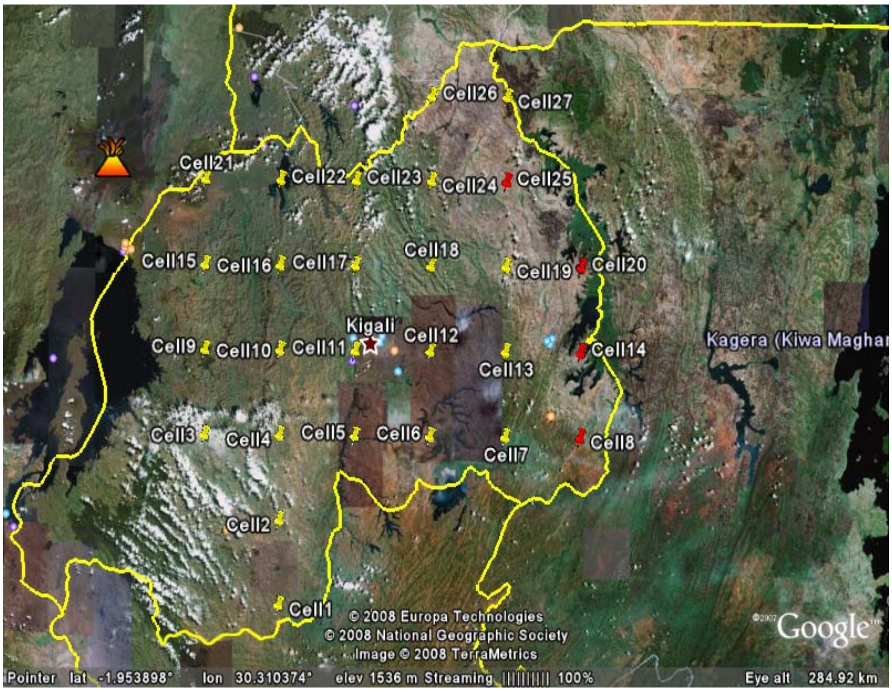

Figure 4 location of the grid centers of the soil water maps for Rwanda

The time series generated for the wetland and agricultural cells are presented in Figure 5. Cells that contain more of 5% water surface got separate indicators and are represented by the value 110% (over-saturation). In the year 2005 60% of the days contained values of which around 60% where identified as water surface. The remaining 82 days with soil water values for both cells show a relative similar pattern (r^2=0.45) and average value with less then 3%. This gives the indication that the wetland is flooded during around 60% of the time and that the behaviour of the soil water during the periods where the wetland is not flooded, is quite similar to the analysed agricultural land area grid.

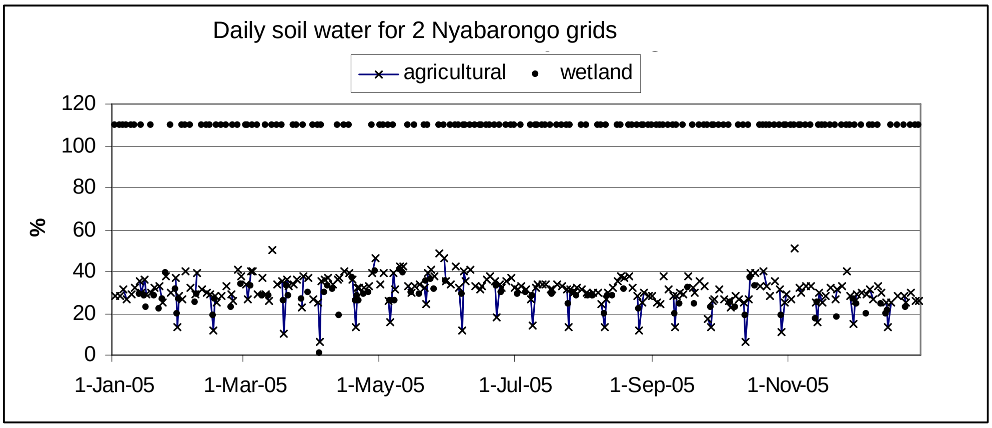

Figure 5 Soil water content for a agricultural grid and a wetland grid (110% means water surface)

5. CONCLUSIONS AND RECOMMENDATIONS

Riverine wetlands and river basins have very strong influences on each other hydrology and functioning. It is therefore important to do a joint analysis of both. However, wetlands are often located in remote areas or poorly gauged what is certainly true for many wetlands in Africa. But, there is a lack of ground data to do a proper understanding of the complex relations between the wetland and the catchment. Therefore a couple of remote sensing born data have been collected and processed for the Kagera catchment in the form of DEM, soil maps, land use maps, daily soil water maps and (sub)-daily rainfall data. The DEM, soil maps and land use maps seemed are extremely useful for catchment modelling tools that are nowadays by default imbedded in GIS based preprocessors, such as the Soil and Water Assessment tool. The delineated (sub)basins and calculated slopes are however very much dependent on the resolution of the DEM. Even thought the Kagera basin is a poorly gauged basin for precipition, it seemed that rainfall estimates derived from satellite images are not very useful up to date for this case.

The automated preprocessing of the GIS data towards a SWAT model does not consider any wetlands or wetland processes. In the Kagera, as well as many other African river basins, wetlands are important landscape features that strongly influence the hydrology. For the identification of wetlands and their flooding periods, an analysis was done of daily soil water data maps. The results show indeed that grids with wetlands are indeed temporally identified as water surface.

Further step to be done is to get riverine wetlands descriptions and processes included into catchment models. Such an integration should consider the contribution of surface water and groundwater to the wetlands, while the wetlands themselves are impacting the groundwater recharge, the river runoff processes and the river hydraulics.

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REFERENCES

Arnold, J. G., Srinivasan, R., Muttiah, R. S. and J. R. Williams, Large area hydrologic modeling and assessment part I: model development. *Journal of the American Water Resources Association*, 34(1), 73 89, 1998.

Hails, A. J., Wetlands, Biodiversity and the Ramsar Convention: The role of the Convention on the Wetlands in the Conservation and Wise Use of Biodiversity, Ramsar Convention Bureau, Gland, Switzerland, 1996.

Owe, M., De Jeu, R.A.M., and T.R.H., Holmes, Multi-Sensor Historical Climatology of Satellite-Derived Global Land Surface Moisture, *J. Geophys. Res*. 113,F01002, doi:10.1029/2007JF000769., 2008.

FAO (Food and Agriculture Organization), The digital soil map of the world and derived soil properties. CD-ROM, Version 3.5, Rome, 1995.

FAO-SAFR, Wetland characterization and classification for sustainable agricultural development, Harare, Zimbabwe, 1998.

Haguma, D., Development of hydrologic model of Kagera River basin using Remote sensing data, thesis, Masters of Water and Engineering, UNESCO-IHE, Delft Netherlands,2007.

Holmberg, J. and T., Lilja, Kagera River basin integrated water resources management project, WSP International Sweden AB, 2003.

Kalnay E., Kanamitsu, M., Chelliah, M. Ebisuzaki, W. and R., Jenne. The NCEP/NCAR 40-Year Reanalysis Project. *Bulletin of the American Meteorological Society*, 77(3):437-471, 1998.

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M., and M., New, A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901–2000) and 16 scenarios (2001–2100).Tyndall Centre Working Paper 55, 2004.

NCDC (Nation Climatic Data Centre), Global daily summary: Temperature and precipitation 1977-1991. CD-ROM, Version 1.0. , 1994.

NCDC (Nation Climatic Data Centre). Global daily climatology network (GDCN). CD-ROM, Version 1.0., 2002.

New, M., Hulme, M., and P., Jones, Representing twentieth-century space-time climate variability. Part II: Development of 1901-96 monthly grids of terrestrial surface climate. *J. Clim*. 13(13), 2217-2238, 2000.

Schuol, J. and K.C., Abbaspour, Using monthly weather statistics to generate daily data in a SWAT model application to West Africa. *Ecol. Model.* 201, 301-311, 2007.

Reynolds, C.A., Jackson, T.J. and W.J. Rawls. Estimating available water content by linking the FAO soil map of the world with global soil profile database and pedo-transfer functions. Proceedings of the AGU 1999 spring conference. Boston, MA, 1999.

van den Bergh, J. C. J. M., Barendregt A. and A.J., Gilbert, Spatial Ecological-Economic Analysis for Wetland Management: Modelling and Scenario Evaluation of Land Use, Cambridge University, 2004.