Remote Sensing for Mapping TSM Concentration in Mahakam Delta: an Analytical Approach

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Abstract

The Indonesian coastal zones have always been under heavy pressures, including those from fisheries, oil industries and sea transportation. The presence of these activities carry a large portion of risk in damaging the environment as well as in destroying the marine resources, leading to the need for an integrated management approach based on an environmental information system that is comprehensive and multi-disciplinary in nature. The Mahakam Delta has the same general problems as other coastal regions in Indonesia. The method is based on bio optical modeling. The forward water analysis comprised the laboratory measurements of water quality (TSM and Chl) and Inherent Optical Properties (IOPs) to derive Spesific Inherent Optical properties (SIOPs). SIOPs (of water, TSM, Chl and CDOM), coefficient f and B were used to developed R(0-) model. The inverse atmosphere analysis comprised the image preprocessing (i.e. geometric correction, atmospheric correction, air-water interface correction). The last step is inverse water analysis, which comprised the development of algorithm and image processing to develop TSM concentration maps. The spectrometer measurements collected in the field were used for obtaining the subsurface irradiance reflectance. The subsurface irradiance reflectance R(0-) is the ratio of upwelling (E_{wu}) and downwelling irradiance (E_{wd}) just beneath the water surface. There are some discrepancies from matching R(0-) model and R(0-) measured in the field, especially in the blue region and NIR region. The reason of the discrepancies could be due to the fact that the Q factor (the angular distribution factor of spectral radiance) is still not understood completely. This model is very susceptible to the decrease of the proportional factor f, and to the increase of the backscattering probability B. The results indicates that red band of satellite sensor is sensitive to detect higher TSM concentration. For Mahakam Delta, red band algorithm was used to derive TSM map, since higher TSM concentration occurred in the delta.

Keywords: Bio-optical model, Total Suspended Matter (TSM)

1. Introduction

Coastal areas have a great pressure from human activities these days. Many big cities in the world and a large portion of economic activities are concentrated in these areas. This pressure will certainly be increased in the future, and will lead to a conflict of interest in the development of coastal zones.

The disturbances are not only caused by activities within the coastal area, but also by disturbances from the main land, such as deforestation and land use change. Erosion brings sediment into the river system, which finally goes to sea. Increasing sediment concentration in water bodies often leads to environmental damage. Therefore it is essential to monitor the water quality for coastal management. This monitoring can lead to better management of water resources and hopefully can protect the coastal zone from the disturbances.

People used to measure water quality by conventional measurements (e.g. Secchi disk, EC meters). Although these kinds of measurements provide relatively accurate data, they require in situ sampling and expensive and time-consuming laboratory work. Nowadays remote sensing offers the possibility of covering a large spatial area with a high temporal frequency. It also provides monitoring of the spatial distribution, which is difficult to carry out by direct sampling. However, it cannot completely replace conventional methods, as the results are not as accurate as from conventional methods.

The Indonesian coastal zones have always been under heavy pressures, including those from fisheries, oil industries and sea transportation. The presence of these activities carry a large portion of risk in damaging the environment as well as in destroying the marine resources, leading to the need for an integrated management using environmental information system that is comprehensive and multi-disciplinary in nature.

The Mahakam Delta has the same general problems as other coastal regions in Indonesia. The major problem in Mahakam Delta is the conversion of mangrove forest to traditional shrimp ponds, which affects the seawater intrusion in dry season to Loa Janan district (Aspar, 2001).

Dutriex (2001) also mentioned that in the early 90's extensive aquaculture (shrimp ponds) began to develop, first in the vicinity of the villages, later everywhere in the delta except in the very upstream locations. Today, the potential area to be deforested is evaluated to be 85000 hectares, which represents about 80% of the total surface of the deltaic land.

This situation gets even worse, due to erosion in the upstream catchments areas. The deforestation upstream and the conversion of mangrove forest in the delta increase the amount of suspended material in Mahakam Delta.

This research only limits the attention to the distribution of Total Suspended Matter (TSM) within the delta. The Mahakam River is divided into three main channels in the delta. Kutai Lama – Muara Kaeli channel in the North, and Sanga-Sanga – Muara Ulu channel in the South, both influenced by fluvial activities. The third one is the channel in the middle, which is the most influenced by tidal activities. The distribution of suspended material within Mahakam Delta is very valuable information for coastal zone management of the Mahakam Delta.

Remote sensing images are needed to monitor such vast area. However, a good method to determine the relationship between TSM concentration and reflectance acquired by satellite sensor is needed. This research adopted analytical method (bio optical modeling) in order to describe the complex pattern of TSM distribution in Mahakam Delta.

Some similar research has been conducted in the Indonesian turbid coastal waters. Several researches (Dekker et. al. 1998; Van der Woerd and Pasterkamps, 2002; and Ambarwulan, 2002) have used bio-optical modeling in their research in Indonesia. All researches came up with the indication that non-linear relationship exists between the satellite radiance image data and the suspended sediment matter, and it is proved to be suitable in Indonesian coastal waters.

This research aims at contributing to the knowledge on Indonesian coastal waters disturbance from human activities (deforestation, waste disposal, land use change, etc.). Previous researches used the bio-optical model for Indonesian estuarine and bay waters; whereas this research is intend to use the model in deltaic turbid waters of Mahakam.

The main objective of the research is to derive Total Suspended Matter (TSM) concentration of turbid coastal water of Mahakam Delta from multisensor images.

2. Description about Mahakam Delta

The Mahakam Delta is located on the east coast of Kalimantan (Borneo) in Indonesia between 0°21' and 1°10' southern latitude, and 117°15' and 117°40' eastern longitude. The delta was formed at the mouth of Mahakam River which flows trough the delta into the Makassar Strait. The western shore of the Makassar Strait is bordered by a 40-50 km wide shelf on which the delta has been progressing since 5000 – 6000 years ago (Allen and Chambers, 1998).

The Mahakam Delta exhibits a very regular fan-shaped morphology typical of fluvial-dominated deltas accumulating in shallow water. The delta plain is densely vegetated and incised by fluvial distributaries (river channels) and tidal channels. The fluvial distributaries are rectilinear and bifurcate seaward from the Mahakam River. They are clustered into a northern system and a southern distributaries system separated by a tide-dominated inter-distributaries zone characterized by sinuous, estuarine-like tidal channels. This tidal inter-distributaries zone covers approximately 30% of the delta plain (Allen and Chambers, 1998).

Mahakam River is the biggest river in East Kalimantan with total length about 920 km, of which about 700 km is navigable. Figure 2.4 shows the drainage pattern of the area, which is dominated by the Mahakam River. The catchment area of this river, covering an area of 77.400 km2, is the third largest in Indonesia (Dahuri, 1992; Allen and Chambers, 1998).

The mean monthly flow in the mouth of Mahakam River is approximately 4150 m3/s (Dahuri, 1992). More recent data (Allen and Chambers, 1998) indicates values ranging from 500 and 5000 m3/s. Large seasonal variations in river discharge occur, with peak flow in the months of March to June and November to December when the inland rainfall is high. During the periods of high discharge, strong floods occur in the upper part of the drainage basin (150 km upstream of the delta), and can rise more than ten meters above normal flow. Peculiarly, there are no evidences of alluvial floods in the area adjacent to the Mahakam Delta (Allen and Chambers, 1998).

3. Extraction of Total Suspended Matter from Remotely Sensed Data

Coastal water often requires site-specific algorithms to take into account the differences in the constituents and their optical properties at different location and times (Ambarwulan, 2002). These differences are caused by several factors such as fluctuation of river flow, sediment load, primary production and phytoplankton. As a result, *insitu* data must be acquired at the same time as the overpass of the satellite. The most common techniques used for analysis of remote sensing data to determine water quality concentration are based on the brightness of reflectance. Those are based on individual band, band ratio, and principal component analysis.
To obtain the water quality concentration from the water living radiance that is detected by the optical sensor, the retrieval algorithms can be used. Morel and Gordon (1980) pointed out three different approaches to determine spectral radiance or reflectance that can be used to estimate the concentrations of constituents in water. The three different approaches are empirical approach, semi empirical approach and analytical approach.

Empirical Approach

It is also called ‘statistical approach’. This approach is based on calculation of statistical relation between the constituent concentration and water leaving radiance or reflectance. Spurious results may occur while using this method, because a causal relationship does not necessarily exist between the parameters studied. Result of empirical models always needs insitu data because the following parameters may change between different remote sensing missions (Dekker at al., 1999):

a. Above the air-water surface:

- The total down welling irradiance (solar elevation)
- The fraction of diffuse to direct solar irradiance
- The amount of specular reflection at the air-water interface
- The roughness of the water surface
- The height and the composition of the atmosphere column between the sensor and the water surface leading to differences in path radiance

b. Below the air-water interface:

- The radiance to irradiance conversion of the subsurface upwelling light signal
- The relation between R (0-) and the specific inherent optical properties
- The relation between inherent optical properties and the optical water quality parameters

There are simple and multiple regression equations. These are the subjects of research done by Ritchie and Cooper (1988), and Baban (1993). Linear and multiple regressions were proved useful for the study of the suspended sediment. They yielded sufficiently accurate concentration estimations. They gave better accuracy if the *insitu* measurement is at the same time as the acquisition date of remotely sensed imagery.

Semi-Empirical Approach

This approach may be used when the spectral characteristics of the parameters of interest are known. In Figure 1, this relates to the forward water section- but only the modules “measured water parameters” and “measured R(0-)” are used for the statistical analysis by focusing on well chosen spectral areas and appropriate wavebands or combinations of wavebands, which are used as correlates. Quantitatively, the coefficients from any such relationship only apply to the data from which they were derived (Dekker *et al*, 1999).

Analytical Approach

The inherent and apparent optical properties are used to modulate the reflectance and vice versa. The water constituents are expressed in their specific (per unit measure) absorption and backscatter coefficients. Subsequently, analytical methods can be used optimally to retrieve the water constituents or parameter from the remotely sensed upwelling radiance or radiance reflectance signal.
In many coastal and inland waters, the combination effects of backscattering and absorption introduce non-linear relationship between the water constituents and spectral reflectance. As has been mentioned by Dekker et al. (1999), the processing from light measurement at a remotely sensor into concentration map of water quality parameter is complex. By modeling, it becomes possible to derive an accurate remote sensing algorithm for the estimation of suspended sediment for the water bodies.

Bio-optical Model

Doerffer (1992) in Ambarwulan (2002) described the retrieval of constituents' concentrations from the reflectance that requires an analytical approach. In analytical approach, the retrieval is based on bio-optical model that describes the relation between reflectance and the concentration of constituents (see Figure 1).

Pasterkamp et al. (1999) described the concentration of optical water quality parameter, which is linked to the R (0-) via the inherent optical properties (IOP) of the water. The IOP is the total absorption (a) and backscattering (bb) of the optical constituents (including water itself). Absorption and backscattering depend on the wavelength (λ), and are expressed in m-1. The subsurface irradiance reflectance R (0-) is a suitable optical parameter to link the IOP to the remotely sensed irradiance data. Several researchers have investigated the relation between R (0-) and the IOP of the ocean in coastal and inland water systems.

1. Research Methods

Field surveys were carried out from 3rd to 5th of July 2003 and 30th of September to 1st of October 2003. The first field survey covered the southern part of Mahakam Delta, and the second field survey covered the middle and northern part of the delta. During the field survey campaign, water quality parameters and field spectrometer measurements were made.

The in situ water sampling and quality measurements were carried out in order to get the true water quality parameter values of the Mahakam Delta. Special attention was given to the measurements of TSM and Chl concentration, since these two were used to determine the Specific Inherent Optical Properties (SIOPs) of Mahakam Delta. Dekker (1993) defined that Total Suspended Matter (TSM) expressed as seston dry weight (including the phytoplankton) that highly determines the scattering of waters. The suspended matter further separated into the phytoplankton and the tripton. Chlorophyll (Chl) represents the sum of chlorophyll a and pheaophytin that is measured in the laboratory.

The spectrometer measurements collected in the field were used for obtaining the subsurface irradiance reflectance. The subsurface irradiance reflectance R(0-) is the ratio of upwelling (Ewu) and downwelling irradiance (Ewd) just beneath the water surface. The result is called R(0-) measured. The general field measurement adopts from the method proposed by Gons for R(0-) measurement (Peters et. al., 2001).

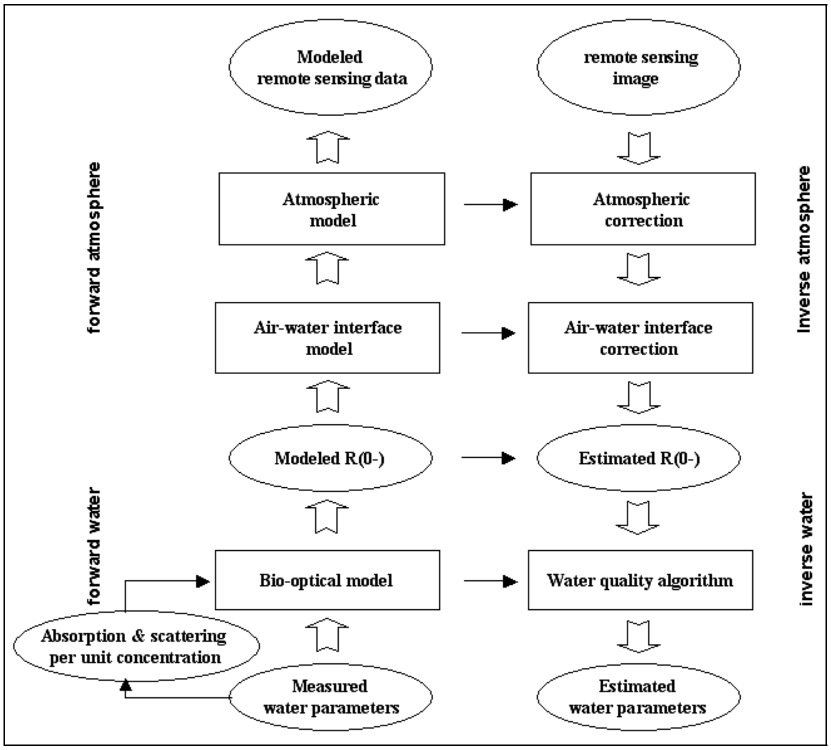

Figure 1. The forward and inverse model for remote sensing of water quality (Dekker *et al*, 2001a)

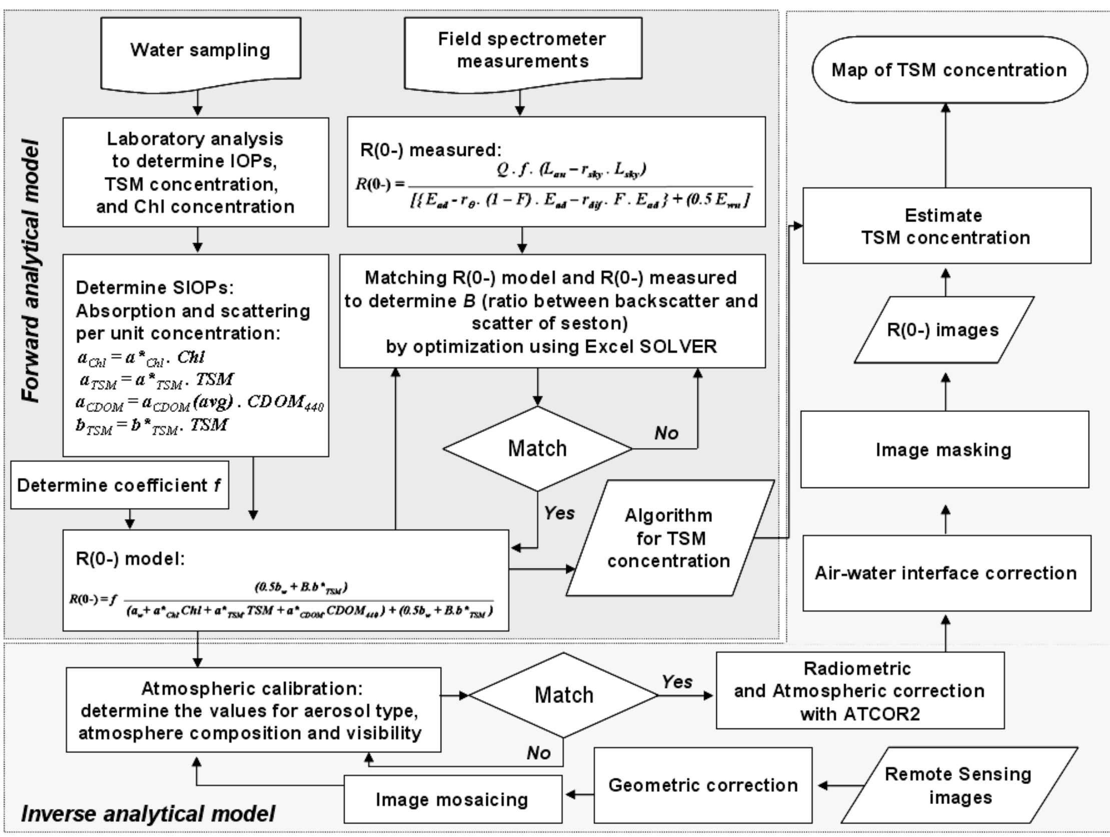

Figure 2. Research Flowchart

The results from field spectrometer were used for comparison with the laboratory Inherent Optical Properties (IOPs) analysis, since its came from the same location. A fiber optic cable (length 1.15 m) with 23° FOV was used for viewing the objects (water surface) with distance from objects approximately 1 m. Reference panel was measured with approximately 20 cm sensor-panel distance, with angle 90°. The averages of two measurements were taken from each location for each object. The angle 42° was used to measure water surface and sky, in order to avoid influence by reflection and shading from the boat. The following measurements were made:

- The upward radiance above the water surface at nadir angle of approximately 42°
- The radiance of skylight at a zenith angle of approximately 42°
- The reflected radiance from a diffuse reflectance panel (a spectralon).
- The reflectance of radiance from a diffuse reflectance panel, whereby the influence of direct sunlight was blocked (a spectralon with shadow).

Beam attenuation, CDOM absorption and seston absorption were measured from the samples in the laboratory. Dekker (1993) lists the definition of these parameters. The beam attenuation represents the total loss of light due to absorption and scattering combined. CDOM also called aquatic humus mainly consist of dissolved organic carbon in the form of fulvic or humid acid. Seston is defined as the gravitimetric concentration of phytoplankton and tripton present in the water. Tripton is the sum of non-alga organic and inorganic material.

The method applied here relies on the concept of forward and inverse modeling, leading to analytical methods (Figure 1). Dekker et. al. (2001b) mentioned that analytical methods show better results than empirical or semi-empirical methods which use simple correlation or reasonable band ratios only instead of sophisticated optical models. However, the analytical method is complicated. One has to understand the behavior of light when it interacts with water, especially with different water constituents (e.g. CDOM, seston, tripton and phytoplankton). Figure 2, shows the flowchart of the research.

The following reflectance model is the most appropriate model for turbid waters (Dekker et. al.; 1998, 2000, 2001a) and this model was also used in previous researches in other Indonesian waters (Dekker et. al., 1998; Ambarwulan, 2002; van der Woerd and Pasterkamp, 2002). The model assumed an optically deep medium so that bottom effect can be ignored, which is the case in Mahakam Delta.

The remote sensing image was corrected for atmospheric and air/water interface distortions first, before the TSM algorithm was applied. The atmospheric correction was done using ATCOR 2 software.

$$R(0-) = f \; \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

Where:

$R(0-)$	:	irradiance reflectance just below the water surface, (dimensionless) for a given wavelength;
$a(\lambda)$	:	total absorption coefficient of water and all substances in the water column (m-1) for a given wavelength;
$b_b(\lambda)$	:	total backscattering coefficient (m-1) for a given wavelength;
f	:	Coefficient depending on geographic latitude and longitude and the volume scattering.

The result of atmospheric correction was the reflectance above the water surface. To apply the algorithm, the image needs to be converted to subsurface irradiance reflectance R(0-). Results of ATCOR are remote sensing reflectance (Rrs) which according to Morel and Gentili (1993, cited in Doxaran et. al., 2002) can be written as a function of the subsurface irradiance reflectance:

$$R_{rs} = \frac{(1 - \rho)(1 - \bar{\rho})\, R(0-)}{n^2\,(1 - \bar{r}\; R(0-))\, Q}$$

Where:

Q	:	the conversion coefficient for L_{wu} to E_{wu} = 3.5
ρ	:	the internal Fresnel Reflectance = 0.029
r	:	the water-air reflection = 0.48 (Doxaran *et.al.*, 2002)
n	:	the refractive index of water = 1.33

R(0-) : subsurface irradiance reflectance

After the radiometric and atmospheric correction, then the R(0-) model was applied to the image to determine the TSM concentration.

2. Results and Discussions

The IOPs of spectral absorption, scattering and backscattering were determined in the laboratory of Vrije Universiteit, Amsterdam. IOP are expressed in terms of absorption per meter: a (m-1) and scattering per meter: b (m-1). The absorption spectra of seston, tripton and CDOM were determined from water sample collected from the field. IOPs of phytoplankton were determined from the literature (BIOPTI 1.0 software; Hoogenboom, 1995). Absorption and scattering of pure water was also determined from literature (Ambarwulan, 2002; Hoogenboom, 1995). The information from inherent optical properties analysis was used to determine the spectral reflectance signature as measured by a remote sensor

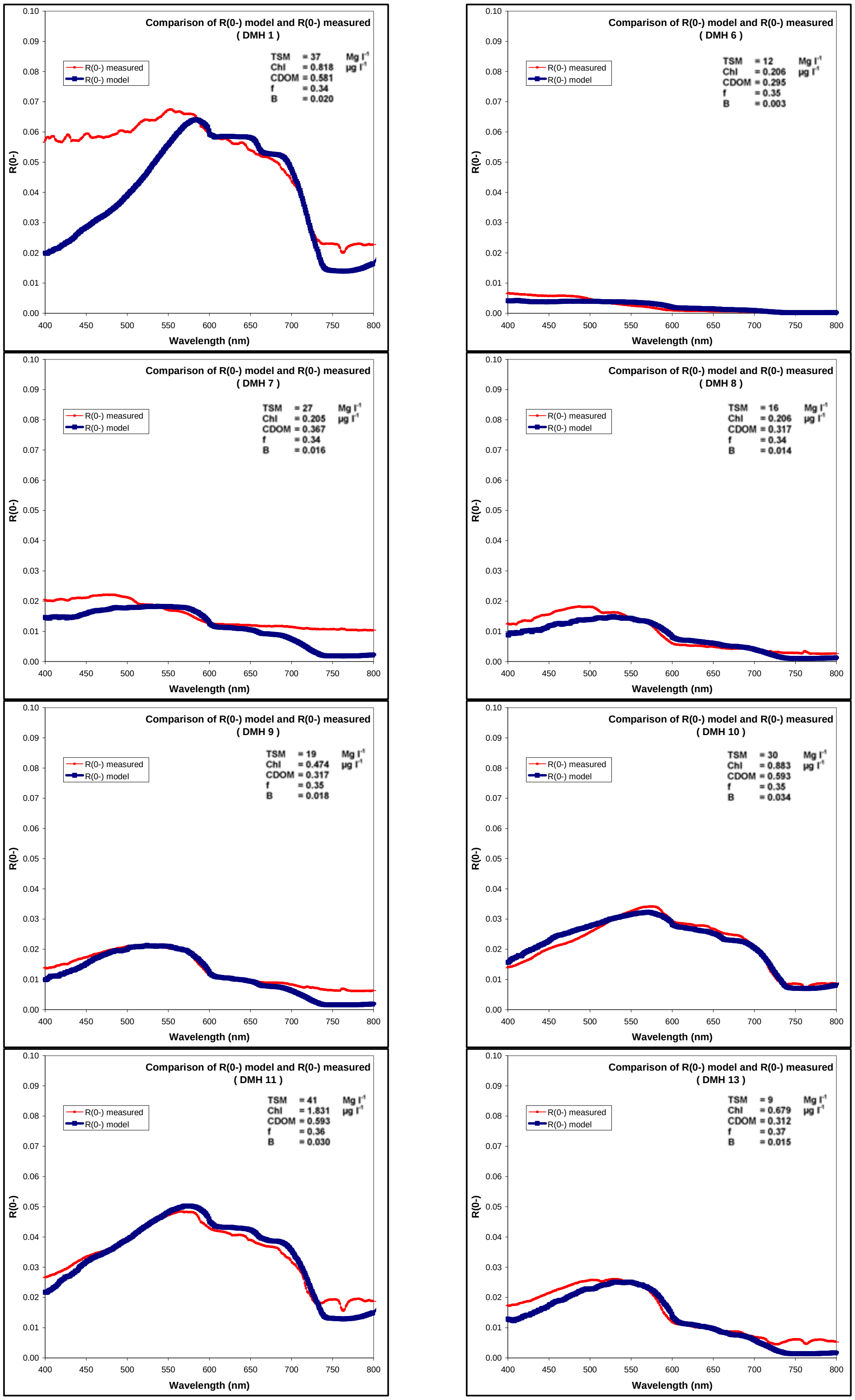

Figure 3. Comparison between R(0-) model and R(0-) measured in Mahakam Delta

R(0-) model for Mahakam Delta was determined from the Specific Inherent Optical Properties (SIOP) and other parameters, e.g. the spectral shape coefficient (f) and the backscatter to scatter ratio of seston (B). The spectral shape coefficient was derived using Walker methods (Peters et. al., 2001), while the backscatter to scatter ratio was derived by fitting the R(0-) model with the R(0-) measured. The SIOPs were calculated from the IOP and the concentration of water parameter measured from the water samples.

Vos et. al. (1998) in Ambarwulan (2002) showed that a workable alternative for the measurement of the volume scattering function is the estimation of f (it is fixed) and B by matching model R(0-) with measured R(0-) values. Matching R(0-) model and R(0-) measured can be done in several steps. First, the R(0-) measurement of each location is determined using the field spectroradiometer. Secondly, determination of R(0-) model is based on the SIOP of the study area. Lastly, R(0-) model is matched with measured R(0-) by varying f (this research used f value from equation 3.3) and B (Ambarwulan, 2002). Vos et al. (1998) has applied the EXCEL solver tool to determine f and B coefficient. Figure 3 shows the result to determine coefficient B by matching the R(0-) model and R(0-) measured.

The TSM algorithm for Mahakam Delta were determined after the coefficient f and B are determined (Figure 2). To get the model that represents the whole area of Mahakam Delta, one set of SIOPs was needed. This was done by averaging the SIOPs of each location, and by different type of water (turbid and clear water). The subsurface irradiance reflectance R(0-) is a function of the solar zenith angle, the volume scattering function and the absorption and scattering properties of water. The spectral absorption causes a reduction in R(0-). The spectral scattering causes an increase in R(0-).

The bio-optical model has been applied in order to simulate the R(0-) of the samples from each location. The R(0-) is calculated using the average of the SIOP dataset and measured concentrations in the model. Figure 4 show the R(0-) model for each water type with different TSM concentration. With all others parameter set to fixed value, an increase of TSM concentration will cause an increase of R(0-) which can be detected by remote sensing.

The algorithm for TSM concentration using the forward bio-optical model can be used to simulate a data set of R(0-) in each of the sensor bands as a function of increasing concentration of TSM. Since the objective of this study is TSM retrieval only, a straightforward method would be an analytical inversion of the bio-optical model for one band. Figure 5 show that the red band from different sensor types gives a good discrimination of TSM concentrations. The red band is sensitive to high TSM concentration. This result is similar to the ones of other researches of Indonesian waters (Dekker et. al., 1998; Ambarwulan, 2002; van der Woerd and Pasterkamp, 2002).

The exponential function has been applied for retrieving the TSM Algorithm from R(0-). Based on literature (Pasterkamp et. al., 1998 cited in Ambarwulan, 2002), the advantages of the exponential function are that both negative values and extremely high TSM can be avoided.

The algorithm has been recalculated for each sensor separately, because the sensitivity differs per sensor. The model for estuarine turbid water was used in this research. The concentration of Chl was assumed to be low (2 µg/l), while CDOM concentration was derived from the lowest CDOM absorption at 440 nm (0.421 m-1) for turbid water. This simplification might produce some errors that give an impact on the accuracy of retrieval TSM. Figure 5 show that the dynamic range (the range of reflectance covered by the highest and lowest concentrations) of the blue and green band gives is not as high as in the red band, van der Woerd and Pasterkamp (2002) also chose the red band base on this reason. Red band gives a good discrimination at higher TSM concentrations and less affected by atmosphere than green and blue bands.

Series of TSM concentration maps were derived from the available images using the algorithm developed from the bio optical model. Seasonal change (dry and wet season) does not affect the TSM concentration in the Mahakam Delta. In fact, Mahakam Delta has almost no dry season (Dahuri, 1992). Allen and Chambers (1998) mentioned that sedimentary process in the delta plain and delta front area is mostly affected by the variations in the ratio between river and tides.

Tide influence is seen in the TSM concentration map derived from Landsat TM 1992 (Figure 6). Comparing this image with other images with the same time acquisition period of the year (February), differences in TSM concentrations occur. TSM concentration from Landsat TM1998 (Figure 6) and SPOT February 1998 (Figure 6) indicates higher concentration in the southern channel. High tide in 1992 affected the river discharge to the southern channel, which means the comparison to monitor the TSM concentration change from 1992 to 1998 cannot be done, due to the different tide conditions.

Landsat ETM+ 2002 and ASTER 2000 were taken in different seasonal conditions. Landsat 2002 was taken in September, in the wet season, while ASTER 2000 was taken in July, in the dry season. The result from these two images is quite similar. Both show the same tide condition. TSM concentrations from both images (Figure 6) indicate that in the river channel higher concentrations can be found, as well as in the southern channel.

3. Error Analysis

The bio-optical model has a good potential to become a fully operational retrieval method for remote sensing of water quality, and it is already proved by many researchers. Due to the difficulties in constructing and understanding the model, some errors still may occur in the model analysis. Ambarwulan (2002) and Turdukulov (2003) mentioned some of the errors in their research about bio-optical modeling.

The error in the R(0-) may be due to the chain of error in the process of obtaining R(0-) from the spectral signal at the sensor. In addition, some assumptions and simplifications have been made in the building of the algorithm.

In this bio-optical model, the scattering of phytoplankton was neglected, and only scattering by the cell mass is accounted for. Because of measurement restrictions, only total seston scattering was measured and used in the bio-optical model. The error caused by this omission will increase with an increase error in Chl concentration.

Turdukulov (2003) has used a sensitivity analysis to analyse errors in bio-optical modelling using BIOPTI-1. This model is sensitive to almost all parameters required. Turdukoluv (2003) also mentioned that bio-optical model is very susceptible to the decrease of the proportional factor f, and to the increase of the backscattering probability B.

Table 1 agrees with Turdukulov (2003) that factor f and B is very susceptible in bio optical modeling. The change of TSM and Chl concentration will affect greatly to the determination of SIOPs, however the most sensitive SIOPs in the model is scattering of seston.

4. Conclusions

Apparently, seasonal variations cannot be traced in the TSM concentrations of the Mahakam Delta. Tides and river discharge are the main causes of variations in TSM concentration in the delta. In high tide condition, the tidal channel can have TSM concentration higher than river channel due to the current, which flows landward. During the low tide, the river channel has higher TSM concentration due to the ebb current and river discharge. The southern channel is the most active channel. From several images it can be seen that the southern channel TSM concentration is higher, especially during the low tide.

This research found that higher concentration occurred either due to tidal condition and river discharge or in the shallow area (high turbidity due to turbulence caused by current). Both conditions do not correlate with the increase of shrimp ponds area.

Factor f and B is very susceptible in bio optical modeling. The change of TSM and Chl concentration will affect greatly to the determination of SIOPs, however the most sensitive SIOPs in the model is scattering of seston.

Acknowledgments

This research was part of a large and integrated research project on Coastal Zone Management (CZM) in Mahakam Delta. The entire project was funded by The Dutch Research Foundation for Scientific Research in Tropical Countries (WOTRO). Image processing phase was carried out in ITC (International Institute for Geo-Information Science and Earth Observation) the Netherlands. Laboratories analysis phase was carried out in Vrije Universitet Amsterdam.

Table 1. Sensitivity of bio-optical model from this resarch

Input parameters	+50%change in input parameter results output to change:	-50%change in input parameter results output to change:
f	50%	-50%
B	42%	-47%
Chl	-2%	2%
CDOM	-14%	21%
a^*_{CDOM}	-14%	21%
$a^*_{phytoplankton}$	-2%	2%
$a^*_{tripton}$	-9%	13%
b^*_{seston}	42%	-47%
TSM	-33.33%	100%
Chl	-33.33%	100%

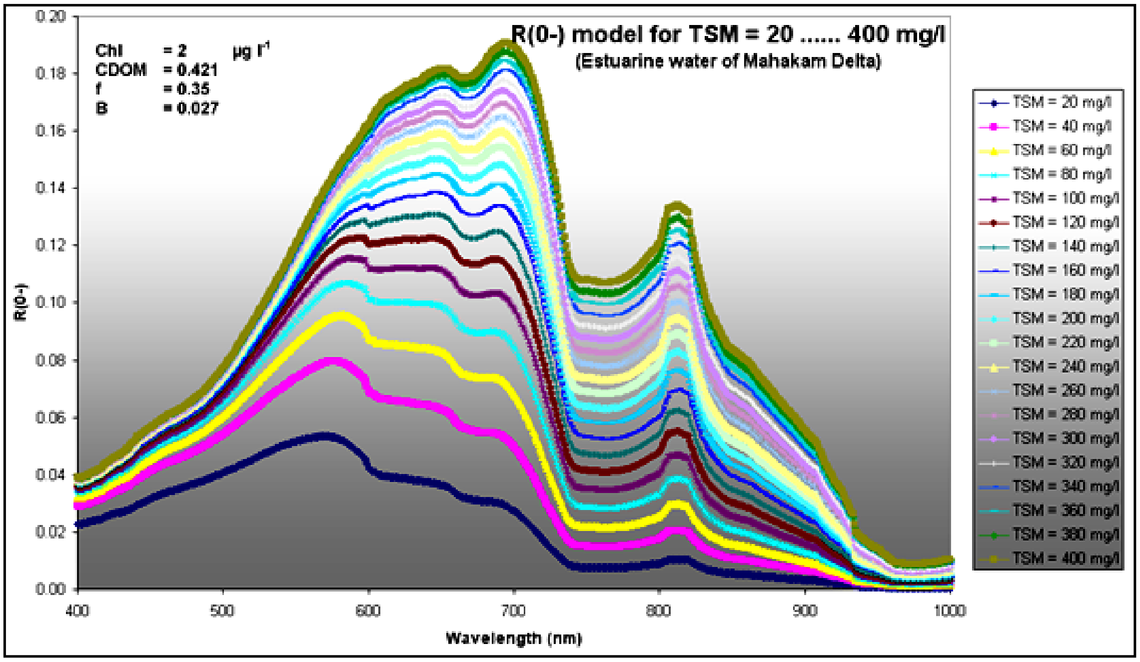

Figure 4. R(0-) model of Mahakam Delta for each TSM concentrations

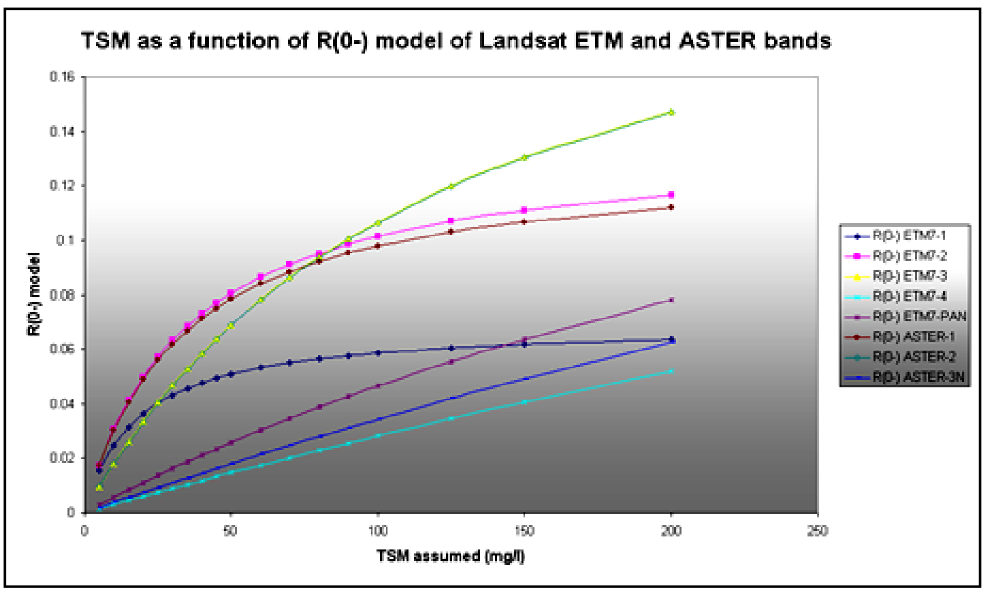

Figure 5. Analytical relationship between TSM and R(0-) model (Landsat ETM and ASTER)

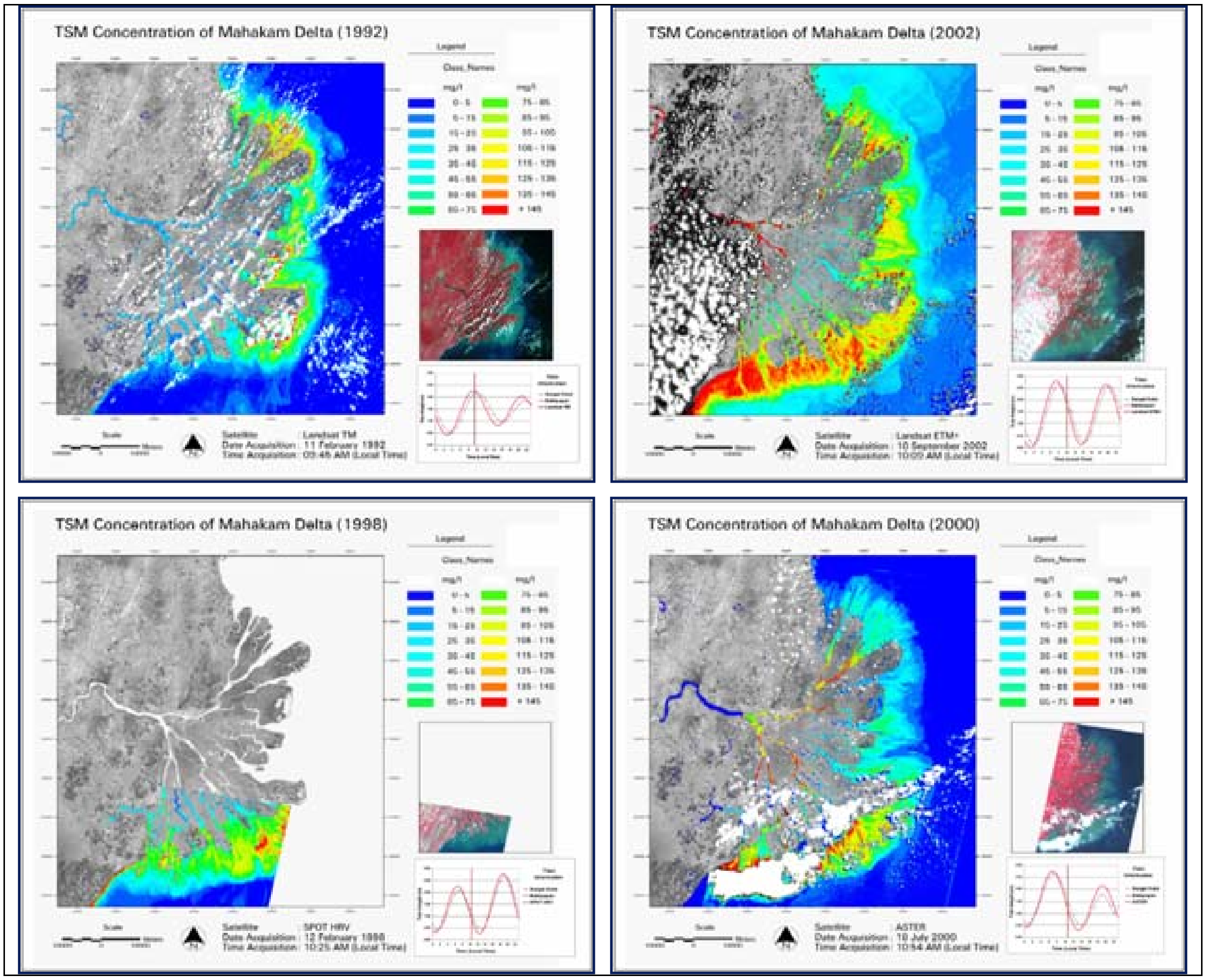

Figure 6. The results of TSM distribution in Mahakam Delta

References

Allen, G.P. and J.L.C. Chambers. 1998. ***Sedimentation in the modern and miocene Mahakam Delta***. Indonesian Petroleum Association; 235 p.

Ambarwulan, W. 2002. Mapping of TSM concentrations from SPOT and Landsat TM satellite images for Integrated Coastal Zone Management in Teluk Banten, Indonesia. MSc Thesis, ITC, Enschede, The Netherlands; 130 p.

Baban, S.M.J., 1993, The evaluation of difference algorithms for bathymetric charting of lakes using Landsat imagery, International Journal Remote Sensing, 1993, Vol. 14, No. 12, 2263-2273.

Dahuri, R. 1992. An Approach to Coastal Resource Utilization: The Nature and Role of Sustainable Development in East Kalimantan Coastal Zone, Indonesia. Unpublished Ph.D Thesis. School for Resource and Environmental Studies. Dalhouise University, Halifax, Nova Scotia; 415 p.

Dekker, A.G. 1993. Detection of optical water quality parameters for eutrophic waters by high resolution remote sensing. Ph.D Thesis, Vrije Universiteit, Amsterdam, The Netherlands; 240 p.

Dekker, A.G., S.W.M. Peters, M. Rijkeboer, and H. Berghuis. 1998. Analytical processing of multitemporal SPOT and Landsat images for estuarine management in Kalimantan Indonesia. In: Nieuwnhuis, G.J.A., R.A. Vaughan, and M. Molenaar (Eds.). 1999. ***Operational Remote Sensing for Sustainable Development***. A.A. Balkema Publishers, Rotterdam, The Netherlands; pp.315-323.

Dekker, A.G., R.J. Vos and S.W.M. Peters. 2001a. Comparison of remote sensing data, model results and in situ data for total suspended matter (TSM) in the southern Frisian lakes. ***The Science of the Total Environment, vol. 268***, pp. 197-214.

Dekker, A.G., V.E. Brando, J.M. Anstee, N. Pinnel, T. Kutser, E.J. Hoogenboom, S.W. Peters, R. Pasterkamp, R.J. Vos, C. Olbert, and T.J.M. Malthus. 2001b. Imaging Spectrometry of Water. In: van der Meer, F.D., and S.M. de Jong (Eds.). 2001. ***Imaging Spectrometry: Basic Principles and Prospective Applications***. Kluwer Academic Publishers, Dordrecht, The Netherlands; pp. 307-359.

Dekker, A.G., R.J. Vos and S.W.M. Peters. 2002. Analytical algorithms for lake water TSM estimation for retrospective analyses of TM and SPOT sensor data. ***International Journal Remote Sensing, 2002, vol. 23***, No. 1, pp. 15-35.

Doxaran, D., J.M. Froidefond, S. Lavender and P. Castaing. 2002. Spectral signature of highly turbid waters Application with SPOT data to quantify suspended particulate matter concentrations. ***Remote Sensing of Environment 81 (2002);*** pp. 149-161.

Dutriex, E. 2001. The Mahakam Delta environment from the 80's up to now: A synthesis of a 15-years investigation. In: T. Kusumastanto, T., D.G. Bengen, B. Widigdo, and I. Soeseno (Eds). ***Optimizing Development and Environmental Issues at Coastal Area: Problems and Solution for Sustainable Management of Mahakam Delta***. Proceeding of International Workshop, CCMRS-IPB, Bogor, Indonesia; pp. 63-68.

Gons, H.J. 1999. Optical teledetection of chlorophyll-a in turbid waters. ***Environmental Science Tecnology, Vol. 33, No. 7***; pp. 1127-1132.

Hoogenboom, E. 1995. ***BIOPTI bio-optical model for inland waters version 1.0.***, IVM-Vreij Universiteit, Amsterdam, The Netherlands.

Morel, A. and B. Gentili. 1993. Diffuse reflectance of Oceanic waters: II. Bidirectional aspects. ***Applied Optics, Vol. 32, No. 33***; pp. 6864-6879.

Pasterkamp, P., S.W.M. Peters, M. Rijkeboer and A.G. Dekker. 1999. ***RESTWES: Retrieval of total suspended matter concentration from SPOT images***. Report Number W-99/33, Institute for Environmental Studies, Vrije University, Amsterdam, The Netherlands

Pasterkamp, R., S.W.M. Peters, and M. Laanen. 2001. ***Measurement Protocol for Determination of Specific Inherent Optical Properties of Natural Surface Waters***. Report number W01/15. Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands.

Peters, S.W.M., R.J. Vos, E.J. Hoogenboom, H. Hakvoort, H. vand der Woerd, M. Rijkeboer and R. Pasterkamp. 2001. ***MERIMON-2000 MERIS for water quality monitoring in the Belgian-Dutch-German coastal zone***. USP-2 01-25, Netherlands Remote Sensing Board (BCRS), Program Bureau, Rijkswaterstaat Survey Department, Delft, The Netherlands; 122 p.

Ritchie, J.C. and Charles M. Cooper, 1988, Comparison of measured suspended sediment concentration with suspended sediment concentration estimated from Landsat MSS data. Int. J. Remote Sensing, Vol.9 No. 3, 379 – 387.

Turdukulov, U. 2003. Determination of water quality parameters using imaging spectrometry: case study for Sajó floodplain, Hungary. MSc Thesis. ITC, Enschede, The Netherlands; 67 p