UTILIZING SATELLITE-BASED REMOTE SENSING DATA FOR WATER QUALITY ASSESSMENT OF INLAND WATER BODIES

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ABSTRACT

Traditional water quality sampling is costly, time consuming and can only provide a point basic water quality condition. Modern spatial information technology such as remote sensing and GIS provide effective tools to acquire and model water quality periodically for large area. In earlier studies, satellite images from various sensors such as Landsat, National Oceanic and Atmospheric Administration (Advanced Very High Resolution Radiometer (NOAA AVHHR), Satellite Pour Observation de la Terre (SPOT), Tiungsat 1, IKONOS, QuickBird and airborne hyperspectral images have widely been used to generate water quality maps of coastal, rivers, lakes and reservoirs. The aim of this paper is to demonstrate the potential use of satellite images to analyse water quality of inland water bodies or reservoir. This study utilise Landsat 7 Enhance Thematic MapperPlus (ETM+) images of two different dates to analyse and compare the Total Suspended Sediment (TSS) concentrations of six different reservoirs located within the Klang Valley Region and Negeri Sembilan. Existing models as introduced by i) Baban, and ii) Keiner and Yan were used to convert multispectral satellite images into water quality maps. The ERDAS Imagine and ArcView GIS software are used to generate the water quality maps from satellite images and manual water quality sampling respectively. Initial results from this study have indicated water quality of reservoirs under investigation can be categorized as Class II and Class III according to the guidelines established by the Department of Environment Malaysia. Land use development and heavy rainfall within the catchments have certainly contribute to the poor water quality of reservoirs.

Keywords: Remote sensing, water quality, total suspended sediment

Introduction

Malaysia can be considered as one of most developed nation among the Developing Countries and has undergone rapid development in many sectors. One of the consequences of rapid development is water pollution. Water pollution can be described as contamination of water by undesirable foreign matter. Water quality measurements include chemical, physical and biological characteristics of water. The physical characteristics consist of parameters such as pH and temperature, while the chemical properties include chlorophyll, suspended solids, turbidity and secchi depth. According to the Department of Environment of Malaysia (DOE) almost half of the coastal waters and beaches being monitored are polluted. Suspended solids are mostly from land-based activities. On river water quality, DOE's checks revealed that most of the rivers in the Klang Valley Region are highly polluted.

As reported in Mobarak (2000), many reservoirs in Malaysia have been found to receive significant pollutant loading from their upstream watersheds. Wide usage of agricultural fertilizers, inappropriate land use management, high intensity rainfall and steep-slope farming are major factors that contribute to the degradation of reservoir water quality. Several jurisdictional agencies still use the traditional method (i.e. collect water sample) to determine reservoir water quality. However, the vast coverage of reservoir water body makes it difficult

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to evaluate the reservoir water quality as a whole because the water sample are only collected at the channel inlets to the reservoir and at several reservoir cross sections.

Many earlier studies (e.g. Kloiber *et. al*, 2002; Islam *et al.*, 2002; Koponen *et al.*, 2002; Ritchie and Cooper, 2001; Brivio *et al.*, 2001; Mat Jafri *et al.*, 2000; Yang *et al.*, 1999; Baban, 1993; Lathrop 1992; Lilliesand *et at.*, 1983) have shown the importance of satellite images in monitoring and analyzing water quality of lakes, reservoirs, coastal waters and rivers. Baban (1993) used Landsat Multispectral Scanner (MSS) to detect chlorophyll-a, temperature, total phosphorus, secchi disk depth, suspended solids and salinity of water. Research by Ritchie and Cooper (2001) have show that remote sensing techniques can be used to assess water quality such as suspended sediments, chlorophyll and temperature. This research has highlighted the potential use of remote sensing technologies for identifying and assessing the quality of surface waters for total maximum daily loads (TMDLs) and for monitoring the effectiveness of the clean up programs. Islam *et al.* (2002) used remote sensing technique to estimate suspended sediment concentration (SSC) and to understand transportation, distribution and deposition of suspended sediment in the estuary and throughout the coastal sea, off the Ganges-Brahmaputra River mouth in India. SSC was estimate from the reflectance of Landsat TM Band 3 data after calibration with field measurement.

Airborne hyperspectral remote sensing techniques could be more superior techniques due to improve spectral and spatial resolutions needed to monitor water quality parameters in the surface. Study by Yang *et al.*, (1999) has demonstrated the advantages of integrating water quality models with remote sensing and GIS. Remotely-sensed data was used and integrate into the water quality model (QUAL2E) and the resulting output is displayed in a GIS. Kloiber *et al.* (2002) in his study used satellite imagery to monitor the lake water quality and trophic conditions. The objective of his study is to develop a method for using satellite remote sensing data to estimate key variable related to lake management issues, such as trophic state condition and water clarity. Three variables have been used to indicate trophic state such as total phosphorus (TP), chlorophyll-a (Chla) and also Secchi disk transparency (SDT).

Research by Mat Jafri *et al.* (2000) has shown that satellite scene from Tiungsat-1 can be used for water quality mapping. A preliminary study by Ismail *et al.* (2002) has shown that Landsat TM satellite image can be used to explore the detectability of various states of water, vegetation health and solid moisture due to the contaminants by analyzing reflectance spectra profile at Pulau Burung solid waste landfill in the Penang Island. Other researcher, Abdullah *et al.* (2000) used remote sensing technique to estimate the concentration of total suspended solids (TSS) by using Landsat TM (Thematic Mapper) in the coastal waters of the Penang Island. The algorithm used is based on the reflectance model which is a function of the inherent optical properties of water which can be related to its concentrations.

In many developed countries, the standard traditional mapping and monitoring techniques such as field observation (i.e. water sampling) of lakes or reservoir have already become too expensive and costly (Ostlund, 2001). To monitor water quality periodically and effectively, alternative method is needed. To improve the information content and limit the cost, remote sensing techniques offers potential source of information and methods for large-scale monitoring of water quality (Koponen *et al.*, 2002).

Study Areas

For this research, six (6) inland water bodies or reservoirs have been selected as study areas. The six (6) reservoirs are Sungai Buloh Reservoir, Sungai Batu Reservoir, Klang Gate Reservoir, Langat Reservoir and Semenyih Reservoir located in Selangor and one (1) in Negeri Sembilan i.e. Sungai Terip Reservior. Figure 1 show the locations of these reservoirs on the Landsat 7 ETM+ satellite image. The main reasons of selecting these areas are the availability of satellite images and these reservoirs are located with the most developed areas in Malaysia.

Figure 1: Locations of Study Areas (reservoirs)

Methodology

The methodology for this study is organized into three (3) main steps, i.e. data collection, data processing and data analysis. In this study, Landsat 7 ETM+ images of two different dates (i.e. 31st May 2001 and 20th September 2001) were used. All the satellites images were acquired from the Malaysian Centre for Remote Sensing (MACRES). Landsat 7 ETM+ consists of eight (8) spectral bands: Band 1, 0.45 - 0.52 µm; Band 2, 0.53 - 0.61 µm; Band 3, 0.63 - 0.69 µm; Band 4, 0.78 - 0.90 µm; Band 5, 1.55 - 1.75 µm; Band 6, 10.4 - 12.5 µm; Band 7, 2.09 - 2.35 µm and Band 8, 0.52 - 0.90 µm. The spatial resolution of Landsat 7 ETM+ image for multispectral, thermal and panchromatic bands are 30 m, 60 m and 15 m respectively. The Landsat images of the Klang Valley Region are located on path 127 and row 58. Figures 2 (a) and (b) show the Landsat 7 ETM+ images (band combination 4, 3 and 2) for the two dates mentioned above. The red areas of the images represent vegetation and forested areas. The green areas represent developed or urban areas. Dark blue areas represent water bodies and the white areas represent cloud or cleared land. All the acquired images are radiometrically corrected and georeferenced to the Malaysian Rectified Skew Orthomorphic (MRSO) system by MACRES.

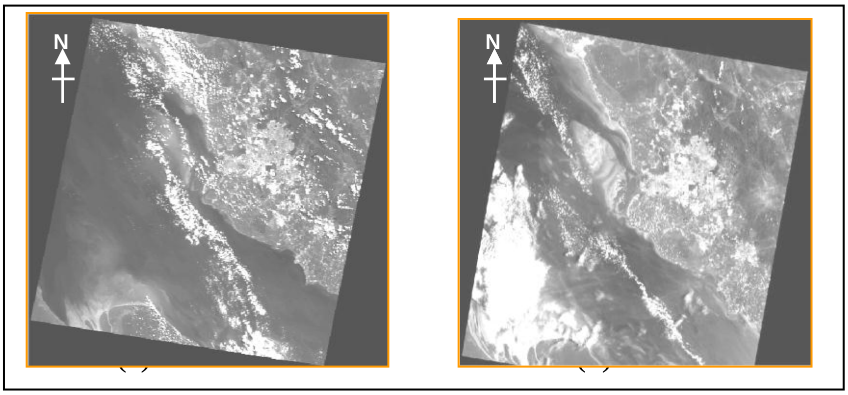

Figure 2: Landsat images acquired on (a) 31st May 2001 and (b) 20th September 2001

Other data sets used are digital topographic data and rainfall data. Land use maps within the catchment areas were generated from Landsat image. The digital topographic data provided by the Department of Survey and Mapping (JUPEM) is in AutoCAD (.dxf) format. In this research, four (4) layers i.e. contour, river, spot height and water body layers were extracted from the digital data.

Water samples of twenty one (21) points within the Klang Gate Reservoir were taken on two different dates i.e. 17th and 23rd March 2004. Although water samples are planned to correspond to the time/date of the satellite pass, this is not possible due to the problem with the onboard Landsat 7 ETM+ sensor. Exact locations of the sample points were determined using Handheld Global Positioning System (GPS). The collected water samples were analyze in the Water Quality Laboratory, Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam. Rainfall data for this study were obtained from the Department of Drainage and Irrigation Malaysia (JPS) and National Soil Erosion Research Centre UiTM (NASEC). All the six (6) rainfall stations are located near the six (6) reservoirs used in this study. Average daily rainfall readings of eight (8) different dates (i.e. 3 days before and on the day satellite images were acquired – for two different dates) were used. Table 1 shows the rainfall readings of different stations.

Table 1: Average Daily Rainfall (mm)

		May 2001				Sept 2001			
Name of Reservoir	Name of Rainfall Station/Date	28	29	30	31	17	18	19	20
Klang Gates	Ibu Bekalan KM 11 Gombak	17.5	0	31.5	0	15	17	49.5	3.5
Sungai Batu	Gombak Dam Site	0	0	3	0	16	10.5	34	25
Langat	Stor JPS Kajang	0	0	46	0	0	0	0	106
Semenyih	Empangan Semenyih	0	0	23	0	0	0	0	0
Sungai Buloh	JPS Rumah Pam Paya Setia	0	0	18.6	1.9	21.5	0.8	0	32.8
Sungai Terip	Stor JPS Sikamat	34.5	0	0	0	3.5	2.5	0	4.5

Notes: - 0 indicates no rainfall
- Readings in millimeter (mm)

Data processing involve the generation of water quality maps, generation of land use map, delineation of catchment area and laboratory work to determine the TSS concentration of the Klang Gates Reservoir. In this study, two existing water quality models developed by Baban (1993) and Keiner and Yan (1998) are given in Formula 1 and 2 respectively. The ERDAS Imagine 8.4 software are used to subset image, extract area of interest (AOI) of the reservoir and generate water quality maps of six (6) reservoirs. The Kriging Interpolation Module in the ArcView software is used to generate TSS concentration maps of data obtained from field observations.

$$\text{Suspended sediment (mg/l)} = -427 + 7.01\,(TM1) \qquad \text{...............} \; (1)$$

$$\text{Log}(S) = 0.334 + 0.098\,(TM3) \qquad \text{...............} \; (2)$$

where S is suspended sediment in surface water
TM1 – indicates the Digital Number of Band 1
TM3 – indicates the Digital Number of Band 3

The unsupervised image classification technique is used to generate land use map from the Landsat image of the 20th September, 2001. Clump and eliminate functions in the ERDAS Imagine software are used to generalize the generated land use map. Land use maps are classified into 4 main categories i.e. water body, forest, agriculture and developed areas. Based on the contours extracted from the digital topographic data and the height range maps generated in the ArcGIS software, the catchment areas for all the reservoirs were manually digitized. Boundaries of only five (5) catchment areas i.e. Sungai Batu, Klang Gates, Langat, Semenyih and Sungai Terip Reservoir are digitized.

Based on the TSS concentration maps generated from Landsat 7 ETM+ images and field water quality sampling the following analysis is carried out: i) comparison of the TSS concentrations of two different dates i.e. 31st May and 20th September 2001, ii) comparison of the TSS concentrations between the two models used i.e. Keiner and Yan (1998) and Baban (1993), iii) comparison of TSS concentration of different reservoirs and iv) effect of land development on the water quality of reservoirs.

Results And Analysis

Tables 2 and 3 summarized the percentage of areas covered by different water quality class generated from Landsat images of all the six reservoirs based on models developed by i) Baban, and ii) Keiner and Yan respectively. Summary on water quality (TSS concentrations) of the six reservoirs under investigation are given in Table 4. The water quality (TSS concentration) maps of the six reservoirs are shown in Figure 3. It can clearly be seen that water quality (TSS concentrations) in two reservoirs i.e. Klang Gate and Langat reservoirs generated for Landsat images of the 31st May 2001 and 20th September 2001 are much better than the other reservoirs (categorized as Class 1). Similar pattern can be observed in the generated water quality maps using both models.

Table 2: Percentage area of the water quality class of the six reservoirs (model by Baban)

	Klang Gate		Sungai Buloh		Sungai Batu		Langat		Semenyih		Sungai Terip	
Date	May	Sept	May	Sept	May	Sept	May	Sept	May	Sept	May	Sept
Class/Percentage	%	%	%	%	%	%	%	%	%	%	%	%
Class I (0-25 mg/l)	88.4	0.0	13.5	0.0	10.4	0.0	84.3	0.0	18.5	0.0	6.4	0.0
Class II (25-50 mg/l)	11.6	2.3	78.5	0.0	84.7	0.0	15.5	0.4	75.6	0.0	74.5	0.0
Class III (50-150 mg/l)	0.1	97.7	8.0	92.2	4.8	99.7	0.3	99.6	5.8	61.7	19.0	48.1
Class IV (150-300 mg/l)	0.0	0.0	0.0	7.8	0.0	0.3	0.0	0.0	2.1	38.3	0.0	51.9

Table 3: Percentage area of the water quality class for the six reservoirs (model by Keiner and Yan)

	Klang Gate		Sungai Buloh		Sungai Batu		Langat		Semenyih		Sungai Terip	
Date	May	Sept	May	Sept	May	Sept	May	Sept	May	Sept	May	Sept
Class/Percentage	%	%	%	%	%	%	%	%	%	%	%	%
Class I (0-25 mg/l)	92.9	0.5	6.1	0.0	20.5	0.0	86.3	0.0	18.5	0.0	21.8	0.0
Class II (25-50 mg/l)	4.8	93.3	88.8	0.0	78.7	3.1	15.5	0.4	75.6	0.0	73.5	0.0
Class III (50-150 mg/l)	2.2	6.2	4.8	90.4	0.7	96.1	0.3	99.6	5.8	61.7	4.9	95.7
Class IV (150-300 mg/l)	0.0	0.0	0.3	9.6	0.0	0.6	0.0	0.0	2.1	38.3	0.0	4.3

Sungai Terip Reserviors in Negeri Sembilan has the worst water quality and can be categorized as Class II-III and Class III-IV for images of 31st May 2001 and 20th September 2001 respectively. Another reservoir which recorded poor water quality is Semenyih Reservior. This could be due to developments (land clearing for agriculture) within these catchments (refer to land use maps in Figure 4 and Table 5). According to DOE (2002) Class I water requires no treatment, while Class II requires conventional treatment. Class III and IV water require extensive treatment before it can be used for water supply. Poor water quality on the 20th September 2001 in the all six reservoirs could be due to heavy rainfall on that day and days before satellite image is acquired.

The TSS concentration maps generated based on 21 water sample data collected at the Klang Gate Reservoir using Kriging Interpolation are shown in figures 5(a) and 5 (b).

Significant difference in the pattern of TSS concentrations can be observed between samples taken on the two dates. High TSS concentration is clearly evident on the upper part of the reservoir for observations taken on the 17th March 2004. For observations taken on the 23rd March 2004, high TSS concentration can be seen in the middle portion of the reservoir.

Table 4 Comparison of the water quality classes for six (6) reservoirs using two (2) different models of two (2) different dates for TSS

Model	**Baban (1993)**		**Keiner and Yan (1998)**	
Reservoir/Dates	**May 31st 2001**	**Sept 20th 2001**	**May 31st 2001**	**Sept 20th 2001**
Klang Gates	CLASS I	CLASS III	CLASS I	CLASS II
Sungai Buloh	CLASS II	CLASS IV	CLASS II	CLASS III
Sungai Batu	CLASS II	CLASS III	CLASS II	CLASS III
Langat	CLASS I	CLASS III	CLASS I	CLASS II-III
Semenyih	CLASS II	CLASS III-IV	CLASS I-II	CLASS III
Sungai Terip	CLASS II-III	CLASS III-IV	CLASS II	CLASS III

Table 5: Land use coverage (acreage) within the catchment areas

	Klang Gate		Sg. Batu		Langat		Semenyih		SgTerip	
	Area (Hec)	%	Area (Hec)	%	Area (Hec)	%	Area (Hec)	%	Area (Hec)	%
Waterbody	197.4	2.4	213.4	3.1	194.8	4.3	340.4	5.3	236.0	6.9
Forest	8021.6	97.7	6552.3	95.4	4381.4	95.7	5975.2	92.9	2767.3	81.4
Agriculture	10.5	0.1	0	0	0	0	0	0	306.8	9.0
Developed Area	0	0	103.9	1.5	0	0	113.1	1.8	92.0	2.7

Conclusions

Although initial study is not comprehensive, the findings from this research can be summarised as follows:-

- Satellite-based image provide a low-cost means of estimating water quality of large waterbody
- Although different models are used to predict water quality (TSS concentration) results obtained are almost similar
- Sungai Terip and Semenyih reservoirs are the two reservoirs with low water quality as compared to Klang Gate, Sungai Batu, Sungai Buloh and Langat reservoirs.
- The Klang Gate and Langat reservoirs have good water quality.
- Development or land clearing for agricultural purposes and heavy rainfall within the catchment areas significantly effect the water quality of reservoirs.

Further comprehensive research is required to relate the spectral reflectance of the remotely sensed images to other water quality parameters are essential before these results can be integrated into water quality monitoring program.

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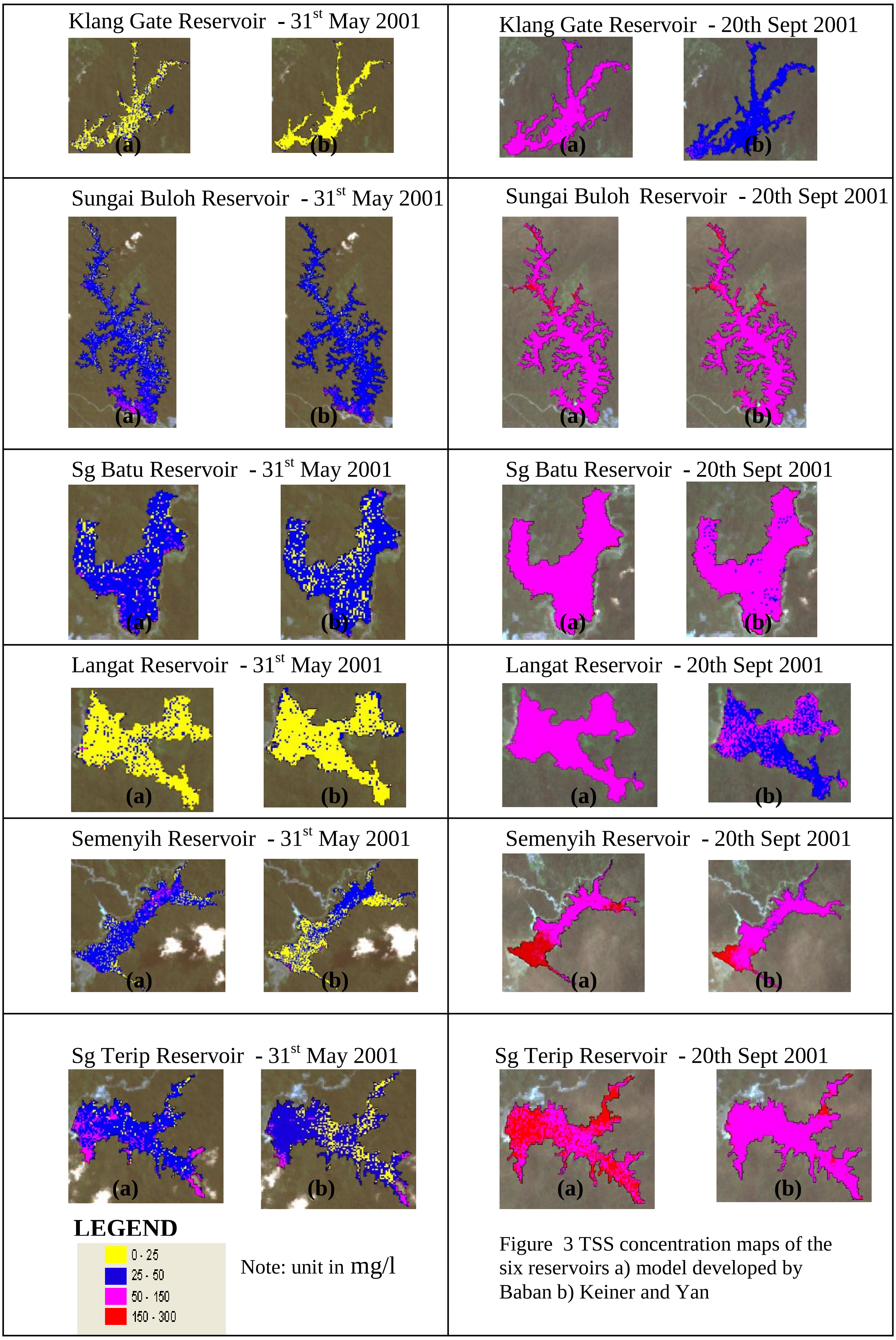

Figure 3 TSS concentration maps of the six reservoirs a) model developed by Baban b) Keiner and Yan

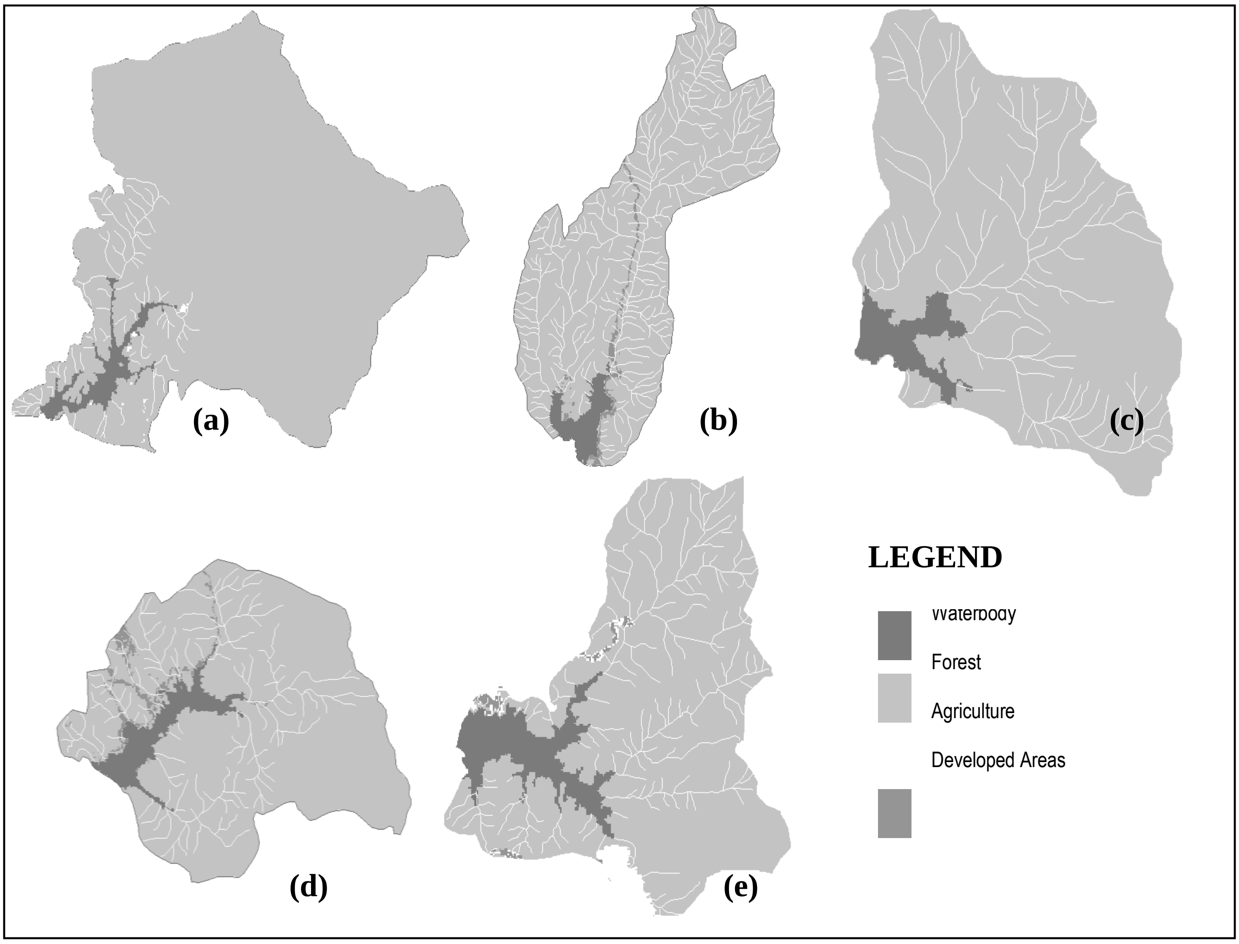

Figure 4: Land use maps of the catchment areas a) Klang Gate b) Sungai Batu, c) Langat, d) Semenyih and e) Sungai Terip reservoirs.

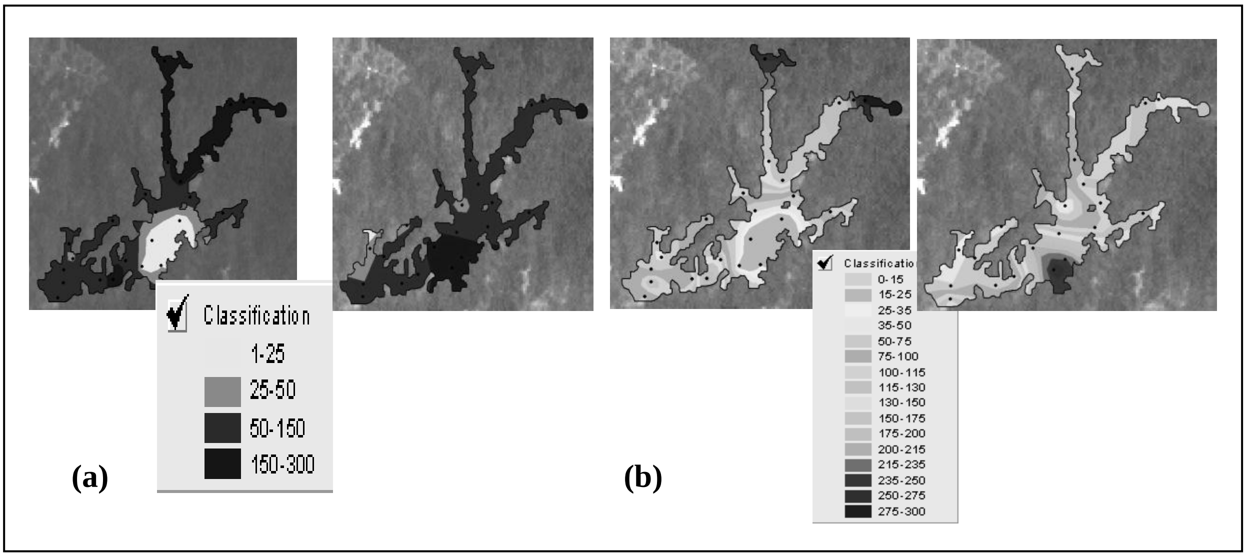

Figure 5: TSS concentration maps generated from water quality sampling of two different dates
a) 17th March 2004 b) 23rd March 2004

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