Doctoral Dissertation

Comparative Study on Water Quality Assessment between Urban and Rural Watersheds: A Case Study of Ciliwung and Ciujung Watersheds, Indonesia

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...The main purpose of acquiring knowledge is to understand the beautifulness, balance and complexity of the universe and those should ultimately bring us closer to our Creator...

Hiroshima

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Ramadhan 7, 1433

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Abstract

Comparative Study on Water Quality Assessment between Urban and Rural Watersheds: A Case Study of Ciliwung and Ciujung Watersheds, Indonesia

This study is an attempt of the assessment and comparison of water quality in the urban and rural watersheds, to understand the current condition of the water quality in both watersheds and to formulate some conclusions which can be taken for future consideration by the local government.

Jakarta, as the capital city of Indonesia, has been growing very fast where the human population and the city area are increasing very significantly compared to other regions in Indonesia. Unfortunately, the economic development of the country and more specifically this metropolitan city has created some environmental problems including water pollution. Ciliwung watershed, where Jakarta city is located, is also affected by this rapid development. The land use and land cover changes very dramatically in the entire watershed from the upper, middle and downstream areas. The establishment of industries and factories along some major rivers and surrounding the Jakarta Bay has doubled the worsening effect of water quality beside the domestic discharge.

Banten Province, a new born province a decade ago, is one of the neighboring provinces to Jakarta city. The establishment of this province, as an effect of decentralization policy implementation, has created a new economic growth region in Java. Without a proper water quality management and planning, the economic growth in Banten Province is worrying to become worsened as what has happened in its neighboring city, Jakarta. Based on this environmental and historical background, this study was therefore conducted.

Chapter 1 discusses about general introduction and literature review. Chapter 3 and Chapter 4 are the main chapters which focus on the water quality assessment in the river systems and the bays, respectively, both in Ciliwung and Ciujung watersheds. However, at the beginning of the study, the author experienced a difficulty in finding accurate standardized watershed boundaries for both watersheds, whereas the correct and accurate boundaries are needed for any ecological study, especially for that regarding water resource. Therefore, the first concern of this study was about watershed delineation. Then, an attempt has been made to utilize the available digital elevation models (DEMs) for creating watershed boundaries for the study areas and evaluate their accuracy, in which this topic is focused deeply in Chapter 2.

The first section of Chapter 2 assesses the thematic information content using subwatershed boundaries mapped using advanced spaceborne thermal emission and reflection (ASTER) global digital elevation model (GDEM), shuttle radar topography mission (SRTM) DEM and a topographic map (Topo-DEM), and verifies the absolute elevation accuracy by the use of a real-time kinematic differential global positioning system (RTK-DGPS) survey. Subwatershed boundaries extracted from the three different DEMs exhibit a high degree of congruency especially in upstream areas. In these areas, SRTM exhibits lower root mean square errors (RMSEs) than the ASTER GDEM. The discrepancies were larger at lower altitudes. The vertical accuracy assessment using the RTK-DGPS data showed strong correlation with the three DEMs at some stations but the accuracy varied from one area to another. The ASTER GDEM and SRTM had lower accuracy than the Topo-DEM due to the influence of artifacts as shown by their total average RMSE (4.42, 3.30 and 3.13 m, respectively). The average RMSE values also indicate that SRTM is comparatively more accurate than ASTER GDEM.

The second section of Chapter 2 discusses about the new released of ASTER GDEM version 2 (GDEM2) and its accuracy. The release of ASTER GDEM2 in October 2011 is expected to increase the accuracy of the previous version (GDEM1). The documents accompanying the release of GDEM2 stated that the newly released data contain improvements in factors such as ground resolution, void reduction, flat lake surfaces and anomaly correction. This study evaluates GDEM2 in comparison with GDEM1, SRTM DEM and topographic-map-derived DEM (Topo-DEM) using inundation area analysis for the projected location of Karian reservoir in Banten Province. The inundation areas resulting from this study showed a better quality in GDEM2 over GDEM1 in terms of maximum contour level. The better contour level in GDEM2 is believed to be related with the removal of voids (artifacts) in GDEM1. However, we also found a regression of quality in GDEM2, contrary to its validation report. By comparing the vertical accuracy of GDEM2 with the RTK-DGPS data, we found that the accuracy of GDEM2 was much lower than that of GDEM1. GDEM2 contains too many undulating effects compared with GDEM1 and other DEMs. Although, the results of this study may be site-specific, it is important that they be considered for the next version of GDEM.

The first section of Chapter 3 evaluates the spatio-seasonal patterns of river- and groundwater quality in the city of Jakarta, Indonesia, using the Nemerow-Sumitomo Water Pollution Index (WPI). The evaluation of water resources in Jakarta is very important because many residents still heavily depend on groundwater resources, which they extract by direct self-pumping; hence, continuous consumption of this water may introduce some health risks. The water quality is influenced by factors such as season and location relative to the pollution sources, so the quality may differ in time and space. To evaluate the water quality in the city, the Jakarta Environmental Management Board (BPLHD) conducted river- and groundwater sampling in July 2007 (dry season),

November 2007 (early rainy season: ERS) and August 2008 (late dry season: LDS). During each season, 67 river water and 75 groundwater samples were collected from stations throughout the city, and approximately 32 biophysicochemical water parameters were measured at each station. The results show that the quality of both the river water and the groundwater was worse in the dry season and toward the northern region. This implies that the local residents should be aware of their consumption of groundwater in the northern region, especially during the dry season. Additionally, the capability of HSPF in creating hydrological simulation model is also elaborated in this section.

The second section of Chapter 3 investigates the water quality of Ciujung River in Banten Province one decade after the implementation of decentralization policy. Recently, Banten Province has achieved well economic growth, hence it is important to assess the water quality in one of the main rivers, Ciujung River, to support the environmental sustainability in harmony with the economic development. Ten years water quality data comprising of 41 water parameters from nine stations were analyzed using multivariative statistics, *i.e.* hierarchical cluster analysis (HCA) and factor analysis/principal component analysis (FA/PCA). The results showed that nine nonmetal elements, seven heavy metal elements and two organic-material-related parameters at Jongjing station, the lower most station in the downstream area, have shown intensifying trends in concentration. The dendrogram of HCA produced four seasonal clusters which indicated that the changes of water quality were still highly affected by the seasonal variability. FA/PCA produced five varifactors, accounting for 55.76% of the cumulative variance, elucidating that most of the water quality were still greatly influenced by the seasonal variability and also by the emerging increase of anthropogenic impact.

The first section of Chapter 4 focuses on the water pollution level in the Jakarta Bay and the relation of biophysicochemical properties of seawater to *E. coli* concentration.

Water quality data taken in ERS (November 2007) and LDS (August 2008) were analyzed. Additionally, to compare pollution level at different seasons, Nemerow-Sumitomo WPI was used. Significant correlation of *E. coli* occurred with only few parameters in the ERS, but with more parameters in the LDS. This might be due to the rainfall intensity in the ERS that was potential to dilute seawater and reduce concentration of some parameters, especially along the offshore stations. However, at the same time, the freshwater coming from land had capacity to force out the polluted water in 13 river systems flowing into the bay; hence it could generate more pollution along the onshore stations. Seawater pollution level slightly increased in the ERS in respect to the addition of polluted water from rivers. In this season, none station was clean, 20 stations were slightly polluted, six stations were moderately polluted and six stations were highly polluted. Meanwhile in the LDS, the number of stations following the above WPI criteria were 9, 16, 3 and 4, respectively, indicating less pollution level. The overall results showed that *E. coli* exhibited significant correlations with more water parameters in the LDS and the WPI showed a little increase in the ERS.

The second section of Chapter 4 evaluates the concentrations of heavy metals and nutrients in the seawater, seagrass and sediments of Banten Bay, Indonesia and their spatial distributional patterns. Field sampling was conducted on August 24 and 25, 2010; seawater and sediment samples were collected from 16 stations and seagrass (*Enhalus acoroides*) samples were collected from six stations. The results revealed that in general, the seawater in Banten Bay was less polluted than that in Jakarta Bay, although some elements were present at higher concentrations. Most of the heavy metal concentrations in the seawater were below detection limits. All heavy metal concentrations in the sediments were also lower than those found in Jakarta Bay. In the seagrass, the concentrations of iron, copper, zinc, mercury, phosphorus, potassium, and nitrogen were higher than those found in Jakarta Bay, Larymna Bay (Greece), and the Gulf of Mexico (concentrations of cadmium and lead were not). The distribution patterns of elements, such as iron, zinc, cadmium, copper, mercury, nitrogen, and phosphorus, revealed that the accumulation in the center of the bay is a result of oceanographic processes.

The third section of Chapter 4 elaborates about a scientific effort to introduce the use of hyperspectral spectroradiometer for detecting spectral reflectance of submerged aquatic plants in response to nutrients increase. Coastal environments are prone to nutrient contamination as a result of excessive use of fertilizers in paddy agriculture on the land. To detect nutrient increases in coastal areas, researchers have used hyperspectral reflectance response to examine some coastal plants, which have proved to be effective as bioindicators. In this study, field hyperspectral technique was evaluated as a tool to detect nutrient concentrations in two coastal plants, i.e., seagrass (*Enhalus acoroides*) and brown algae (*Sargassum* sp.), taken from Banten Bay Indonesia, at laboratory scale. Although our initial experiments are still too few in elucidating an accurate relationship of nutrients and spectral signature, we are pleased to communicate that there is scientific evidence that hyperspectral measurement can be used to detect nutrient concentrations in coastal vegetation. Two types of fertilizers—urea, which contains 46% nitrogen, and triple super phosphate (TSP), which contains 14–20% soluble P2O5, commonly used by the local paddy farmers—were applied to both coastal plants in the aquarium experiment. The results of factorial analysis of variance (ANOVA) tests and pigment related indices have proved that some significant differences exist in several wavelengths in response to the fertilizer treatments. This study revealed that brown algae were more sensitive to the same amount of fertilizer applied than seagrass.

Chapter I

General Introduction

1.1 Background

Water quality is one important factors associated with the environmental healthiness. The environmental quality of a city or region can be easily judged by visual observation of the surface water, such as river water and coastal water. If we found that the rivers are very dirty and polluted, we can assume that the other environmental factors, such as sewerage system, waste management, land use change, may not be properly managed either.

Although water quality assessment is a very classical study and abundance publications have been produced in this field, but we believe that this topic is still very actual, especially in developing countries, and many new aspects can still be interesting to deal with. The impacts of water pollution to biodegradation and human diseases are also emerging in many different countries. Beside regular monitoring and water quality evaluation studies which involve the standard and well-established analytical chemistry, the application of new technology, such as remote sensing and hyperspectral analysis, is also challenging to be introduced for water quality assessment in association with aquatic vegetation, for instance.

Jakarta city is always interesting for water quality assessment study. The city has a long history of water pollution back to the era of 1970’s. The city has failed to create a “zero waste” policy. The Jakarta’s canals and rivers become common dumping sites of rubbish and garbage. The waste water from domestic sludge and some other from industries are flushed straight away to the canals without having a proper water treatment, creating more contaminated water in the rivers and coastal areas. As a result, lately the groundwater quality is also influenced and its quality shows a declining trend. Even though, the monitoring and evaluation studies on water quality are regularly conducted. Even more, some projects regarding better management of the water resources have also been implemented by both the provincial and national government.

Ciliwung watershed, wherein the famous “Puncak” tourism region in the upstream area and Jakarta city in the downstream area lie on, is considered as one of the urbanized watersheds in Java Island. The land use and land cover have changed dramatically along with the economic development and human population increase since few last decades. The majority of land utilization almost in the entire watershed has gradually altered from the agricultural purpose into business, industrial and human settlement purposes. As a consequence, the quality of water resources in this watershed is also threatened. Climatic disasters, such as floods, landslides, and polluted-water-related diseases, always routinely become the newspaper headlines.

Having located side by side with Jakarta city and learning from what occurred to the water resources in Jakarta city and Ciliwung watershed in general, Banten Province has to prepare their management planning for protecting their water resources in the whole province, especially in Ciujung watershed as one of the largest watersheds in the area. As a new born province, where the majority of the territory is still considered as rural area, Banten Province get to learn from the historical mismanagement of water resources in Jakarta city. Therefore, first of all the actual condition of water quality in the land area as well as in the coastal region of Banten Province is required. The information of this water quality is important for the installment of the appropriate water resources management system which can integrate the entire watershed as one interconnected rural watershed management system.

In any environmental study, the definition of the study area boundary is a necessary. Therefore, the delineation boundary of the study area is an important element to be provided prior to the execution of the study. In fact, no institution could provide a standard watershed boundary for whole Indonesian territory, at the time of this study, which is distributed for scientific purposes. Of course each institution, such as ministry of forestry and ministry of public work, may produce their own watershed boundaries for their own purposes. However, there is no information regarding its accuracy and standardization of this product. Hence, the first part of this study is focusing on creating the accurate watershed boundaries from several digital elevation models (DEM) datasets and assessing their accuracy assessment.

1.2 Research objectives

The main objective of this study is to assess and compare the water quality in urban and rural watersheds in both rivers and coastal environments. In this study case, Ciliwung and Ciujung watersheds were taken as examples of urban and rural watersheds, respectively. In addition, due to the lack of accurate watershed boundaries of the study areas, the first part of this study is focused on creating the delineation boundary of the study areas from several elevation sources, including its accuracy assessment as one important aspect in remote sensing science.

In order to achieve the above goal, several important works have been conducted. Each chapter investigates about a particular issue and tries to solve its own specific objectives. Therefore, if we break down the main objective of the study into several specific objectives, the list of all objectives in this study can be formulated as follows:

1. To create an accurate watershed boundary using several digital elevation models (DEMs) – ASTER GDEM, SRTM DEM, and digital topographic map (hereinafter referred to as Topo-DEM) and investigate their accuracy. In addition, the vertical accuracy of each DEM is also evaluated by using real-time kinematic differential global positioning systems (RTK-DGPS) taken from field observation.
2. To investigate the accuracy of ASTER GDEM version 2 (as an improved version of ASTER GDEM), SRTM DEM, GDEM1 and Topo-DEM using inundation area analysis. The vertical accuracy of all DEMS is also evaluated using RTK-DGPS data.
3. To evaluate the river- and groundwater quality in Jakarta using Nemerow-Sumitomo’s water pollution index (WPI) and to see their spatio-seasonal patterns. The study is again divided into three phases: a) to measure the water quality of both the river- and groundwater, b) to analyze the seasonal patterns of WPI in the dry and rainy seasons, and c) to analyze the spatial distribution of WPI in the five districts of Jakarta city.
4. To analyze the emerging trends of economic development and the water quality of Ciujung River in Banten Province and, one decade after the implementation of decentralization policy using descriptive and multivariate statistics analysis.
5. To investigate the water quality of the Jakarta Bay using WPI by comparing the offshore and onshore areas at different seasons and to analyze the relationships

between biophysicochemical properties of the seawater and *Escherichia coli* concentration at different seasons.

6. To investigate the water quality of the Banten Bay by measuring the heavy metal and nutrient concentrations in the seawater, seagrass, and sediments and to understand the distributional patterns of heavy metals and nutrients in the Banten Bay using geographic information systems (GIS) technology.
7. To assess the use of hyperspectral spectroradiometer technology in detecting the spectral reflectance of two submerged coastal plants – seagrass (*Enhalus acoroides*) and brown algae (*Sargassum* sp.) – in response to the nutrient enrichments at laboratory experiment.

1.3 Research scopes and limitations

The scopes of this study focus on water quality assessment in two watersheds, both in the land and in the coastal environment, including the utilization of hyperspectral to detect spectral reflectance of submerged aquatic plants in response to the increase of nutrients. In addition, this study also covers the assessments of watershed delineation analysis and the accuracy of several digital elevation models (DEMs).

It is very important to mention the limitation of this study. Although this study mainly focuses on the comparative assessment of water quality in urban and rural both watersheds, this is not a vis-à-vis comparison. The water analysis of the rivers and the coastal environments in both watersheds is just based on the availability of the data. For instance, it is good to have the data of river- and groundwater quality in Jakarta Bay, but the data is limited to the year of 2007 and 2008. Meanwhile for the data of Ciujung River, we could get monthly data from 1998-2010; however it is just limited to river water quality. No groundwater quality is available. The different types of data, observation time and different methodology also occur for the water quality in the Jakarta Bay and Banten Bay. It is impossible to have similar methodology, similar types of data and similar observation time in both watersheds.

1.4 Research framework

As indicated in the previous section, this study is begun with the study on watershed delineation boundary from several DEMs and assessing their accuracy assessment. The next parts are focusing on water quality studies on the rivers and bays in both concerned watersheds and a hyperspectral study related to water quality as an addition. The whole framework of the study is be described as that shown in Figure 1-1.

1.5 Software utilization

We employed a number of software used for data processing and analysis: ArcGIS 10 (ESRI Inc., Redlands, California, USA), BASINS 4 (US EPA, Pennsylvania, Washington, USA), ENVI 4.8 (Exelis, Boulder, Colorado, USA), GNSS 3.10.11 (Ashtech Inc., Sunnyvale, California, USA), Google Earth 6.1.0.5001 (Google Inc., Mountain View, California, USA), Matlab 7.10.0.499 (Math Works Inc., Natick, Massachusetts, USA), Microsoft Office 2010 (Microsoft Inc., Redmond, Washington, USA), Ocean Data View (ODV) 4.2.1 (Alfred-Wegener Institute, Bremerhaven, Germany), SAMS 3.2 (University of California, Davis, California, USA), SSPS 16 (SPSS Inc., Chicago, Illinois, USA).

1.6 Dissertation backbone

A doctoral dissertation is a piece of scientific work. Its contents should not include but real facts and scientific findings. All sentences in a dissertation have to be written with full of consideration and responsibility. Ideally, each sentence in a dissertation has to be evaluated and reviewed by experts in the field. The only way that all sentences in a scientific work being reviewed is by submitting the work to the journal, so that it can be corrected and criticized by experts in the international society.

It is an important to state here that all sections in this dissertation are based on the published papers, implying that any written sentence in this dissertation has been scientifically reviewed by experts in the field. At the time of submitting the dissertation, six papers of this dissertation have been published / accepted and one other was still being reviewed by the journal. These papers become the backbone for this dissertation; hence any quotation taken from this dissertation should be referred to its corresponding paper.

1. Suwandana, E., K. Kawamura, Y. Sakuno and E. Kustiyanto. 2012. Thematic information content assessment of the ASTER GDEM: a case study of watershed delineation in West Java, Indonesia, *Remote Sensing Letters*, 3(5), 423–432. **(SECTION 2.1).**
2. Suwandana, E., K. Kawamura, Y. Sakuno, E. Kustiyanto and B. Raharjo. 2012. Evaluation of ASTER GDEM2 in comparison with GDEM1, SRTM DEM and Topo-DEM using inundation area analysis and RTK-DGPS data. *Remote Sensing - MDPI*, (accepted). **(SECTION 2.2).**
3. Suwandana, E., K. Kawamura, Y. Sakuno and P. Raharjo. 2011. Evaluating spatio-seasonal patterns of river- and groundwater quality in the city of Jakarta, Indonesia, using pollution index. *Journal of Japanese Agriculture Systems Society*, 27(3), 91–102. **(SECTION 3.1).**
4. Suwandana, E., K. Kawamura and D. Arianti. 2012. Emerging Trends in Economic Development and River Water Quality in Banten Province, Indonesia: One Decade after Decentralization Policy Implementation (2000-2010). *International Journal of Sustainable Development & World Ecology*, (submitted). **(SECTION 3.2).**
5. Suwandana, E., K. Kawamura, K. Tanaka, Y. Sakuno and P. Raharjo. 2011. *Escherichia coli* and biophysicochemical relationships of seawater and water pollution index in the Jakarta Bay. *American Journal of Environmental Sciences*, 7(3), 183–194. **(SECTION 4.1).**
6. Suwandana, E., K. Kawamura and E. Soeyanto. 2011. Assessment of the heavy metals and nutrients status in the seawater, sediment and seagrass in Banten Bay, Indonesia and their distributional patterns. *Journal of Fisheries International*, 6(1), 18–25. **(SECTION 4.2).**
7. Suwandana, E., K. Kawamura, Y. Sakuno, M. Evri and A.H. Lesmana. 2012. Hyperspectral reflectance response of seagrass (*Enhalus acoroides*) and brown algae (*Sargassum* sp.) to nutrients enrichment at laboratory scale. *Journal of Coastal Research*, 28(4), 956-963. **(SECTION 4.3).**

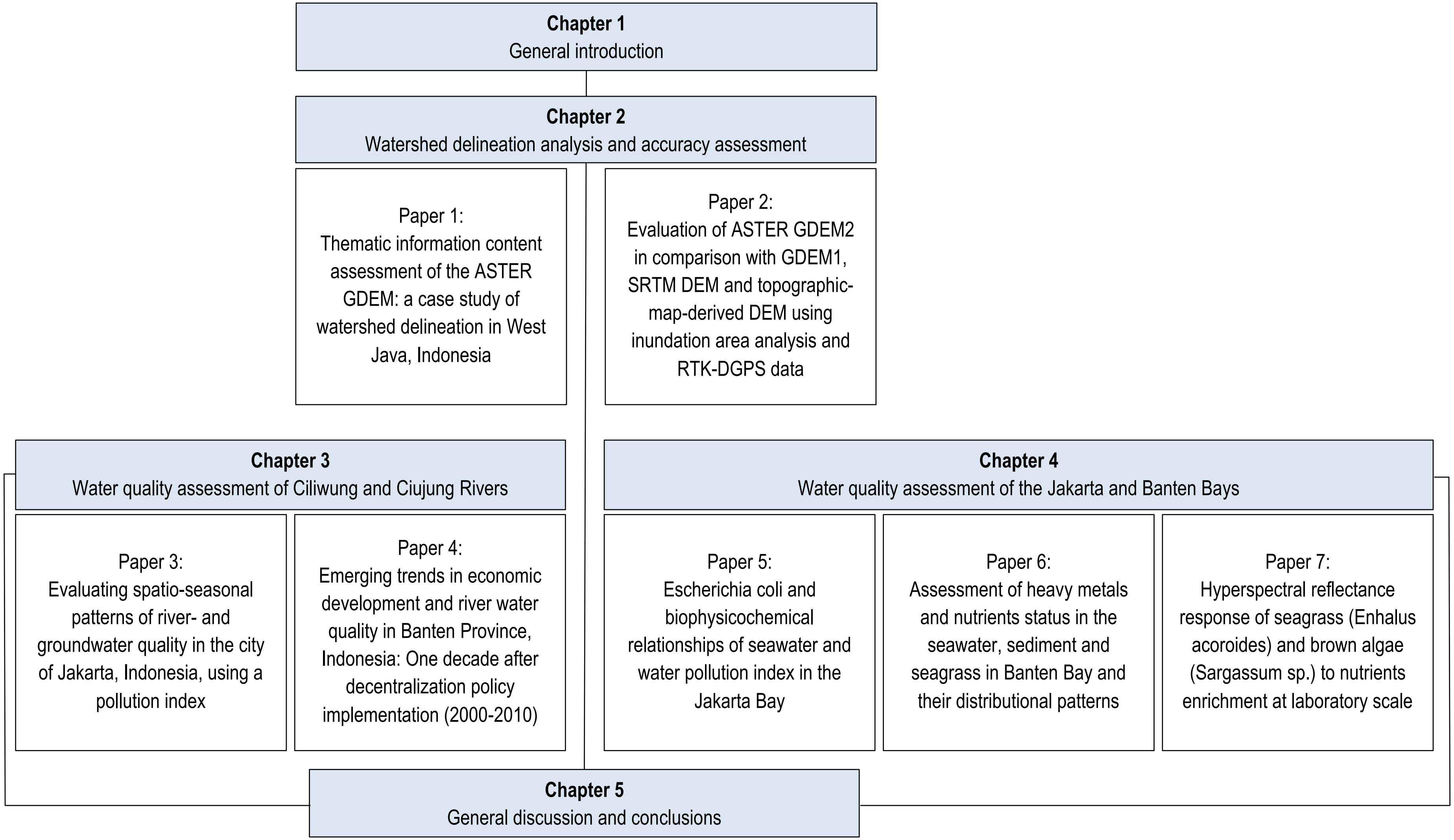

Figure 1-1: Research framework.

2.2 Evaluation of ASTER GDEM2 in comparison with GDEM1, SRTM DEM and topographic-map-derived DEM using inundation area analysis and RTK-DGPS data

(Remote Sensing–MDPI, 2012 (accepted)).

2.2.1 Introduction

The release of the Advanced Spaceborne Thermal Emission Radiometer - Global Digital Elevation Model version 2 (ASTER GDEM2) has enriched the availability of free-of-charge digital elevation data sources, which are especially useful for developing countries, and prompted users to assess its quality and accuracy. In addition, the GDEM2 version is expected to increase the accuracy of its previous version (GDEM1). In this study, we evaluated the quality of GDEM2 relative to GDEM1, the Shuttle Radar Topographic Mission (SRTM) DEM (Farr and Korbick, 2000) and topographic-map-derived DEM (Topo-DEM) using inundation area analysis. The vertical accuracy of each DEM was evaluated using the Real-Time Kinematic Differential Global Positioning System (RTK-DGPS) data collected from a 3-day field survey.

Since their initial release in 2003, SRTM DEM (hereinafter called as SRTM) has been improved several times, culminating most recently with version 4. SRTM version 4, which has a 3 arcsec (approximately 90 m x 90 m) ground resolution, is reported to have a vertical error less than 16 m at a 90% confidence level (Jarvis *et al.*, 2008; Rodríguez *et al.*, 2006). In addition, ASTER GDEM data have been improved by GDEM2 version in October 2011. It has been reported that the overall accuracy of GDEM2, which has a 30 m ground resolution, is approximately 17 m at a 90% confidence level (ASTER GDEM Validation Team, 2011), which is three meters more accurate than GDEM1. Assessments of the accuracy in many different locations throughout the world are critical for improving the next generation of GDEMs.

2.2.2 Objectives

In this section, we investigated the accuracy of GDEM2 using inundation area analysis and to compare it with the vertical accuracy of SRTM and Topo-DEM. The vertical accuracy of each DEM was also evaluated using the Real-Time Kinematic Differential Global Positioning System (RTK-GPS) data taken from the field survey.

2.2.3 Materials and methods

2.2.3-1 Study area

To analyze the quality of the newly released GDEM2 in comparison to other DEMs, we focused on the projected location of the Karian dam in the Ciujung watershed, Banten Province, Indonesia. Karian is one of several locations proposed by the local government for the construction of a new dam in the anticipation of population growth and an increased need for water supply by 2025. The coordinates of the dam axis are 106º 16’ 56.10” E; 6º 24’ 45.40” S and 106º 17’ 14.70” E; 6º 24’ 57.50” S.

2.2.3-2 DEM datasets

GDEM1 and GDEM2 data were obtained from http://asterweb.jpl.nasa.gov, and SRTM v4.1 data were acquired from http://srtm.csi.cgiar.org. The Topo-DEM data were derived from digital topographic maps (scale 1:25,000) after being transformed into a DEM using the Triangulated Irregular Network tool in ArcGIS 10 (ESRI, Redlands, CA, USA). The topographic map itself was originally derived from aerial photos (acquired in 1993/1994) using analytical photogrammetric methods, and their accuracy was determined by a field survey by the National Mapping Coordination Agency of Indonesia (the history of the map is written in the legend of the map). The grid size of the Topo-DEM was set to 12.5 m based on both the map accuracy specifications and the scale (Tobler, 1988). Consequently, the grid size of the other DEMs was also resampled to 12.5

m using nearest neighbor interpolation, and the raster pixel type/depth was set to use a 16-bit signed integer format for map algebra operations.

All four of the DEMs (GDEM1, GDEM2, SRTM and Topo-DEM) were referenced to a World Geodetic System (WGS84) horizontal datum and to an Earth Gravitational Model 1996 (EGM96) vertical (geoid) datum. To avoid horizontal offsets, a simple “shifting” method was applied following the method of Hirt et al. (2010), where one dataset was systematically shifted by small increments (0.5 arc seconds) in all directions and compared against an unshifted dataset. The occurrence of offsets was judged by the root mean square error (RMSE). The results revealed that horizontal offsets did not occur any of the DEMs.

For the purpose of the analysis, we considered Topo-DEM to be the most accurate of the compared DEM datasets because Topo-DEM was produced from high-resolution aerial photos followed by photogrammetry and was verified using a field survey. Therefore, the elevation values contained in the Topo-DEM are actually the bare ground elevations, and thus, this dataset is termed a Digital Terrain Model (DTM). In addition, the elevation values in SRTM and ASTER GDEM constitute the height of the tree canopies and man-made features and thus are termed Digital Surface Models (DSMs) (Miliaresis and Delikaraoglou, 2009).

2.2.3-3 Inundation area analysis

The basic idea of inundation area analysis is to delineate the impoundment area in a watershed that will be covered by water for a specific purpose, such as for flood and contingency planning analysis (Manfreda *et al.*, 2011; Han *et al.*, 1998; Sippel *et al.*, 1994), sedimentation in urban drainage (Moojong *et al.*, 2008), irrigation system (Hagiwara *et al.*, 2002) and tsunami run-off area (McAdoo *et al.*, 2007). Because the main source of information for this analysis is elevation data, inundation area analysis is therefore suitable for evaluating the quality of DEMs. The quality of a DEM itself is mainly dependent on the accuracy of the elevation values, the number of voids (artifacts) and the number of anomalies. In addition to inundation area analysis, other methods are often used for assessing quality of a DEM, including watershed delineation analysis (Gamett, 2010) and stream networking analysis (Hosseinzadeh, 2011; Hengl *et al.*, 2010).

In this study, inundation area analysis was applied to determine the maximum contour level (MCL) for the proposed Karian dam. The MCL represents the widest possible inundation area (i.e., the impoundment area) in a watershed that can be covered by water, and the quality of a DEM is evaluated based on the MCL values. The location of the dam axis was used as the basis for the analysis. After applying a fill-and-sink removal procedure (Lindsay, 2005), all DEM sources were analyzed in ArcGIS 10.

2.2.3-4 Vertical accuracy assessment

In addition to the inundation area analysis, by which the MCL (impoundment boundary) is evaluated, an assessment of the vertical accuracy of each DEM was also investigated using RTK-dGPS data obtained from a geodetic survey according to a procedure that was previously used in a study in Greece (Mouratidis *et al.*, 2010). To examine the accuracy of the DEMs at the watershed scale, the geodetic survey was implemented in several locations of the Ciujung watershed (Figure 2-12).

Two dGPS Promark3 handsets (Magellan, USA) equipped with 110454-type antennas and 111359-type radio modems were employed during a 3-day field observation study. At each station, the fixed GPS unit was set to a known position (above a national geodetic control point) (Soetadi, 1988), and the mobile GPS unit, the so-called rover, was used to record the x-y-z positions along a trajectory. An initialization-bar occupation process was required before data collection at each station to resolve the integer ambiguity between the satellites and the rover (Magellan Navigation Inc., 2005). Both GPS devices were set to record the positional data at 5-second intervals.

Due to the presence of unpaved roads along certain trajectories, especially in the upstream areas where a car could not travel smoothly at a constant speed, we installed the rover GPS on a motorbike. The use of a motorbike, of course, has an advantage and disadvantage. The advantage was that the motorbike could travel over unpaved roads without difficulty, and the disadvantage was that the motorbike induced a small amount of vibration on the equipment.

The Global Navigation Satellite Systems (GNSS) software version 3.10.11 (Ashtech, USA) was used in the post-processing analysis, and we used the RMSE to assess the accuracy due its capacity to encompass both the random and systematic errors in the data (Nikolakopoulos *et al.*, 2006). The RMSE has become a standard statistical tool for analyzing DEM accuracy and has been used by the U.S. Geological Survey (USGS) and in many other studies (Hirt *et al.*, 2010; Miliaresis and Delikaraoglou, 2009; Mouratidis *et al.*, 2010).

2.2.4 Results and discussion

2.2.4-1 Inundation area analysis

The inundation area analysis applied using the available DEMs produced four impoundment boundaries for the proposed Karian dam. The produced boundaries differ in their MCL, size and volume (Table 1). However, in this study, we only focused on the MCL because the size and volume are secondary products that require a separate investigation.

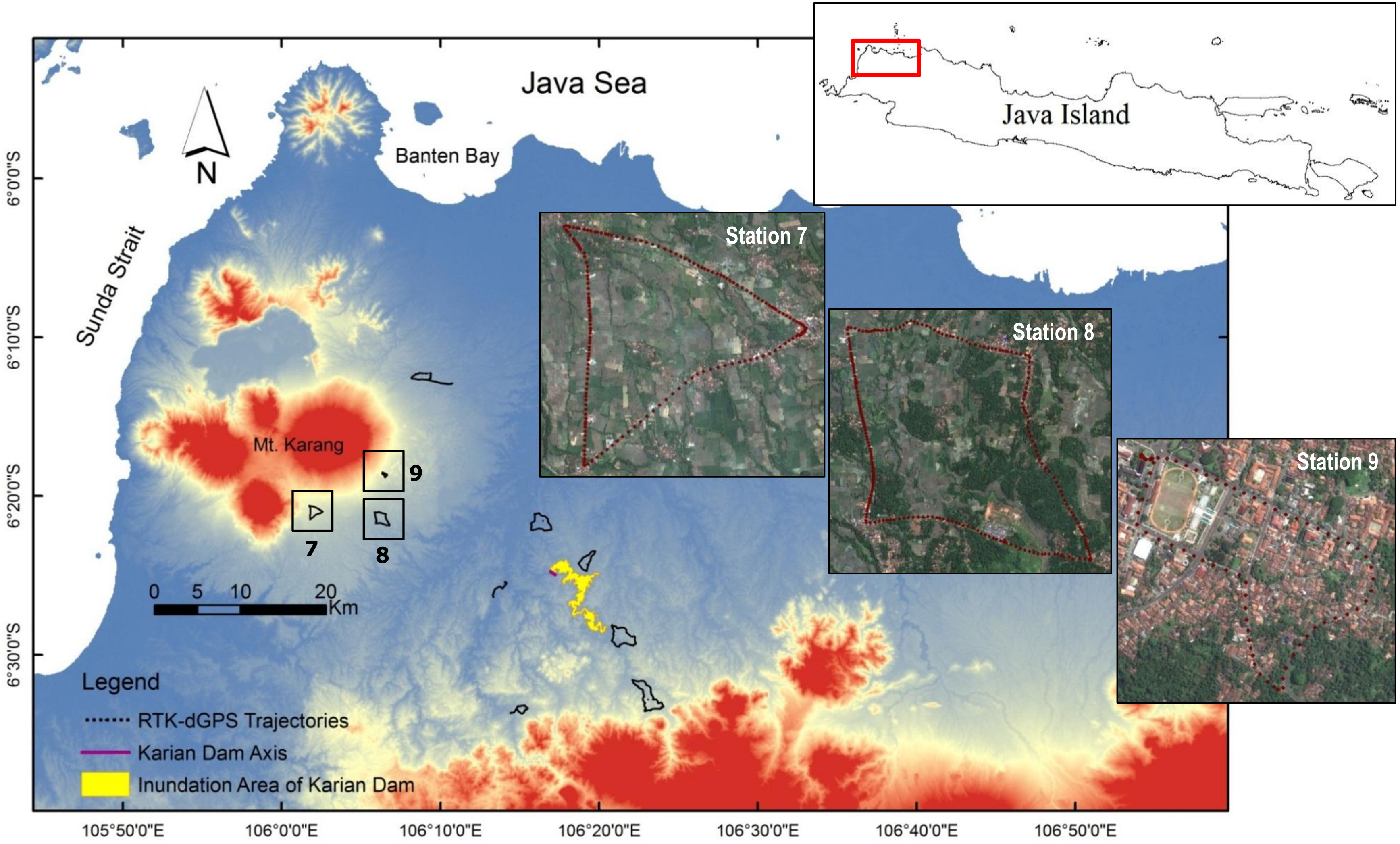

Figure 2-12: A map of the study site showing the RTK-dGPS trajectories, three of which are enlarged and overlaid on Google Earth images.

Table 2-5: Maximum contour level, inundation area and water volume derived from various DEMs in the projected location of the Karian dam.

Topo-DEM			SRTM DEM			ASTER GDEM1			ASTER GDEM2		
CL	IA	WV	CL	IA	WV	CL	IA	WV	CL	IA	WV
63 (over)			70 (over)			56 (over)			65 (over)		
62 (max)	10.56	154.33	69 (max)	14.81	177.62	55 (max)	6.51	73.61	64 (max)	8.01	99.75

Notes: CL = Contour Level (m); IA = Inundation Area (km^2); WV = Water Volume (million m^3).

Of the evaluated models, The MCL resulting from GDEM2 was the most similar to the MCL obtained using Topo-DEM, which was considered the most accurate dataset among the comparable DEMs. The MCLs obtained using Topo-DEM and GDEM2 were 62 m and 64 m, respectively. The SRTM data produced a slightly higher MCL of 69 m. In addition, the GDEM1 data yielded the lowest MCL value of only 55 m. The shapes of the impoundment boundaries obtained using GDEM2 and SRTM were highly similar to that of the Topo-DEM. Meanwhile, a small difference in the boundary was observed for GDEM1 (Figure 2-13).

The more accurate contouring level of GDEM2 relative to SRTM and GDEM1 demonstrated that GDEM2 has been improved regarding voids, anomalies and flat lake surface problems. These artifacts have been substantially reduced from GDEM1 by the National Geospatial-Intelligence Agency (NGA) using an extensive visual identification method (ASTER GDEM Validation Team, 2012). The remaining difference in the MCL of Topo-DEM and the MCLs of SRTM/GDEM2 could be related to conceptual differences in DTM/DSM. The effect of the canopy and man-made features on the elevation value is an interesting subject for future studies. The factors influencing the large differences in the size and volume of the impoundment boundaries also require further investigation.

Although the observations reported here are based on a simple analysis, the results imply that GDEM1 users should be cautious when using these data, especially when GDEM1 is used for hydrologic studies that require precise results, such as flood disaster analysis. Up to this point, the use of GDEM2 and SRTM is strongly recommended because these datasets provided better impoundment boundaries.

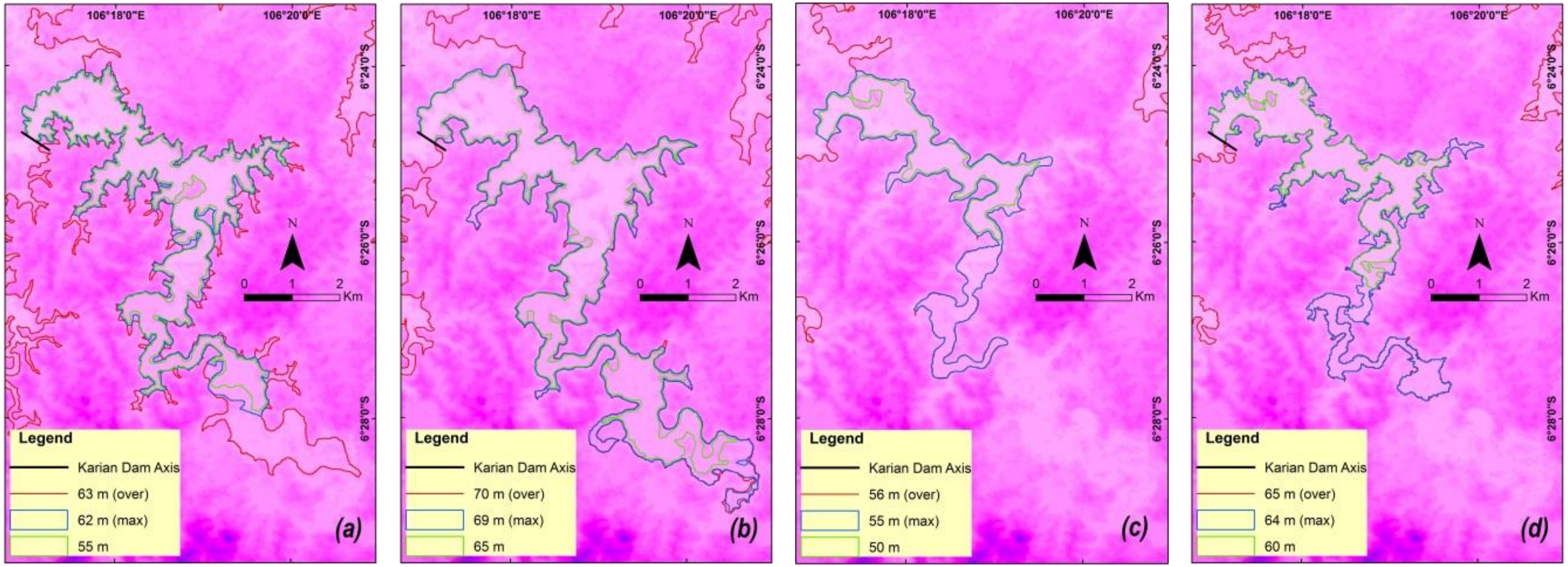

Figure 2-13: Contour level of the inundation areas for the proposed location of the Karian dam produced from **(a)** Topo-DEM, **(b)** SRTM DEM, **(c)** ASTER GDEM1, and **(d)** ASTER GDEM2.

The results of this analysis, however, could not provide information regarding the accuracy of the vertical elevation of the DEMs. Although an MCL is based on elevation values, the created boundary is strongly dependent on the conditions surrounding the dam axis and the projected dam, such as the terrain, slope and land cover. The accuracy of a DEM in a large watershed can only be evaluated by conducting an intensive geodetic survey, in which a huge number of geographic positions (x, y and z) of the earth are densely recorded over a trajectory in several different types of terrain and land cover. After performing a geodetic survey, the vertical profile of each DEM can be compared with the elevation values that were measured in the field.

2.2.4-2 Vertical accuracy assessment

Although the analysis presented above demonstrated an improvement of GDEM2 over GDEM1, the elevation values of the DEMs must also be assessed. In this section, the vertical accuracy of each DEM is evaluated based on the height values derived from a geodetic RTK-dGPS dataset.

2.2.4-2a The quality of RTK-DGPS data

Within the limitation of the survey design, as described in the Materials and Methods section, the RTK-dGPS data produced satisfactory Positional Dilution of Precision (PDOP) values with an average of 2.26 ± 0.54 (determined from 3,661 survey points); 36.5% of the values were within the range of 1–2, whereas the remaining 63.5% were within the range of 2–5. Based on the work of Kaya and Saritaş (2005), the PDOP ranges of 1–2 and 2–5 are classified as ‘excellent’ and ‘good’, respectively. The number of satellites in view (SV), with an average of 8.21 ± 1.30, was also adequate for typical hydrological studies (Figure 2-14b).

The measures of PDOP and SV are useful for assessing GPS data quality (Kaplan and Hegarty, 2005; Natural Resources Canada, 1995). An additional important measure of GPS quality is the estimated accuracy of GPS data. It was difficult to estimate the overall horizontal and vertical accuracies of our data because the rover GPS traveled across different types of land cover. The results showed excellent accuracy when the rover GPS traveled across open roads; however, the accuracy decreased when certain high objects (e.g., trees and man-made features) were present along the roadsides or when the distance between two GPS unit was greater than 1 km.

An example of the vertical accuracy assessment is presented using data from Station 6 (Figure 3), where two peaks of biases appeared in the result due to the aforementioned influences. At this station, the estimated horizontal and vertical accuracies were 0.625 m and 0.605 m, respectively, or 0.427 m and 0.402 m, respectively, when the influencing factors are filtered out. The biases from the other stations were higher and dependent on the land cover types along the roads and the distance between the pair of GPS units. Here, we note that the survey design requires certain improvements to eliminate the effects of the land cover types and decrease the distance between the GPS units.

2.2.4-2b Vertical accuracy of the DEMs

After filtered out the large outliers influenced by high objects, the RTK-dGPS data were used to measure the vertical accuracy of all DEMs compared in this study, including the Topo-DEM. Although the Topo-DEM was considered to have the most accurate data, it may contain certain elevation biases relative to the RTK-dGPS data. The vertical accuracy assessment was applied not only to the DEMs at their original resolutions but also to the DEMs after being resampled to the smallest resolution, which was equal the 12.5 m resolution of the Topo-DEM.

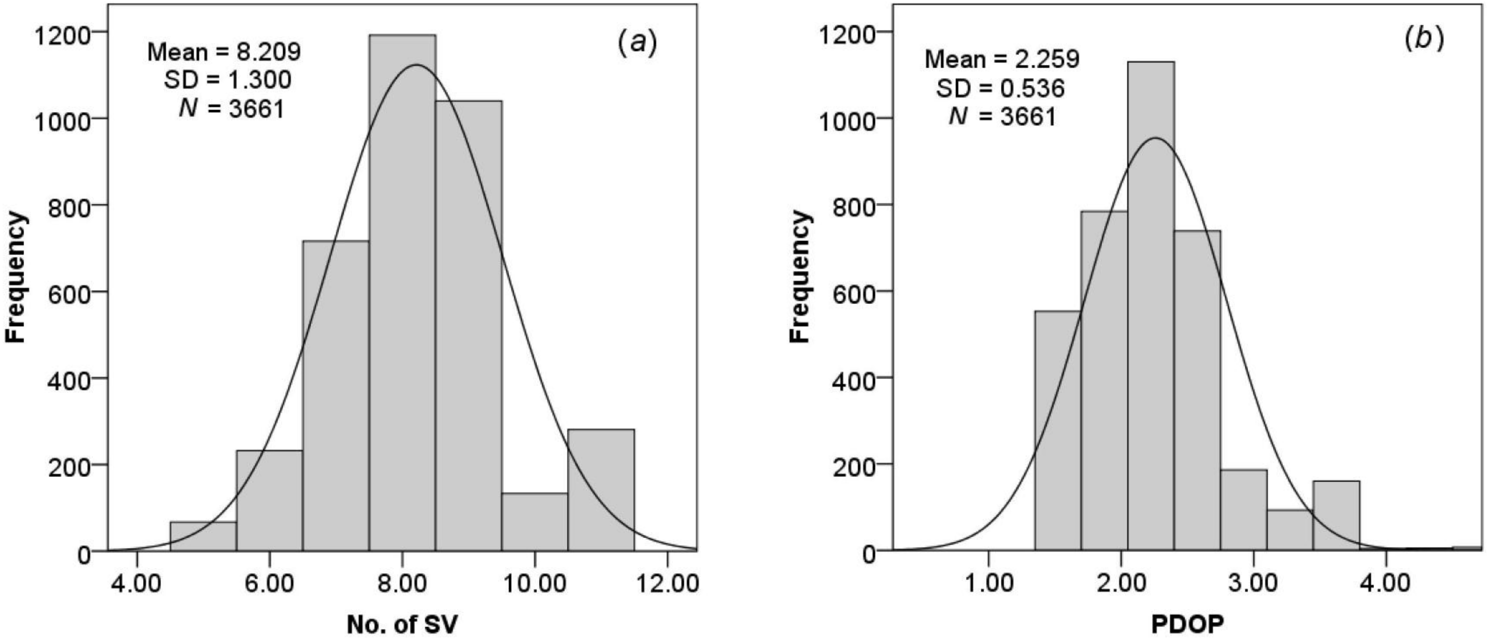

Figure 2-14: Histogram distribution of the Positional Dilution of Precision (PDOP) (a) and number satellites in view (SV) (b) from all RTK-DGPS data in all stations (SD = standard deviation).

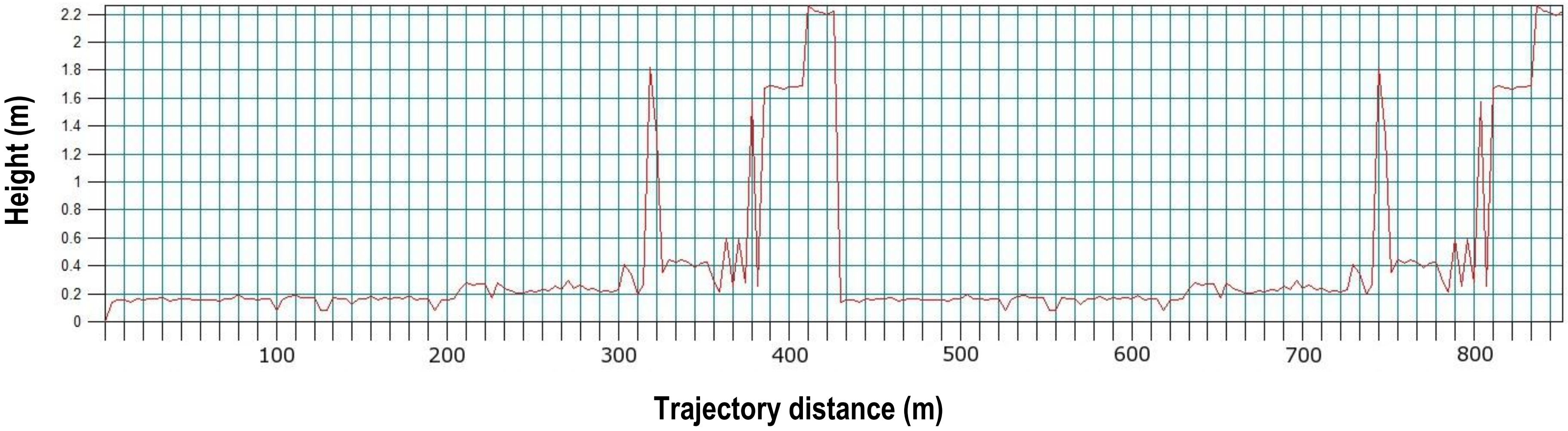

Figure 2-15: Estimated vertical accuracy of RTK-dGPS data for Station 6.

Table 2-6: Results of vertical accuracy assessment between various DEMs with RTK-dGPS data using a linear regression model.

Station	**RMSE (m) (α = 0.95) (original resolution)**				**RMSE (m) (α = 0.95) (resampled to 12.5 m resolution)**				**Slope**
	Topo-DEM	SRTM	GDEM1	GDEM2	Topo-DEM	SRTM	GDEM1	GDEM2	(%)
B01	2.927	3.571	3.512	5.319	2.927	3.269	3.526	4.912	2.66
B02	4.020	2.348	3.801	4.771	4.020	1.963	3.835	4.330	2.92
B03	3.110	3.924	5.393	5.745	3.110	2.742	5.169	5.194	3.67
B04	3.676	3.820	4.159	4.690	3.676	2.935	4.101	4.140	4.04
B05	3.044	4.171	3.985	6.230	3.044	3.146	4.036	6.003	4.82
B06	1.414	2.635	2.470	4.914	1.414	1.725	2.426	4.523	4.49
B07	3.175	2.898	4.459	5.821	3.175	2.725	4.430	5.412	2.56
B08	4.033	3.505	6.233	7.759	4.033	3.185	6.117	7.158	2.99
B09	2.598	2.214	2.629	6.203	2.598	1.510	2.523	5.890	3.86
B10	4.535	4.006	4.046	6.513	4.535	3.495	4.056	4.911	3.23
B11	2.712	2.661	3.807	4.543	2.712	2.388	3.728	4.232	2.46
Average	3.204	3.250	4.045	5.683	3.204	2.644	3.995	5.155	3.43

Our results showed when comparing the DEMs at their original resolutions, the Topo-DEM demonstrated the most accurate data with an average RMSE of 3.204 m at the 95% confidence level (Table 2). Among the satellite-derived DEMs, the SRTM data showed a better vertical accuracy than both GDEM1 and GDEM2. More surprisingly, the vertical accuracy of GDEM2 was less than the accuracy of GDEM1, as it achieved a much higher RMSE compared to GDEM1. This result was surprising because it was contradictory to the accuracy reported by the GDEM2 validation team (ASTER GDEM Validation Team, 2011).

After resampling to 12.5 m x 12.5 m resolution, the comparison of the accuracy of all DEMs was repeated. The resampling procedure greatly increased the accuracy of all DEMs, as demonstrated by their average RMSEs. Moreover, the vertical accuracy of SRTM was now better than that of Topo-DEM, which indicates that the Topo-DEM data may need certain corrections or revalidation. Nevertheless, this procedure demonstrated that SRTM continued to yield a better accuracy than both GDEM versions, and GDEM2 data yielded the lowest vertical accuracy of all the tested DEM datasets. The greater accuracy of SRTM over GDEM1 has been previously reported in many studies (Hirt *et al.*, 2010; Gamett, 2010; Pryde *et al.*, 2007; Kervyn *et al.*, 2008). However, this study is the first investigation to report the lower accuracy of GDEM2 data.

To determine the cause of the relatively low accuracy of GDEM2, we plotted the vertical profiles of the DEMs along the dGPS trajectories. Three examples of these profiles are shown in Figure 4. We chose these trajectories because for these data, the rover travelled along good-quality paved roads. These results demonstrated that the GDEM2 data contain a large extent of undulation effects, thereby causing high RMSE values.

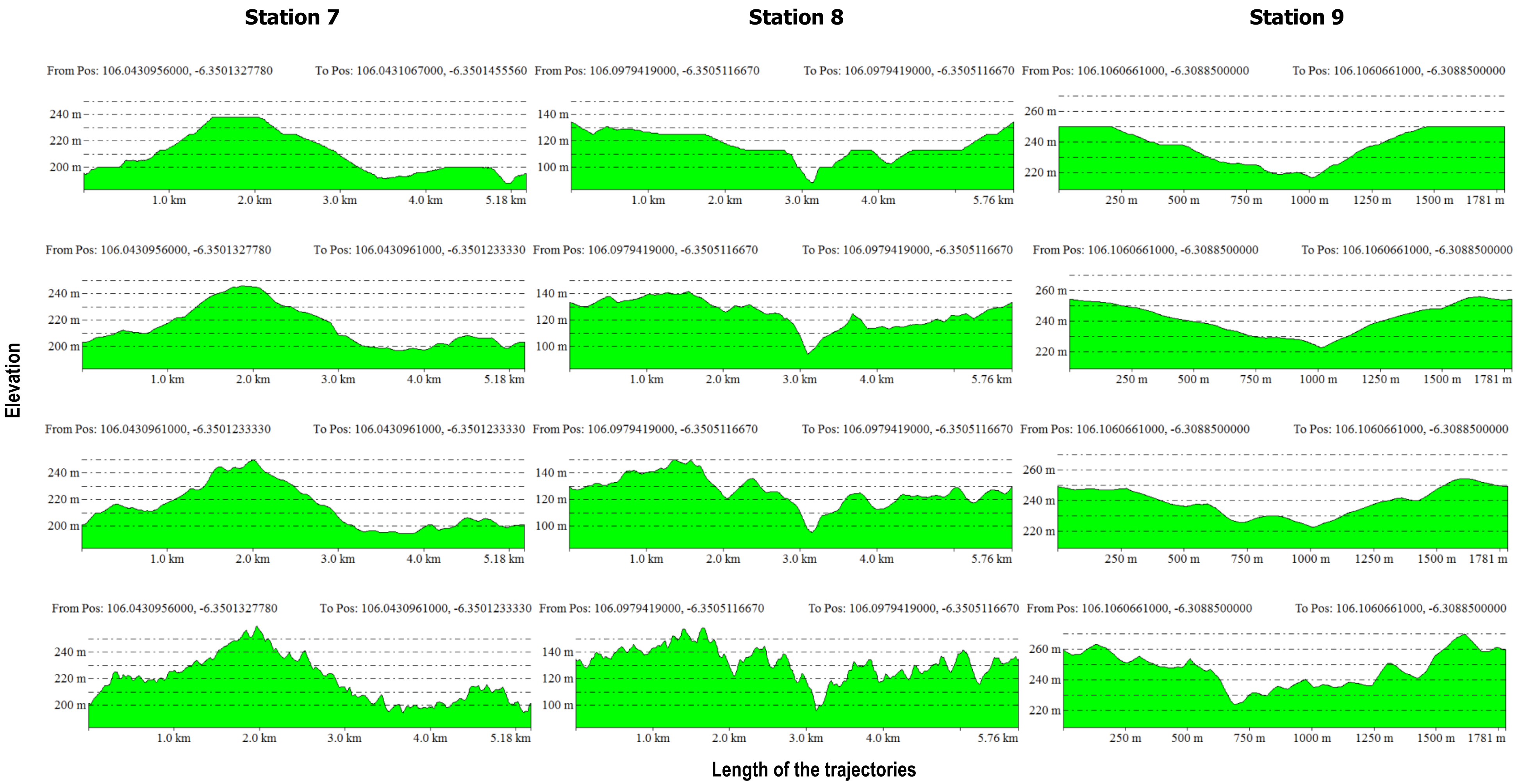

Figure 2-16: Vertical profiles of digital elevation data along the RTK-dGPS trajectories as indicated in Figure 2-12. The sequence of the elevation data from the first row to the last row is Topo-DEM, SRTM DEM, ASTER GDEM1 and ASTER GDEM2.

Given that the rover GPS for these stations was moving along good-quality paved roads, it is impossible that the trajectories reflect a large degree of unevenness of the roads. Instead, we believe that the undulation effects in GDEM2 may have been introduced during the validation process. The GDEM2 validation team has explained that the validation process included cloud effects removal, land cover reclassification, canopy effects reduction, the addition of a number of scenes and other factors (ASTER GDEM Validation Team, 2011), through which the undulation effects may have been inadvertently introduced.

2.2.4-2c Undulation effects

In addition to the elevation difference in the DTM/DSM, which was previously addressed, it is always important to remember that elevation information contained in a dataset is different depending on the baseline reference. GPS delivers ellipsoidal heights, whereas SRTM and GDEM provide mean sea level (MSL) heights. The difference between these data, which is called the geoid height, varies for any location of in world because the MSL heights are affected by gravitational forces.

We analyzed station 7 an example of the dataset (Figure 5). In our data, the elevation of the Topo-DEM was mostly (but not in all cases) lower than the SRTM and GDEM because the later datasets contained the bare ground elevation. In addition, the SRTM and GDEM elevations were higher than in the Topo-DEM because they included the canopy height information. At this station, the average geoid heights are 3.835 m, 4.478 m and 5.372 m for SRTM, GDEM1 and GDEM2, respectively. Although disparities between the DEMs are best judged according to their RMSE values (Hirt *et al.*, 2010; Miliaresis and Delikaraoglou, 2009; Mouratidis *et al.*, 2010), the average geoid heights and the undulation pattern, as displayed in Figure 5, can help in understanding the disparities between datasets.

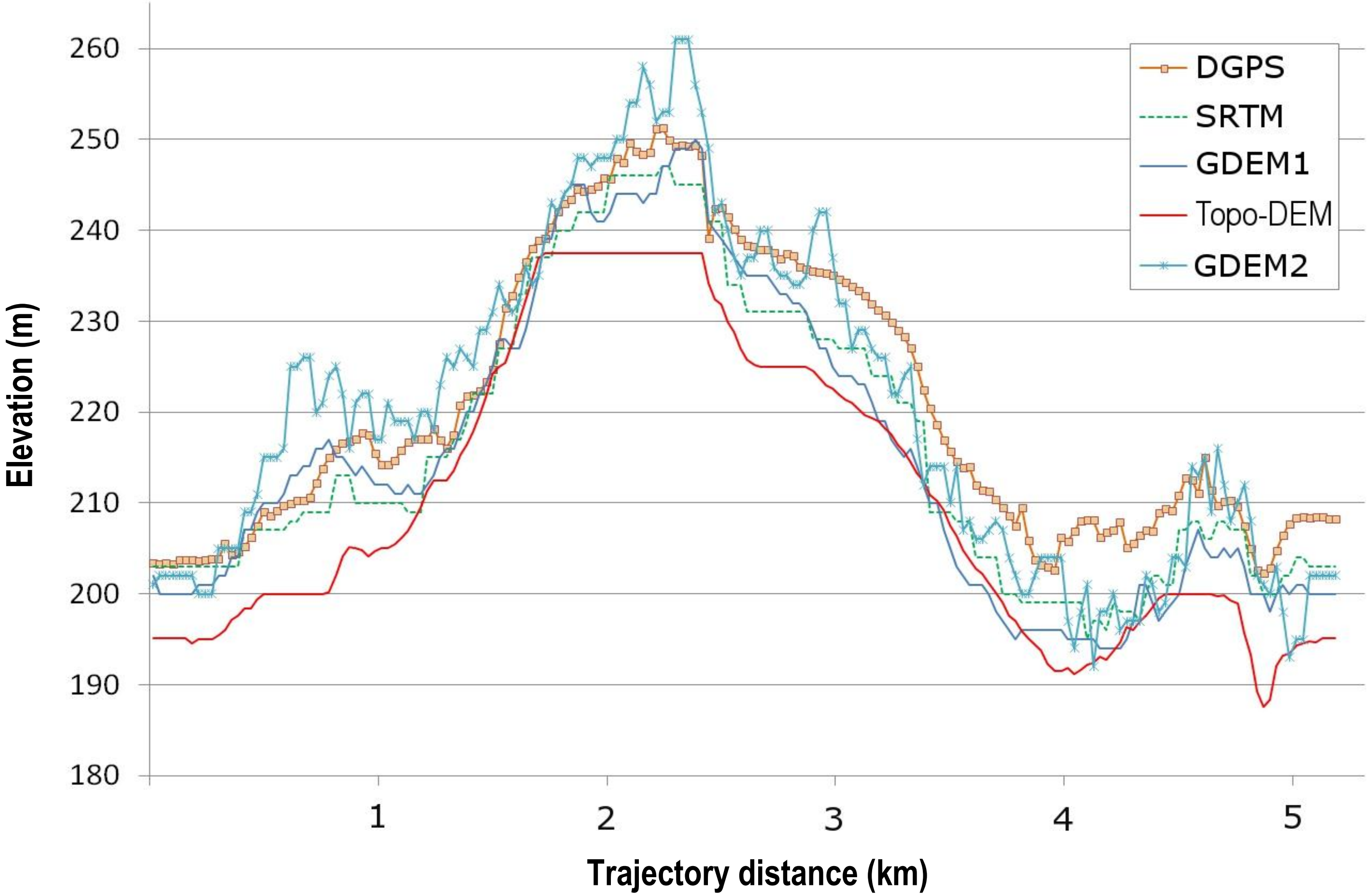

Figure 2-17: Height disparities and different undulation levels among the DEMs for station 7.

2.2.5 Conclusions

This study provides additional information for public users and the GDEM2 validation team regarding the quality of GDEM2 data. Inundation area analysis of the projected Karian dam (Indonesia) and the RTK-dGPS data collected from Ciujung watershed were used to assess the quality of GDEM2 data. The results of inundation area analysis showed that the GDEM2 data were highly improved by the removal of voids and anomalies and thereby produced a better MCL (impoundment boundary). The MCL produced from GDEM2 was 64 m, which the value was much better than the MCL produced from GDEM1 (55 m) and closer to the MCL produced from Topo-DEM (62 m) and SRTM-DEM (69 m), However, the vertical accuracy of GDEM2 was found to be lower than that of GDEM1 and the other DEMs, as indicated by the RTK-dGPS data and the RMSE values. The average RMSE values for the Topo-DEM, SRTM, GDEM1 and GDEM2 were 3.204, 3.250, 4.045 and 5.683, respectively. The lower accuracy of GDEM1 could be caused by undulation effects, which were found throughout the observed stations. Although our initial findings cannot be generalized to all GDEM2 data, but we are pleased to report that there is evidence that the undulation effects in GDEM2 present in the study area. We believe that the undulation effects may have been introduced during the validation process perhaps due to cloud effect removal, land cover reclassification or other factors that are unknown to the authors. To obtain a clear understanding of these effects, an intensive study involving additional sampling stations over a wider area is necessary in the future.

Chapter III

Water Quality Assessment of Ciliwung and Ciujung Rivers

As an urban watershed, Ciliwung is a place for some big cities such as Bogor, Cibinong, Depok and Jakarta that are growing very fast due to population increase and economic development. Here, Jakarta is the frontline city that borders with the Jakarta Bay. Meanwhile, Ciujung watershed is occupied only by smaller cities such as Rangkasbitung, Pandeglang and Serang, where Serang is bigger than two other cities and borders with the Banten Bay.

Due to population increase and economic development, the pressure level on water resources utilization in both watersheds is different. Of course, in Ciliwung watershed, people have put more pressures on water resources compared to the ones living in Ciujung watershed, resulting different river- and groundwater usage in both watersheds. To compare ecosystem health in terms of water resources condition, an assessment of river- and groundwater quality in both watersheds is a necessary.

This chapter discusses about water pollution level in some major rivers in both watersheds. In Ciliwung watershed, the water quality assessment was conducted for both the river- and groundwater but concentrated only in the 13 rivers in Jakarta city. Meanwhile, the water assessment in Ciujung watershed was conducted only for the river water, but the observation stations were located from the upper, middle and downstream area of Ciujung River.

The data sources for water quality assessment in the Jakarta City were obtained from the Jakarta Environmental Management Board (BPLHD Jakarta). The data was derived from the measurements in 2007 and 2008, both in rainy and dry seasons. At each season, 75 groundwater and 67 river water samples were collected at stations throughout the city, where 32 water parameters were measured at each station. Meanwhile, the water quality assessment for Ciujung River was obtained from Water Resources Office of Banten Province. Water quality has been collected by monthly basis since 1999 from 9 stations locating in the upper, middle and downstream of Ciujung River. More than 41 water parameters have been measured at each station, but only several parameters have been constantly measured, from which the statistical analysis was conducted.

3.1 Evaluating spatio-seasonal patterns of river- and groundwater quality in the city of Jakarta, Indonesia, using a pollution index

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3.1.1 Introduction

Jakarta is one of the fastest growing cities in Asia. It is occupied by around 9.5 million inhabitants within a total area of 662 km^2. This city-province is divided into 6 districts, in which 5 districts on the mainland (*i.e.,* North, West, East, South and Central Jakarta) and another district named the "Thousand Islands" that consists of 105 islands located in the Jakarta Bay.

Rapid development and population increase in Jakarta have introduced some environmental problems to the city. Some issues, such as urban waste (Steinberg, 2007), air and water pollution (Sato and Harada, 2004; WRI, 1996), coastal pollution (Williams *et al.,* 2000), and drinking water shortages (Douglass, 2005; Jensen, 2005), are among the problems faced the government. Besides poor sewerage systems, weak law enforcement also tends to contribute to the water pollution in Jakarta (Colbran, 2009; Steinberg 2007).

There are 13 major rivers flowing through the city of Jakarta. These rivers receive pollutants from industrial and household sources in both solid and liquid forms. Solid wastes such as plastics, wood, and bottles can easily be found in the canals and rivers. To some extent, river water has a potential to pollute groundwater through diffusion in soil layers, which is the reason why groundwater pollution is often classified as nonpoint source pollution (Lerner, 2008; Bartram and Balance, 1996).

River water pollution in Jakarta has been present for years as reported in some publications. In the late 1970s, Gracey *et al*., (1979) reported high concentrations of Enterobacteria, such as *Escherichia coli* (*E. coli*), *Klebsiella* sp., *Citrobacter*, *E. cloaceae*, *E. agglomerans*, and *Salmonella*, on isolated medium samples from the Ciliwung River.

Recently, the environmental conditions have tended to persist or worsen (Suwandana *et al*., 2011d; Colbran, 2009; Meij *et al*., 2009; Steinberg, 2007; Williams *et al*., 2000; Uneputty and Evans, 1997).

The increasing demand for water has led to overutilization of groundwater aquifers by excessive pumping (Steinberg, 2007). There are several ways that groundwater is accessed in Jakarta, including through traditional wells and pumps. Electric water pumps are responsible for the largest withdrawals. In turn, excessive water pumping generates other associated problems, such as infiltration of the shallow aquifers by polluted river water, salinization, and land subsidence (Schmidt *et al*., 1988).

In water resource science, many different methods have been developed to evaluate water quality in an ecosystem or a city. Until recently, there are at least 55 Water Pollution Indices (WPI) and Water Quality Indices (WQI) that have been developed by scientists to evaluate water quality in ecosystems and cities. One of the methods is the Nemerow-Sumitomo WPI (Terrado *et al*., 2010; Karami *et al*., 2009; Prakirake *et al*., 2008), which was originally developed in the United States in the 1970s. Later, it was adopted by the Ministry of the Environment of Indonesia along with the regulation No. 115/2003, which addresses water-quality measurement guidelines.

The quality of river water and, most importantly, groundwater, is influenced by many factors. Both water resources are exposed to contaminants released during industrial, agricultural and household activities. Precipitation also affects the quality of water resources, and thus, the quality may differ in time and space.

3.1.2 Objectives

This study evaluates the spatio-seasonal patterns of river- and groundwater quality in Jakarta using the Nemerow-Sumitomo WPI. The study is divided into three phases: 1) measuring water quality both in the river- and ground water, 2) analyzing seasonal patterns of WPI in dry and rainy seasons, and 3) analyzing spatial distribution of WPI within five districts of Jakarta. This study could provide information for residents who still utilize groundwater resources to help them decide whether to continue self-pumping or to get water supply from the water service companies.

3.1.3 Materials and methods

Water-quality data from river- and groundwater was obtained from the Jakarta Environmental Management Board (BPLHD Jakarta). Three sampling sessions were conducted by BPLHD in July 2007 (dry season), November 2007 (early rainy season) and August 2008 (late dry season). During each season, 75 groundwater and 67 river water samples were collected at stations throughout the city, and 32 water parameters, consisting of 5 physical, 25 chemical and 2 biological parameters, were measured at each station. Table 3-1 lists the measured parameters and their corresponding permissible values (PV*s*). The PV*s* for this study were based on the Jakarta Governor No. 582/1995 regulation regarding standardization of river water quality and the Ministry of Health No. 416/1990 regulation regarding water-quality monitoring.

The Nemerow-Sumitomo WPI equation was used in this study to evaluate the spatio-seasonal patterns of river- and groundwater quality in the city of Jakarta. The function of this equation was to standardize the concentrations of all water parameters such that the different concentration ranges for each water parameter were rescaled by the equation to produce a relative value that lies within a comparable range (Nemerow and Sumitomo, 1970). The WPI is a function of relative values (C_i/L_i), where C_i represents the concentration of parameter i and L_i represents the PV of parameter i defined by the above regulations.

WPI = a function of (C_i/L_i)'s (1)

$= f\,(C_1/L_1, C_2/L_2, C_3/L_3, \dots C_n/L_n)$

$(i = 1, 2, 3, \dots, n)$

Then, the WPI for a specific water use j (WPI_j) is further expressed by the following equation:

$$WPI_j = \sum_{i=1}^{n} \sqrt{\frac{(C_i/L_{ij})^2_{\max} + (C_i/L_{ij})^2_{ave}}{2}} \tag{2}$$

where C_i is the measured concentration of parameter i, L_{ij} is the PV for parameter i assigned for water use j, and $(C_i/L_{ij})_{max}$ and $(C_i/L_{ij})_{ave}$ are the maximum and average values of C_i/L_{ij} for water use j, respectively.

For the water parameters for which the higher value represents a higher level of pollution, such as nitrate and heavy metals, the values of C_i/L_{ij} obtained from field measurements can be directly calculated using the above equation, with a following prerequisite. The prerequisite is that if the value of C_i/L_{ij} obtained from the measurement is greater than 1.0, then the C_i/L_{ij} value must be standardized by applying the following equation:

$$(C_i/L_{ij})_{new} = 1.0 + k \times \log(C_i/L_{ij})_{ave} \tag{3}$$

where k is the free constant (usually 5).

For the parameters where the lower value represents a higher level of pollution, such as dissolved oxygen (DO), the C_i/L_{ij} values obtained from field measurements must be standardized by using the following equation:

$$(C_i/L_{ij})_{new} = \frac{C_{im} - C_i}{C_{im} - L_{ij}} \tag{4}$$

where C_{im} is the saturation value for any parameter at room temperature (*e.g.*, for DO, C_{im} at 25ºC is 7).

Table 3-1: Water parameters and their corresponding permissible values (PV) in Jakarta.

	No	Parameters	Unit	Permissible Values (PV)	
				Groundwater [a]	River Water [b]
Physical	1	Conductivity	µmhos/cm	*nd* [c]	500
	2	Total Dissolved Solids (TDS)	mg/l	500	500
	3	Total Suspended Solids (TSS)	mg/l	*nd*	*Nd*
	4	Turbidity	NTU	25	100
	5	Temperature	^{o}C	*nd*	*Nd*
Chemical	6	Mercury (Hg)	mg/l	0.001	0.001
	7	Ammonia (NH_3)	mg/l	*nd*	1.00
	8	Potassium Permanganate ($KMnO_4$)	mg/l	10	15
	9	Iron (Fe)	mg/l	1.00	2.00
	10	Fluoride (F)	mg/l	1.50	1.50
	11	Cadmium (Cd)	mg/l	0.005	0.010
	12	Chloride (Cl)	mg/l	600	250
	13	Chromium (Total)	mg/l	0.05	0.05
	14	Manganese (Mn)	mg/l	0.50	0.50
	15	Nitrate (NO_3)	mg/l	10	10
	16	Nitrite (NO_2)	mg/l	1.00	1.00
	17	Nickel (Ni)	mg/l	*nd*	0.10
	18	Dissolved Oxygen (DO)	mg/l	*nd*	3.00
	19	Phosphate (PO_4)	mg/l	*nd*	0.50
	20	pH		6.5 – 9.0	6.0 - 8.5
	21	Phenol	mg/l	*nd*	0.05
	22	Zink (Zn)	mg/l	15	1.00
	23	Sulfate (SO_4)	mg/l	400	100
	24	Sulfide (H_2S)	mg/l	*nd*	0.10
	25	Copper (Cu)	mg/l	*nd*	0.10
	26	Lead (Pb)	mg/l	0.05	0.10
	27	Oil and Fat	mg/l	*nd*	Nil
	28	Blue Methylene	mg/l	0.50	1.00
	29	Chemical Oxygen Demand (COD)	mg/l	*nd*	20
	30	Biological Oxygen Demand (BOD) 20^{o}C 5 days	mg/l	*nd*	10
Biological	31	*Escherichia coli*	ind/dl	50	1000
	32	Fecal Coliforms	ind/dl	10	2000

[a] Source: the Indonesian Ministry of Health regulation, No. 416/1990.

[b] Source: the Jakarta Governor regulation, No. 582/1995. These PVs are designed for the rivers of category B.

[c] *nd*: not determined.

For parameters for which the PV (L_{ij}) is defined by a range of numbers, such as for pH, where the PV ranges from 6 to 8.5, a standardized value of C_i/L_{ij} is required, which is calculated by the following equation:

If $C_i \leq$ average L_{ij}

$$(C_i / L_{ij})_{new} = \frac{C_i - (L_{ij})_{ave}}{(L_{ij})_{\min} - (L_{ij})_{ave}}$$

(5)

If $C_i >$ average L_{ij}

$$(C_i / L_{ij})_{new} = \frac{C_i - (L_{ij})_{ave}}{(L_{ij})_{\max} - (L_{ij})_{ave}}$$

(6)

where $(L_{ij})_{min}$ and $(L_{ij})_{max}$ are, respectively, the minimum and maximum values of L_{ij} (*e.g.*, pH: min = 6, max = 8.5). The $(L_{ij})_{ave}$ is the average value of L_{ij} (*e.g.*, pH: (6 + 8.5) / 2 = 7.25).

Based on river water use, river systems are classified into 4 categories. Category *A* includes rivers for which the water is directly used for drinking water; category *B* includes rivers for which the water is used for drinking water processing; category *C* includes rivers for which the water is used for fisheries and animal husbandry; and category *D* includes rivers for which the water is used for agriculture and other urban uses. However, because of water degradation, category *A* rivers does not longer exist in Jakarta.

The PV*s* for this study were based on the Jakarta Governor No. 582/1995 regulation regarding standardization of river water quality and the Ministry of Health No. 416/1990 regulation regarding water-quality monitoring. Each river category had its own set of PVs designed by those regulations. However, to facilitate comparison, the PV set for category *B* rivers was applied to all rivers in this study, regardless of their river category.

Finally, according to the above regulations, the WPI was classified into four criteria expressing the river water and groundwater pollution levels listed below.

$0.0 \leq \text{WPI} \leq 1.0$ = clean water (meets the PV criteria)
$1.0 < \text{WPI} \leq 5.0$ = slightly polluted water
$5.0 < \text{WPI} \leq 10$ = moderately polluted water
$\text{WPI} > 10$ = highly polluted water

However, because water pollution in Jakarta has been getting worse, and most of the present-day WPIs are greater than 10, the above classification is no longer sufficient. Therefore, the last classification of ‘highly polluted water’ needed to be reclassified into several pollution levels. Otherwise, it would be very difficult to differentiate the pollution levels. For this purpose, the new classification scheme proposed in this study, which follows the format of the above regulations, is listed below.

$10 < \text{WPI} \leq 15$ = highly polluted water
$15 < \text{WPI} \leq 20$ = very highly polluted water
$20 < \text{WPI} \leq 25$ = extremely polluted water
$\text{WPI} > 25$ = the most extremely polluted water

To compare the pollution level of each river and groundwater category in a season, the differences were examined using Tukey’s Honestly Significant Difference (HSD) test following two-way ANOVA. The statistical analyses were made using an SPSS statistical package version 16.0 (SPSS Inc., Chicago, Illinois). Meanwhile, ArcGIS version 9.3.1 (ESRI Inc., USA) was used to create water pollution maps.

In addition, to understand the seasonal periods in the study site, e.g. the starting, the ending and the peak time of the rainy and dry season, a simple hydrological simulation model was undertaken using Hydrological Simulation Program-Fortran (HSPF) combined with BASINS 4.0 software. As a part of Environment Simulator

(Yamashita *et al.*, 2007), HSPF is a comprehensive watershed simulation model developed by the United States Environmental Protection Agency (US EPA), in which one of the capabilities is to design and simulate the process of water circulation that occurs in a watershed. In a complex model, it can even include sediment transport and the movement of pollutants (Bicknell *et al.*, 2001). More detail explanation about the model building in HSPF is given in Appendix B.

3.1.4 Results and discussion

3.1.4-1 River- and groundwater parameters

In this section, the comparison of river water pollution is made by river category, whereas the comparison of groundwater pollution is made by district. As stated above, there are three river categories in Jakarta (*i.e.,* categories *B*, *C* and *D*) and there are 5 districts (*i.e.,* North, West, East, South, and Central Jakarta).

Figure 3-1 gives an example of the averaged river water parameters of July 2007 (dry season) at 14 stations along category *B* rivers, including the Ciliwung, Kalibaru, Krukut and Kali Mampang Rivers. These rivers are very important because the water is used by the water utility company that later distributes the water through pipeline networks.

It can be observed in the graph that the averaged concentrations of some parameters were already above their PVs, or in the case of DO, below their PV. The parameters (average and corresponding PVs) include NH_3 (2.55; 1.00 mg/l), $KMnO_4$ (25.00; 15.00 mg/l), DO (1.62; 3.00 mg/l), H_2S (0.41; 0.10 mg/l), oil and fat (0.10; 0.00 mg/l), COD (42.20; 20.00 mg/l), BOD (15.20; 10.00 mg/l), log *E. coli* concentrations (7.93; 3.00 ind/dl) and log fecal coliform concentrations (7.42; 3.30 ind/dl).

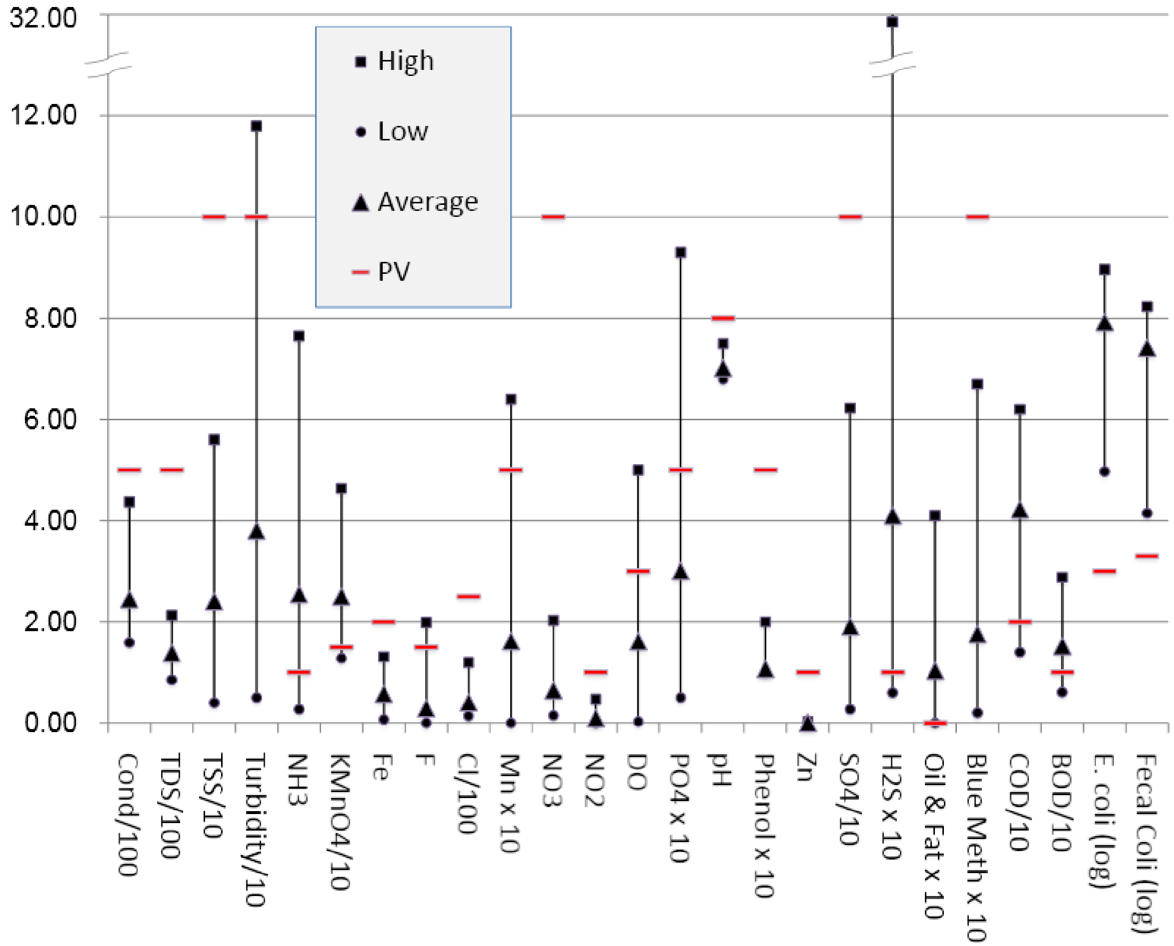


Figure 3-1: Concentrations of river water parameters measured from stations along the Ciliwung, Kalibaru, Krukut and Kali Mampang Rivers in July 2007. The values are standardized within a comparable range.

Table 3-2: The averages and standard deviations (SDs) of the eighteen river water parameters in the three seasons for the categories *B*, *C*, and *D*, and the corresponding permissible values (PVs).

Parameter	Unit	Average ± standard deviation (SD)									PVs [a]
		River category *B*			River category *C*			River category *D*			
		Jul 07	Nov 07	Aug 08	Jul 07	Nov 07	Aug 08	Jul 07	Nov 07	Aug 08	
Conductivity	µmhos/cm							0.31±0.76	0.28±0.94	0.43±1.20	0.05
TDS (×10^3)	mg/l							1.66±3.84	1.45±4.98	2.27±6.59	0.50
TSS	mg/l		307±136						137±205		100.0
Turbidity	NTU		252±216			149±236					100.0
NH_3	mg/l	2.55±2.53		3.00±3.03	6.40±5.41	1.85±1.10	3.55±2.17	9.94±8.51	6.08±4.54	14.1±15.4	1.00
$KMnO_4$	mg/l	25.0±10.5	38.7±25.2	28.1±18.8	57.0±34.9	20.4±5.70	34.5±17.8	63.4±35.8	47.9±46.3	73.3±73.2	15.0
Fe	mg/l				0.76±0.31	0.43±0.43		0.76±0.31			2.00
Cl	mg/l							711±945	713±2,639		250.0
DO	mg/l	1.62±1.26	2.46±1.72	1.48±1.24	1.87±1.45	2.77±2.75	1.07±1.40	1.54±1.80	1.62±1.91	2.06±2.74	3.00
PO_4	mg/l				1.50±1.30		0.87±1.14	2.00±1.45		1.48±1.08	0.50
SO_4	mg/l							147±350	136±391	128±122	100.0
H_2S	mg/l	0.41±0.81	0.49±0.38	0.20±0.16	4.57±5.46	0.41±0.30	3.27±5.20			3.35±4.56	0.10
Oil & fat	mg/l	0.10±0.12	1.19±3.36	0.10±0.07	0.19±0.26	0.31±0.21	0.37±0.60	0.34±0.56	0.35±0.86	0.58±0.52	0.00
Blue methylene	mg/l							1.48±1.12			1.00
COD	mg/l	42.2±15.7	67.7±36.9		90.5±85.1	41.4±19.5	25.0±13.3	102±73.4	113±137	44.2±29.2	20.0
BOD	mg/l	15.2±7.13	21.0±11.0	59.6±29.6	39.8±30.5	16.3±7.34	59.9±24.2	44.1±25.7	37.9±37.8	102±65.9	10.0
E. coli (log)	ind/dl	7.93±8.39	6.73±6.97	7.25±7.57	9.08±9.43	7.24±7.62	11.1±11.6	8.89±9.41	11.8±12.6	9.00±9.74	3.00
Coliforms (log)	ind/dl	7.42±7.79	5.83±5.86	6.93±7.39	8.67±9.03	6.52±6.67	10.4±10.9	8.04±8.49	8.85±9.64	7.82±8.43	3.30

[a] The Jakarta Governor regulation, No. 582/1995; these PVs are designed for category *B* rivers. Both *E. coli* and fecal coliform concentrations are presented in logarithmic form.

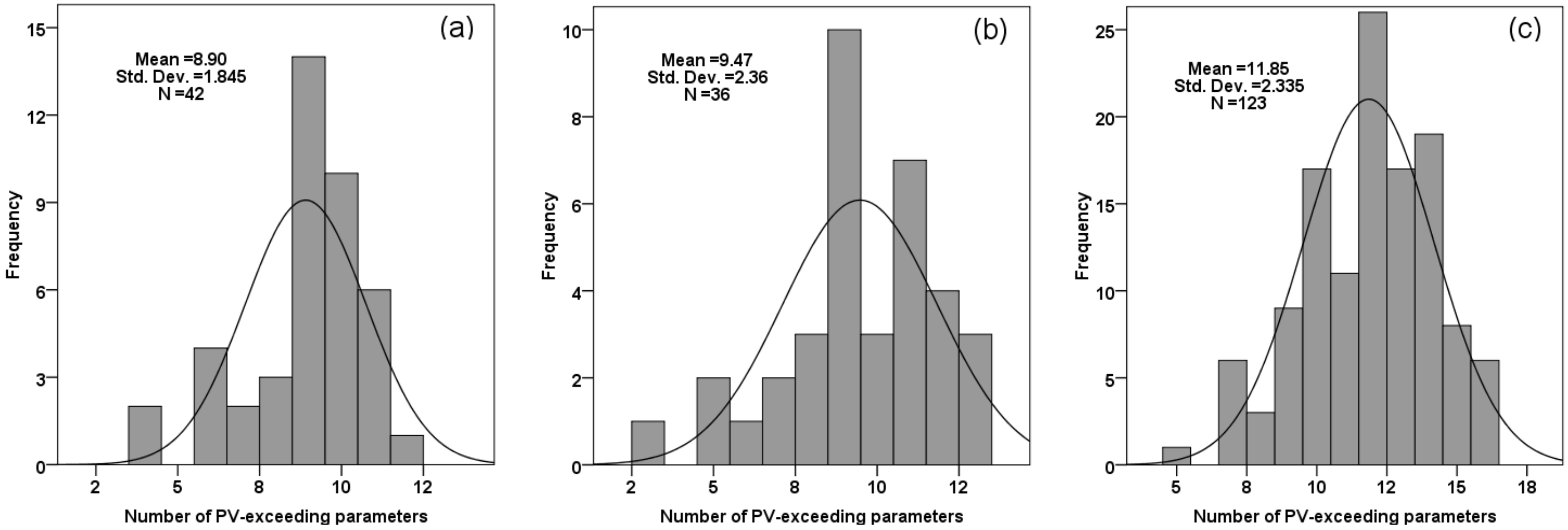


Figure 3-2: The frequency distribution of the number of permissible value (PV)-exceeding parameters in category *B* (a), *C* (b), and *D* (c) rivers obtained by compiling all of the data from all of the seasons.

The averaged concentrations (±SD; standard deviation) with the corresponding PV*s* for the category *B*, *C*, and *D* rivers during the three seasons (July 2007, November 2007, and August 2008) are summarized in Table 3-2. However, it is important to note that this table does not describe all of the data, because the eighteen parameters listed in this table are those for which the averaged concentrations in each category exceeded their PVs. In fact, each station has different parameter exceedances that may not be listed in the table because of the lower averaged concentrations in a certain category.

Before calculation of the WPI, the number of PV-exceeding parameters listed in Table 3-2 was used to describe the water condition in the rivers and ground aquifers. In this table, category *B* rivers had fewer average PV-exceeding parameters than category *C* and category *D* rivers. For example, during July 2007 (rainy season), the average numbers of PV-exceeding parameters were 9, 11, and 15 for category *B*, *C*, and *D* rivers, respectively. This result indicates that category *C* and *D* rivers had worse water conditions compared with those of category *B* rivers.

By compiling all of the data from all of the seasons, the mean values ± SDs of the number of PV-exceeding parameters were found to be 8.90 ± 1.84, 9.47 ± 2.36, and 11.85 ± 2.33 for categories *B*, *C*, and *D*, respectively, as is demonstrated in Figure 3-2. A two-way ANOVA test also showed significant differences among the river categories for all compiled seasons ($P < 0.01$).

The averaged concentrations and standard deviations for several parameters in category *C* and *D* rivers were also higher than those of category *B* rivers in all seasons, as shown by the concentrations of NH_3, $KMnO_4$, H_2S, oil and fat, COD, BOD, *E. coli* and fecal coliforms. Before the WPI calculation is presented, these results again provide a first impression that water conditions in category *C* and *D* rivers are worse than in those of category *B* rivers.

A similar analysis was performed to assess the groundwater condition. Figure 3-3 shows an example of the averaged groundwater parameters of 15 stations of the North Jakarta District in August 2008 (late dry season). Some parameters for which the averaged concentrations exceeded the corresponding PVs are TDS (586; 500 mg/l), Fe (1.70; 1.00 mg/l), Mn (0.84; 0.50 mg/l), $KMnO_4$ (1.37; 1.00 mg/l), log *E. coli* concentrations (4.30; 1.70 ind/dl) and log fecal coliform concentrations (6.35; 1.00 ind/dl). The list of parameters for which the averaged concentrations were above their corresponding PVs is given in Table 3-3. Again, the table represents only the averaged concentrations for each district, while the actual values and PV exceedances of the parameters may be different from one station to another. The table enables us to provide a general impression of the groundwater conditions. For example, the North Jakarta District had more PV-exceeding parameters, especially during August 2008 (late dry season), indicating worse water conditions compared with those of the other districts. However, an ANOVA could not be performed due to low frequencies of the PV-exceeding parameters. Thus, the groundwater condition was only statistically analyzed by calculating the WPI, which will be explained in the next section.

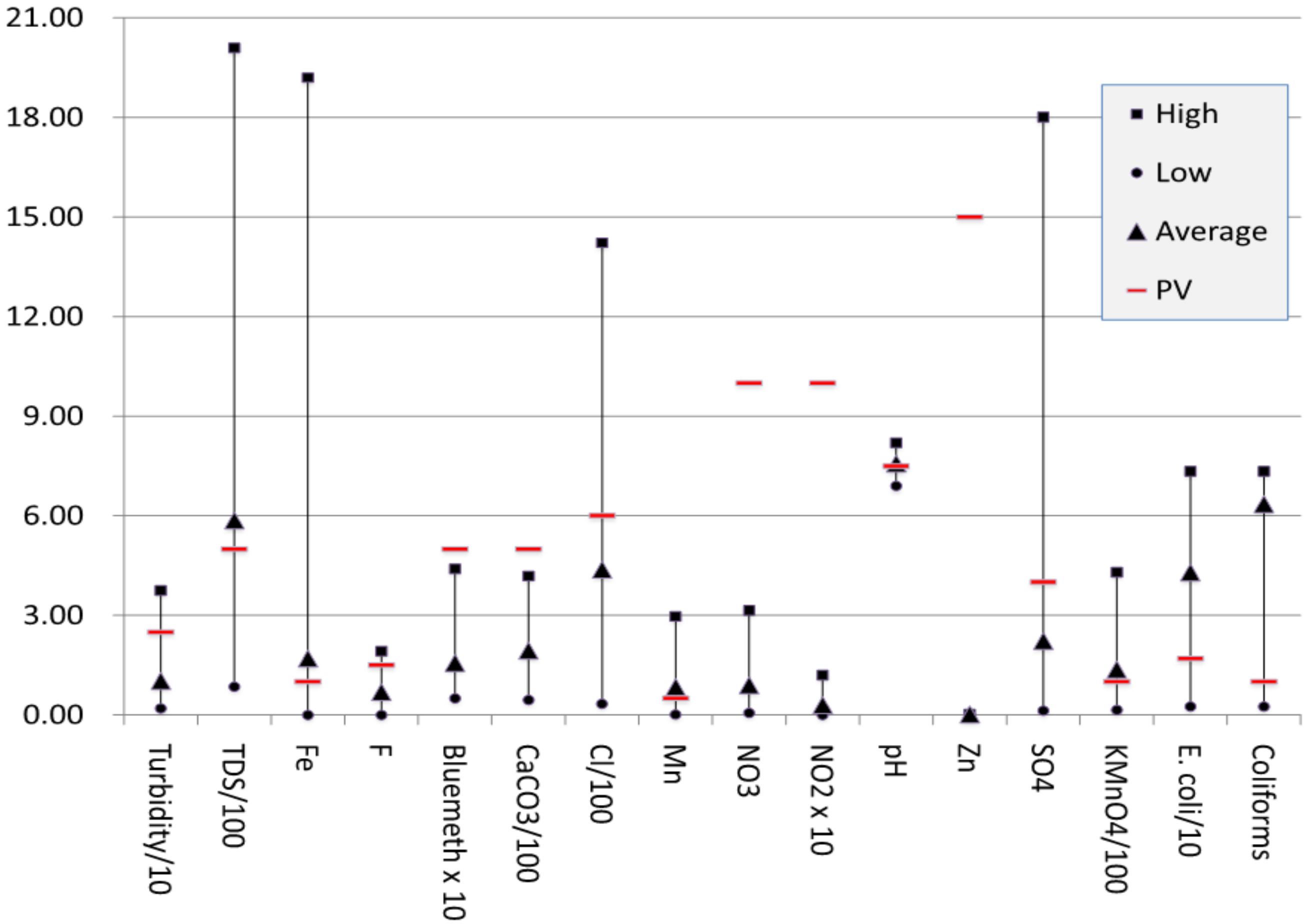


Figure 3-3: Concentrations of groundwater parameters measured from stations in the North Jakarta district in August 2008. The values are standardized within a comparable range.

Table 3-3: The averages, standard deviations and corresponding permissible values (PVs) of the groundwater parameters that have exceeded the PVs, presented by district for all seasons.

District (number of stations)	Season	Parameter					
		TDS ($\times 10^3$) (mg/l)	Fe (mg/l)	Mn (mg/l)	$KMnO_4$ (org) (mg/l)	*E. coli* (log) (ind/dl)	Coliform (log) (ind/dl)
South Jakarta (17)	Jul 07					5.01±5.59	4.98±5.59
	Nov 07					3.20±3.76	2.69±3.28
	Aug 08					3.02±3.26	2.44±2.71
East Jakarta (17)	Jul 07					4.77±5.36	4.29±3.73
	Nov 07			0.59±0.91		3.93±4.50	3.15±3.76
	Aug 08			0.56±0.88		3.77±4.29	3.09±3.56
Central Jakarta (11)	Jul 07			0.64±1.01		3.29±3.48	3.92±4.37
	Nov 07			0.54±0.99		4.52±5.02	3.15±3.76
	Aug 08		1.65±2.40	0.56±0.88		5.11±5.46	5.10±5.49
West Jakarta (17)	Jul 07					2.89±3.27	2.23±2.64
	Nov 07	5.27±6.65		0.62±0.48		6.05±6.64	5.51±6.10
	Aug 08		1.06±2.43	0.56±0.62		5.96±6.64	5.24±5.66
North Jakarta (15)	Jul 07	1.20±1.02		1.12±1.03		5.32±5.42	5.13±5.47
	Nov 07	7.66±5.91		0.70±0.70		5.20±5.64	5.01±5.52
	Aug 08	5.86±4.98	1.70±5.07	0.84±0.83	13.7±10.9	6.30±6.78	6.35±6.82
PVs [a]		0.50	1.00	0.50	10.0	1.70	1.00

[a] The Indonesian Ministry of Health regulation, No. 416/1990. Both *E . coli* and fecal coliform concentrations are presented in logarithmic form.

Table 3-4: The number of stations and percentages of stations classified into each river water pollution index class.

WPI	Number of stations (percentage)		
	July 2007	November 2007	August 2008
5.0 < WPI ≤ 10	0 (0.0%)	0 (0.0%)	2 (3.0%)
10 < WPI ≤ 15	26 (38.8%)	35 (52.2%)	25 (37.3%)
15 < WPI ≤ 20	24 (35.8%)	25 (37.3%)	33 (49.2%)
20 < WPI ≤ 25	15 (22.4%)	5 (7.5%)	5 (7.5%)
WPI > 25	2 (3.0%)	2 (3.0%)	2 (3.0%)
Total	67 (100%)	67 (100%)	67 (100%)

Table 3-5: The number of stations and percentage of stations classified into each groundwater pollution index class.

WPI	Number of stations (percentage)		
	July 2007	November 2007	August 2008
$0.0 < \text{WPI} \leq 1.0$	19 (25.3%)	20 (26.7%)	14 (18.7%)
$1.0 < \text{WPI} \leq 5.0$	24 (32.0%)	31 (41.3%)	30 (40.0%)
$5.0 < \text{WPI} \leq 10$	16 (21.3%)	12 (16.0%)	17 (22.7%)
$\text{WPI} > 10$	16 (21.3%)	12 (16.0%)	14 (18.7%)
Total	75 (100%)	75 (100%)	75 (100%)

3.1.4-2 Seasonal patterns of river and ground WPI

The summary of the overall results of river-WPI calculations, shown in Table 3-4, illustrates that most of the sampling stations were distributed from ‘highly polluted’ ($10 < \text{WPI} \leq 15$) to ‘the most extremely polluted’ (WPI > 25) during all seasons, with only 2 stations during August 2008 that were considered to have ‘moderately polluted water’. The table also indicates that the river-WPI*s* appeared to be better during the rainy season (November 2007) and worse during the dry season (July 2007 and August 2008).

Approximately 38.8% of the stations fall within the river-WPI range of $10 < \text{WPI} \leq 15$ (highly polluted water) during July 2007 (dry season). The percentage of this class increased to 52.2% in November 2007 (rainy season) and later decreased to 37.3% in August 2008 (late dry season).

Therefore, during the rainy season, more than 50% of the stations in this class exhibited lower pollution levels compared with during the dry seasons. Although this table indicates that the river-WPI*s* appeared to be slightly better during the rainy season (Figure 3-4a), statistically the river condition was not significantly different between seasons ($P = 0.39$) as proved by two-way ANOVA test.

The results of ground-WPI calculations depicted in Table 3-5 demonstrate that the sampling stations were distributed from ‘clean water’ to ‘highly polluted water’. The seasonal variations can also be observed in this table because the number of stations at which the ground-WPI fall above 5 (WPI > 5) were fewer during the rainy season than during the dry season. The percentage of this class was 32.0% during the rainy season (November 2007), but was higher during the dry season of July 2007 (42.6%) and the late dry season of August 2008 (41.4%). In contrast, 68.0% of the ground-WPI*s* fall below 5 (WPI < 5) during November 2007, while 57.3% and 58.7% of this class fall below 5 during July 2007 and August 2008, respectively.

Figure 3-5 illustrates the monthly precipitation during the years of 2007 and 2008 at the Cawang rainfall gauge, Jakarta, where the rain intensity in November 2008 was higher than that of July 2007 and August 2008. To support this data, a simple hydrological simulation model was conducted in the neighboring area (Ciujung watershed) to see the general pattern of rainfall intensity in that region. The model showed that the water debit and the corresponding rainfall intensity in Ciujung watershed also showed higher level values in November compared to those in July and August (Figure 3-6). The model proved that the seasonal variation occurred uniformly in a large region, including Jakarta city and its neighboring watersheds. This HSPF model was built from long procedures as that explained in detail in Appendix B.

Although more evidence is required, the rainwater supply may contribute to the lower percentage of polluted waters during rainy season through dilution within the rivers and infiltration in the ground layers. Several studies reported that the relationship between rainfall and water quality can differ from one area to another, depending on precipitation rate, urban landscape, upstream agriculture practices, and many other local characteristics (Bartram and Ballance 1996, Sampson *et al.*, 2006, Hill *et al.*, 2006). Additionally, every water parameter could also be different in its responses to rainfall intensity. Some parameters, such as TSS, alkalinity, and conductivity, are very sensitive, and some others may not be so responsive (Prathumratana *et al.*, 2008).

3.1.4-3 Spatial distribution of river and ground WPI

The overall average (±SD) river-WPI in category *B* rivers (13.89±2.88) was lower than that of category *C* (16.29±4.7) and *D* (16.87±4.1) rivers. To compare the pollution level of each river category, two-way ANOVA was applied to the river-WPI*s* (Table 3-6). The results revealed that the river-WPI*s* were significantly different among the river categories during each season ($P < 0.01$). The Tukey's HSD test confirmed that category

B rivers showed significant differences with category *C* ($P < 0.05$) and *D* rivers ($P < 0.01$) (Table 3-7 and Figure 3-4b). These findings and the previous findings about the number of PV-exceeding parameters lead to the conclusion that the rivers in category *B* were less polluted than those in category *C* and *D*. To some extent, the results support the government policy that water utility companies only use the water from the category *B* rivers as the source for drinking water because the other two river categories were proved to be more polluted.

Figure 3-7 illustrates the spatial distribution of the river-WPI*s* during the different seasons covered in this study. The red color gradation and circle size express the magnitude of water pollution, where a darker color and bigger circle-size represent a higher level of pollution, and vice versa.

The spatial and seasonal distributions of ground-WPI*s* can be identified from Table 3-8. For example, the percentages of the number of stations that fall within the ‘clean water’ class ($0.0 < \text{WPI} \leq 1.0$) in the South Jakarta District were 47%, 53% and 29% for July 2007, November 2007 and August 2008, respectively. These percentages explain that the majority of the stations in the district were still ‘clean’ during all seasons. The percentage of this class during the dry season appeared to be less than that of in the rainy season, implying a higher pollution level.

In contrast, the majority of the stations in the North Jakarta District fall within the ‘highly polluted water’ ($\text{WPI} > 10$) during all seasons, with 60%, 40% and 57% falling in this class for July 2007, November 2007 and August 2008, respectively. The percentage of the number of stations in this class was also higher in the dry season, implying there was more pollution in that season compared with the rainy season. These findings again suggest the presumable impact of the rainfall intensity on the reduction of groundwater pollution during the rainy season.

The overall average (±SD) ground-WPI for South, East, West, Central, and North Jakarta were 2.79 ± 3.84, 3.72 ± 3.84, 4.08 ± 4.41, 6.01 ± 4.9, and 10.6 ± 5.7, respectively. A two-way ANOVA test showed significant differences in pollution among the districts for all seasons ($P < 0.01$) (Table 3-6). However, although slightly better in the rainy season, statistically the water condition was not significantly different between seasons ($P = 0.27$). The Tukey's HSD test confirmed that ground water condition in the North Jakarta District were significantly different with those of the other four districts ($P < 0.01$) (Figure 3-8), also the water condition in the Central Jakarta District showed significant difference with the one in the South Jakarta District ($P < 0.05$) (Table 3-7).

The North Jakarta District exhibits the highest level of groundwater pollution. This result can be explained by the following two facts: first, the district is close the coastal area of the Jakarta Bay, so it is susceptible to the seawater intrusion (Schmidt *et al.*, 1988, Douglas 2005); second, the North Jakarta District lies in a location into which all of the rivers in Jakarta flow, so the area receives and accumulates pollutants from other regions.

Figure 3-9 displays the groundwater pollution index at different seasons yielded from the study. The figures demonstrate how the pollution levels are distributed within the city and highlight the fact that the southern part of the city contains far fewer polluted stations compared with the central and northern regions.

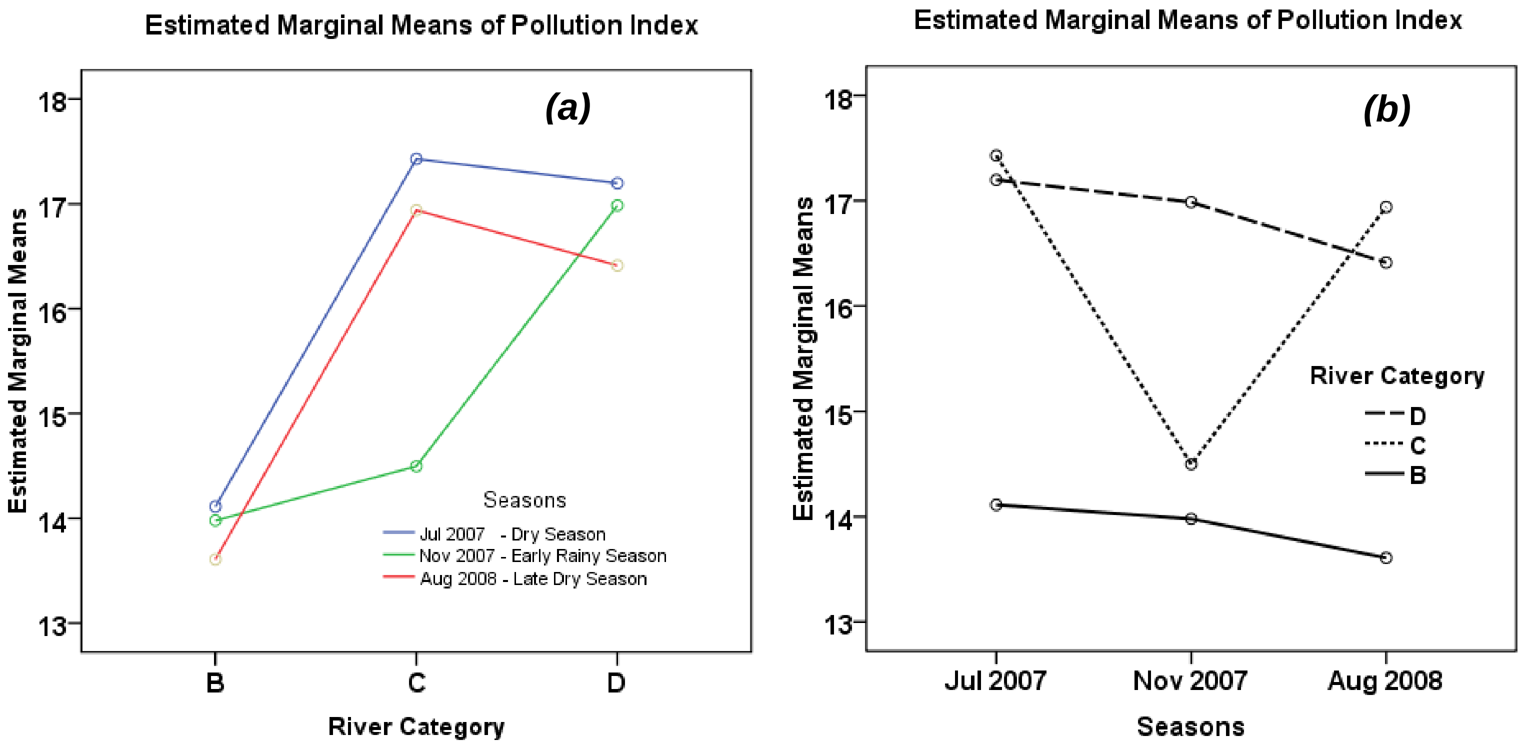


Figure 3-4: Estimated marginal means of the river water pollution index between seasons (a) and between river categories (b).

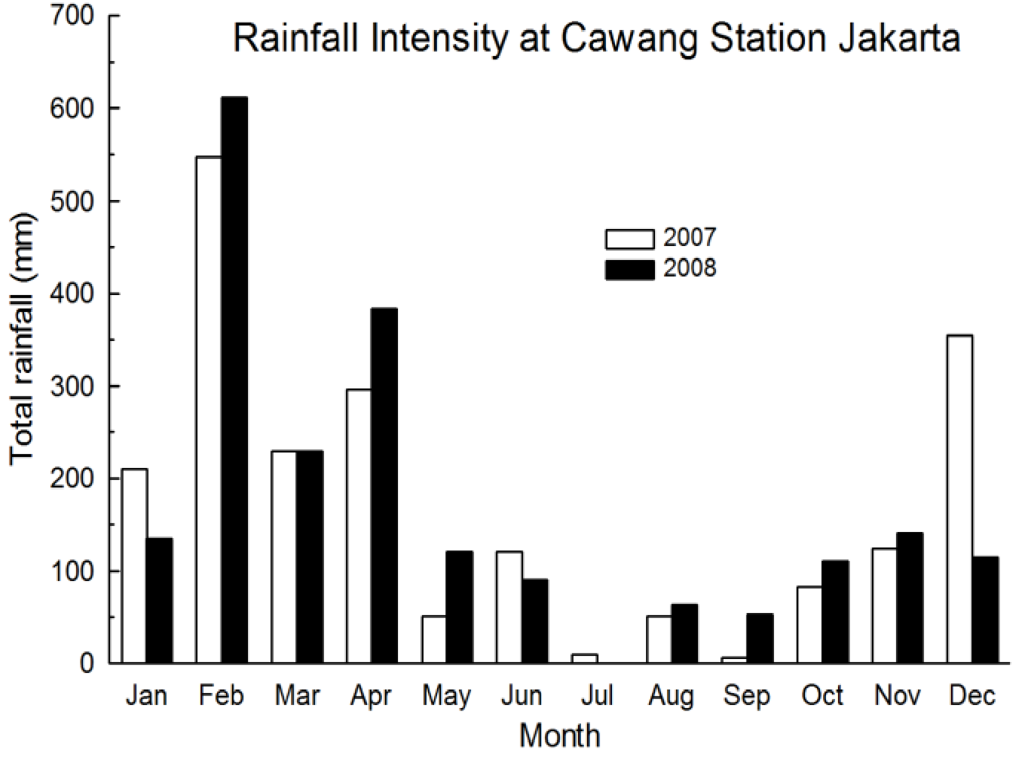


Figure 3-5: Monthly changes of precipitation (mm) during 2007 and 2008 at the Cawang rainfall gauge, Jakarta.

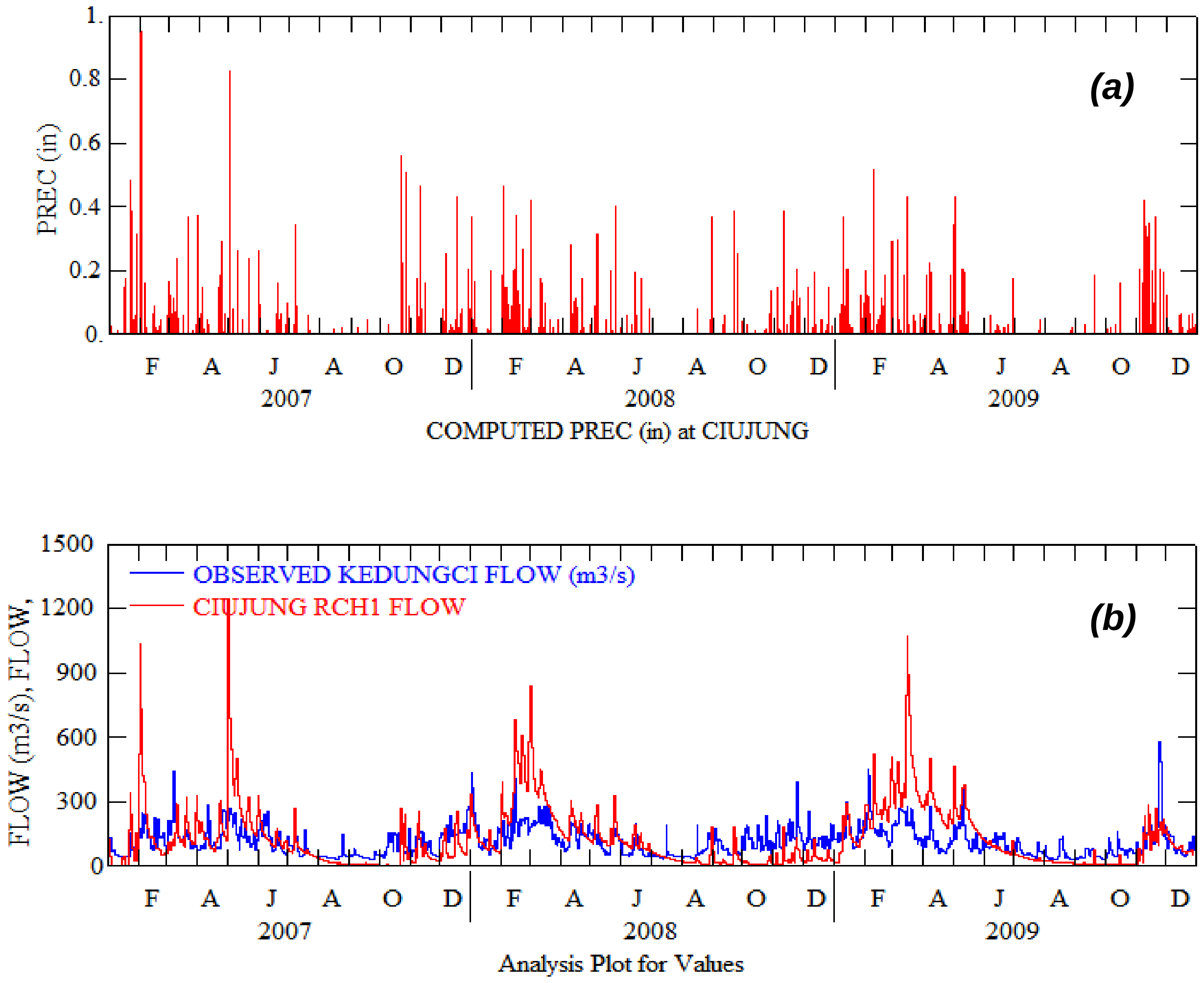


Figure 3-6: Hydrological simulation model of precipitation (a) and water debit (b) in the neighboring watershed (Ciujung watershed) from the data collected during 2007 – 2009.

Table 3-6: The outputs obtained from two-way ANOVA tests for river- and ground water pollution index (WPI).

	Type III Sum of Squares	**d.f.**	**Mean Square**	**F**	***P*-value**
River water					
River_categories	276.39	2	138.20	8.60	<0.01
Seasons	30.06	2	15.03	0.94	0.39
Seasons*River_categories	54.13	4	13.53	0.84	0.50
Error	3086.42	192	16.08		
Total	55814.67	201			
Groundwater					
Jakarta_districts	1766.33	4	12.86	21.22	<0.01
Seasons	54.66	2	27.33	1.31	0.27
Seasons*Jakarta_districts	102.86	8	20.81	0.62	0.76
Error	4349.77	209			
Total	12523.55	224			

Table 3-7: The outputs obtained from Tukey' Honestly Significance Difference (HSD) tests for river- and ground water pollution index (WPI).

	Mean Difference	**Standard Error**	***P*-value**
River water (river category)			
Category B vs. Category C	-2.39	0.91	<0.05
Category B vs. Category D	-2.97	0.72	<0.01
Category C vs. Category D	-0.58	0.76	0.729
Groundwater (Jakarta districts)			
North vs. West	6.55	0.97	<0.01
North vs. Central	4.62	1.05	<0.01
North vs. East	7.03	0.94	<0.01
North vs. South	7.69	0.94	<0.01
South vs. Central	3.07	1.02	0.02

Table 3-8: The number of stations and percentages of stations classified into each groundwater pollution presented by district comparison.

District (number of sampling stations)	Number of stations (percentage)											
	Clean (good)			Slightly polluted			Moderately polluted			Highly polluted		
	Jul 07	Nov 07	Aug 08	Jul 07	Nov 07	Aug 08	Jul 07	Nov 07	Aug 08	Jul 07	Nov 07	Aug 08
North Jakarta (15)	1 (7)	1 (7)	0 (0)	0 (0)	2 (13)	4 (29)	0 (0)	6 (40)	2 (14)	9 (60)	6 (40)	8 (57)
West Jakarta (15)	3 (20)	4 (27)	2 (13)	10 (67)	8 (53)	7 (47)	10 (67)	2 (13)	5 (33)	0 (0)	1 (7)	1 (7)
Central Jakarta (11)	1 (9)	1 (9)	2 (18)	5 (45)	6 (55)	4 (36)	5 (45)	1 (9)	1 (9)	3 (27)	3 (27)	4 (36)
East Jakarta (17)	6 (35)	5 (29)	4 (24)	5 (29)	9 (53)	7 (41)	5 (29)	2 (12)	5 (29)	2 (12)	1 (6)	1 (6)
South Jakarta (17)	8 (47)	9 (53)	5 (29)	4 (24)	6 (35)	8 (47)	4 (24)	1 (6)	4 (24)	3 (18)	1 (6)	0 (0)

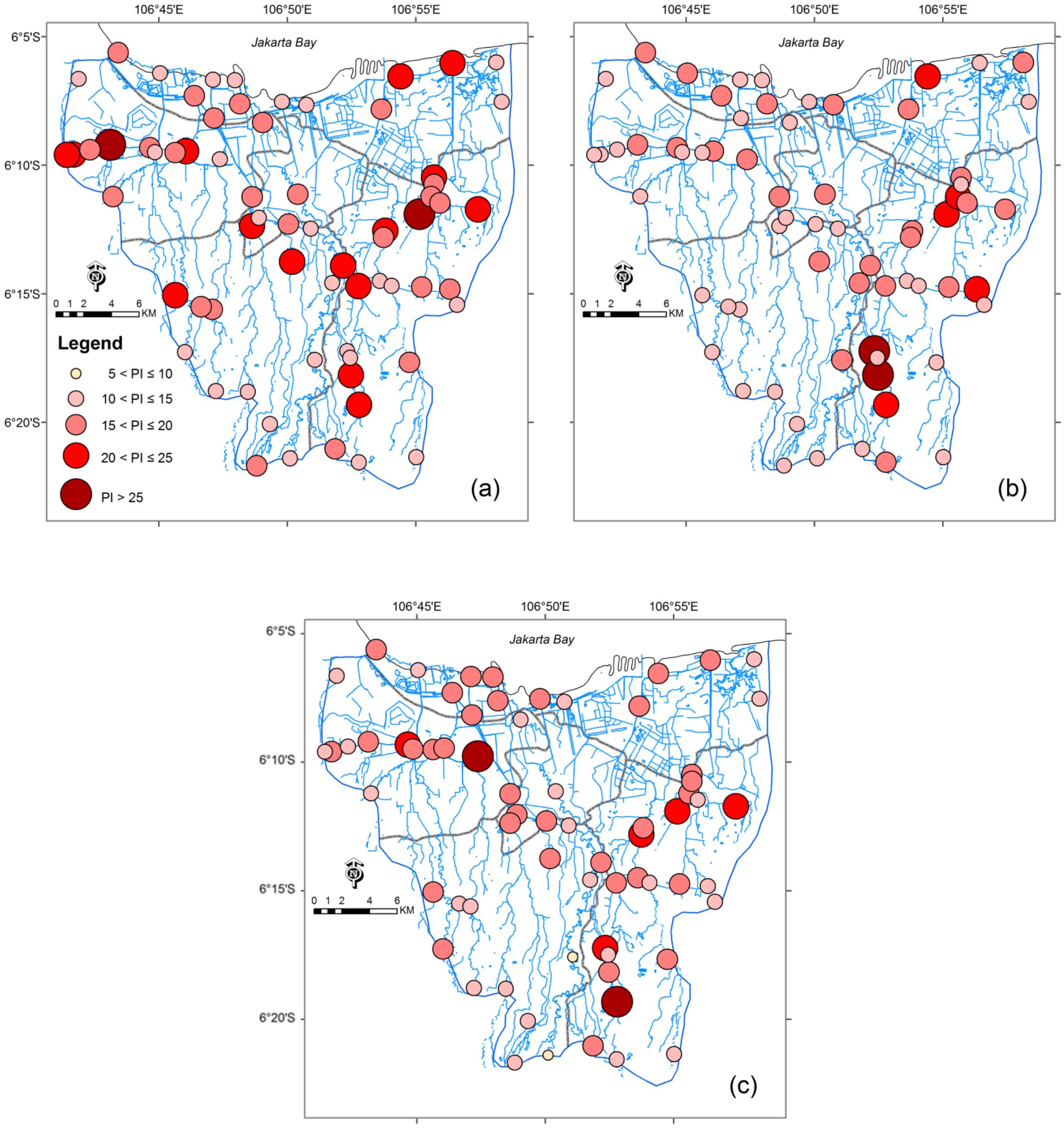


Figure 3-7: Spatial distribution of river-water pollution indices in the city of Jakarta during the (a) dry season (July 2007), (b) early rainy season and (November 2007) and (c) late dry season (August 2008).

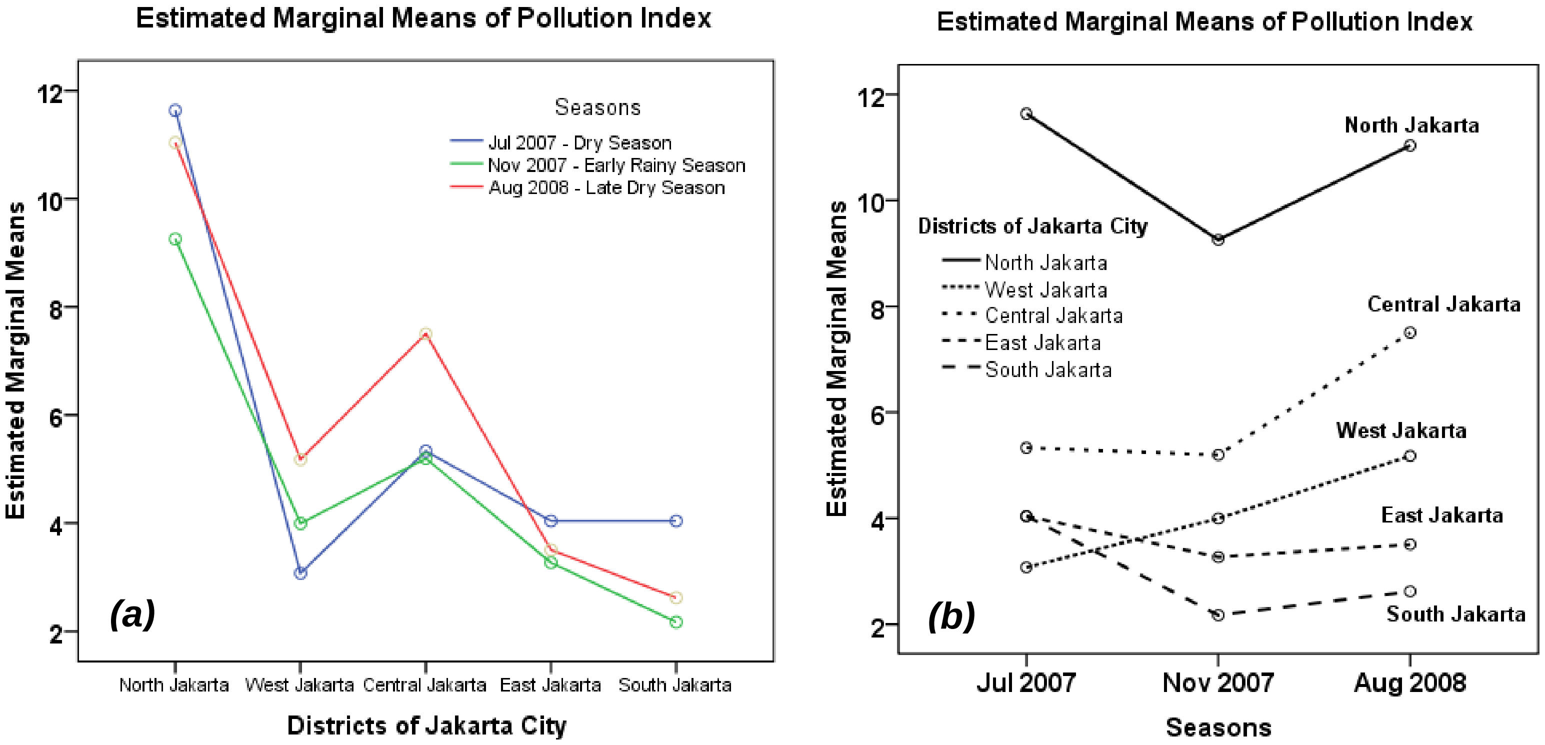


Figure 3-8: Estimated marginal means of the ground water pollution index between seasons (a) and river categories (b).

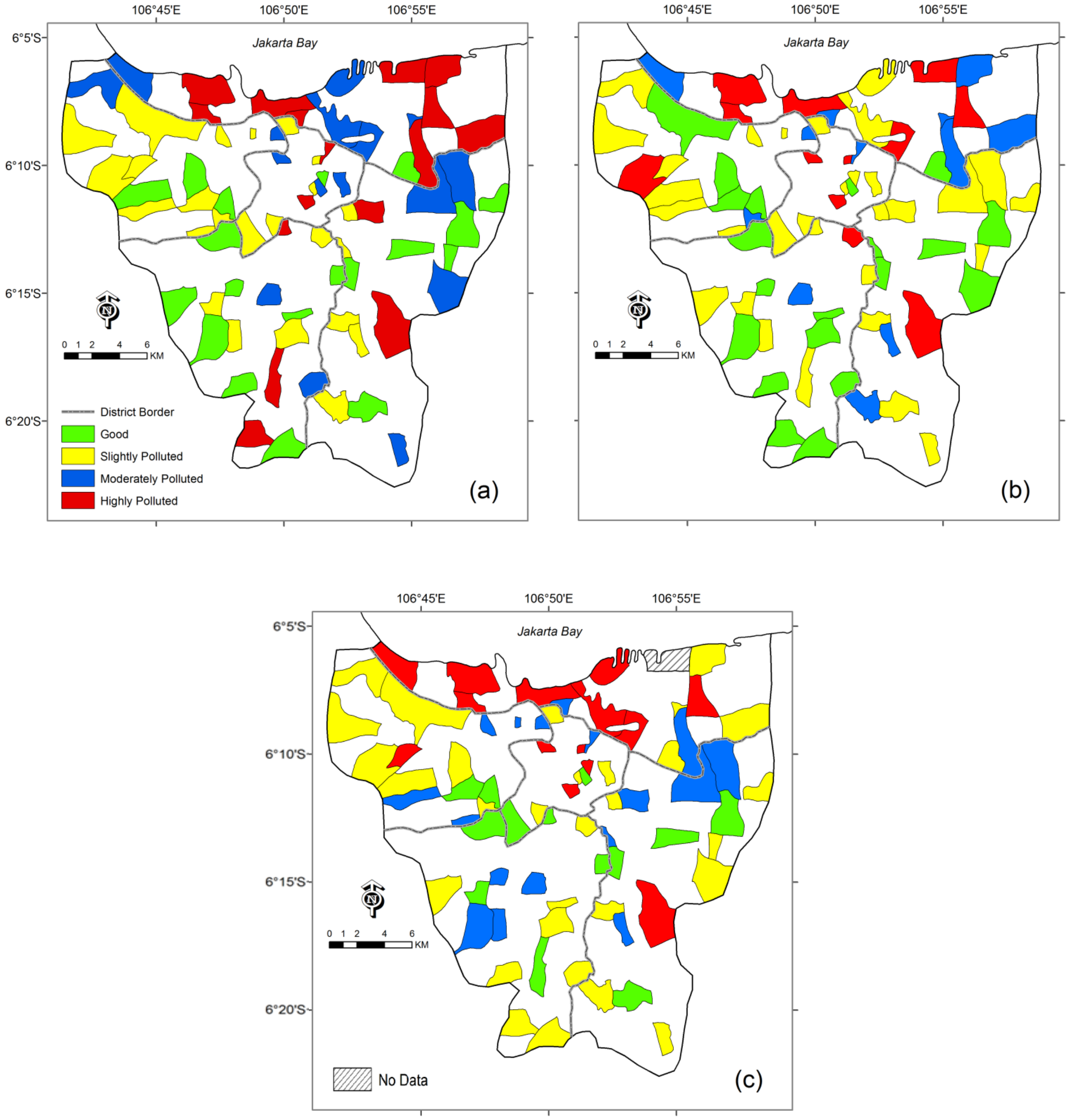


Figure 3-9: Spatial distribution of groundwater pollution indices in the city of Jakarta during the (a) dry season (July 2007), (b) early rainy season and (November 2007) and (c) late dry season (August 2008).

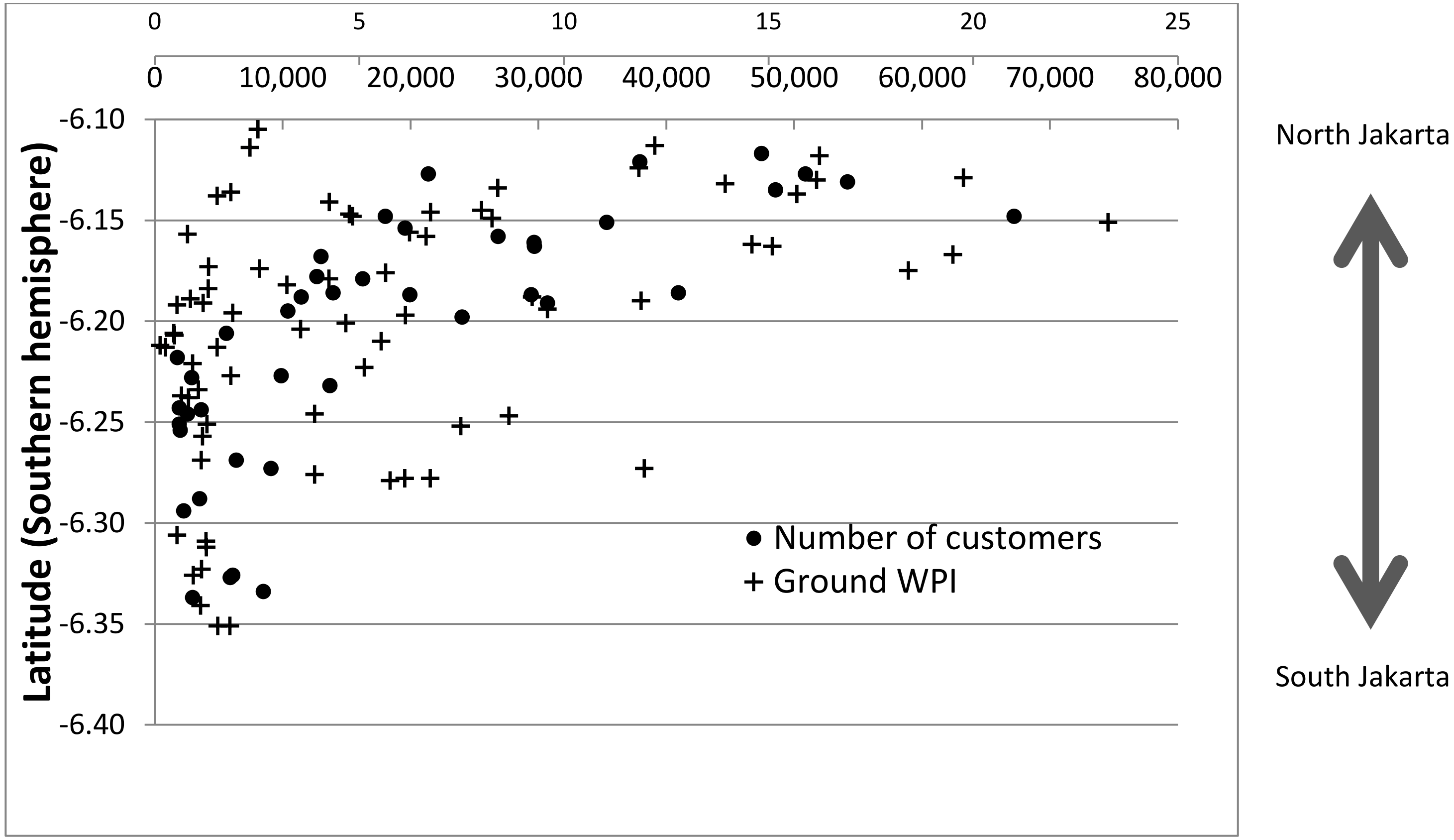


Figure 3-10: The groundwater pollution index plotted over the number of customers of the Jakarta water company (PD. PAL JAYA) in 2009. More customers found towards the northern parts of Jakarta as respect to the pollution level of the groundwater.

Finally, when the groundwater pollution index at each station was plotted over the number of customers of Jakarta water company (PD. PAL JAYA) in 2009 at each sub district, it could answer why the number of customers in the North Jakarta is higher than that of in the South Jakarta (Figure 3-10). It is of course due to the higher pollution level of the groundwater in the North Jakarta. It could be concluded that people in North Jakarta depend very much on the water company, while people in South Jakarta could still get the water by direct pumping from ground water.

3.1.4-4 River fluxes in Jakarta river systems

Understanding the whole river systems in Jakarta city is very important for water quality management, because river discharge plays important role not only for the quality of groundwater but also for seawater in the Jakarta Bay (Koropitan *et al.*, 2009; Kagabu *et al.*, 2012). Ciliwung river, the main river in Jakarta river systems, has become an urban watershed where many development activities have taken place in both upstream and downstream, resulting excessive entry of pollutants from domestic, industrial, agricultural and livestock sources.

A study regarding total pollution load and river carrying capacity using QUAL2Kw program in Ciliwung river has been done by Moersidik (JICA report: unpublished), especially on the loads of DO, BOD and COD. The report summarizes that the averaged DO concentration at the upstream river ranged from 6.1 to 10.3 mg/l; reduced to 3.9 to 9.2 mg/l in the middle river and decreased further to 0.6 to 3.1 mg/l in the downstream area. The smaller the DO concentration in the downstream is, the greater the BOD concentration, and vice versa.

The pollution in the groundwater is another concern of Jakarta city. The pollution is caused by the excessive usage of groundwater and the infiltration of river and seawater. Kagabu *et al.* (2012) reported that the greater groundwater flux is ‘vertical downward flux', which means that the shallower groundwater intrudes into the deep one because of excessive ground water pumping since last few decades. The groundwater potential is expected to be more effected by shallow groundwater that is highly polluted by urban contaminants. At the same time, seawater intrusion in the coastal area of North Jakarta increased significantly.

3.1.5 Conclusions

In this study, we investigated the spatio-seasonal patterns of river- and groundwater in the city of Jakarta, Indonesia, using the Nemerow-Sumitomo Water Pollution Index (WPI). The evaluation of water resources in Jakarta is very important because many residents still heavily depend on groundwater resources, which they extract by direct self-pumping; hence, continuous consumption of this water may introduce some health risks. The water quality is influenced by factors such as the seasons and the location relative to the pollution sources, so the quality may differ in time and space. To evaluate the water quality in the city, the Jakarta Environmental Management Board (BPLHD) conducted river- and groundwater sampling in July 2007 (dry season), November 2007 (early rainy season) and August 2008 (late dry season). During each season, 67 river water and 75 groundwater samples were collected from stations throughout the city, and approximately 32 biophysicochemical water parameters were measured at each station. This study has proved that the river water in Jakarta was indeed highly polluted and that most of the stations were already beyond the critical level. The groundwater conditions were better, but some stations were already highly polluted.

The spatio-seasonal pattern of both river- and groundwater pollution in the city can be established from the results of the study. The water pollution index (WPI) for both water resources appeared to be higher toward the northern region especially in the dry season. Therefore, it is recommended that the city residents be more careful about their consumption of water from groundwater aquifers extracted by self-pumping, particularly in the northern regions and during the dry season. The causal relationship between river- and groundwater pollution in the city of Jakarta is another topic to be investigated in the future.

3.2 Emerging trends in economic development and river water quality in Banten Province, Indonesia: One decade after decentralization policy implementation (2000-2010)

(Submitted to the International Journal of Sustainable Development & World Ecology).

3.2.1 Introduction

The decentralization (autonomy) policy has been implemented in Indonesia since 1999 (Seymour and Turner, 2002). Since then, eight new provinces have been established, including Banten Province, to add up a total number of 33 provinces. By this policy, each province has its own freedom to self-govern and manage their budget and development planning with less interference from the central government (Yonariza and Shivakoti, 2008). By 2011, this policy has resulted in the creation of new economic regions (Firman, 2011).

For some countries, economic development is like a coin. It has two side effects; one side can create regional development that leads to human prosperity, and the other side can create environmental quality degradation and land cover change (Abdullah and Nakagoshi, 2006; Hasse and Lathrop 2003; Stagl, 1999). The negative effects of regional development can actually be minimized by good management (Collin and Melloul, 2003; Chakrabarty, 2001), but in most cases especially in developing countries, this is what usually too complex to be implemented (Rakodi, 2001). Jakarta city and Ciliwung watershed is an example wherein economic development and environmental degradation, *i.e.,* air and water pollution, show strong negative correlation (Suwandana *et al*., 2011; Colbran, 2009; Steinberg, 2007).

In the frame of promoting sustainable development, an evaluation on water quality and environmental degradation has to be done parallel with the improvement of economic sectors. The negligence in doing such a work may create other cities like Jakarta, where the rehabilitation of river water quality has become too late. This study was focusing on the investigation of water quality in Ciujung River using descriptive statistic and multivariate analyses. The analysis on economic development of Banten Province was also discussed to see the impact of decentralization policy implementation in this province. So far, there was no such study has been done in Indonesia, which the result from this study would be useful for the improvement of the environmental management programs.

3.2.2 Objectives

The objective of this study is to investigate the water quality in Ciujung River using descriptive statistic and multivariate analyses. In addition, the analysis on economic development of Banten Province was also discussed to see the impact of decentralization policy implementation in this province. This study is expected to provide information for the local government regarding the current status of Ciujung River and to take any necessary action for protecting the environmental quality in harmony with the economic development.

3.2.3 Materials and methods

3.2.3-1 Study area

Banten Province, located in the west part of Java Island, constitutes several big rivers including Ciujung River. Mount Halimun, lying at an elevation of 1850 m, is the originating point of Ciujung River and the water flow ends up in the Banten Bay. The river has approximately 63 km long and passes through many villages and one big city (Rangkasbitung). The river is an integration of some small rivers, including Ciberang, Cisimeut, Cilaki and Cibogor rivers. All of these rivers altogether shape up the Ciujung watershed which covers a hydrological area of approximately 1,915 km^2.

Compared to Ciliwung watershed, where includes some urban cities (Jakarta, Bogor, Cibinong and Depok), Ciujung watershed is still considered as rural area. The upper most part of the watershed is still covered by a conserved natural forest and the area in downstream is mostly used for agriculture activities. However, the population increase and economic development have started stimulating the changes in land use and land cover throughout the watershed. Some new industries were established along the Ciujung River and several new residential places and real estates were constructed in some cities, such as Rangkasbitung, Pandeglang and Serang.

3.2.3-2 Economic data

Selected social economic data were obtained from the Statistical Office of Banten Province (BPS Banten). The analysis of each economic indicator was compared with the same indicator in the national level. The focus of the analysis was on the economic data after the implementation of decentralization policy (2000–2010).

3.2.3-3 Water quality data

Composite water quality measurement has been regularly carried out at nine stations of Ciujung River in monthly basis by the Water Resources Office of Banten Province since 1998. The determined stations have been considered to represent upstream, middle stream and downstream area of the river, as those presented in Figure 3-11. At the each station, 41 water quality parameters were measured. However, only the data recorded from 2000–2010 were used in the analysis. Meanwhile, in the multivariate statistics analysis, only 25 water parameters recorded from 2005–2010 were analyzed, due to the continuity of the data.

3.2.3-4 Statistical analysis

Descriptive statistics were performed to describe the water quality condition in the study site and to see the trend of each water parameter during 10-year observation. We used the standard limits from the Indonesian Government Decree No. 82/2001 regarding water quality management and water pollution control. An intensive analysis was focused on the lower most station in the downstream area (station no. 9), because the station is believed to receive and accumulate pollutants from the entire upstream stations. The range, mean and standard deviation of water quality data of Ciujung River is presented in Table 3-9.

However, descriptive statistics cannot explain the relationship between water parameters, due to complexity of the data. Hence, multivariate statistics were applied to explore more about the data and to find if any meaningful unexplained information. Multivariate statistics are able to figure out beneficial information which may not be able to be overcome by simple statistics (Li *et al*., 2009; Zhao and Cui, 2009; Shrestha and Kazama, 2007). In water quality studies, multivariate statistical techniques, such as cluster analysis (CA), principal component analysis (PCA) and factor analysis (FA), help in the interpretation of the complex database and offer a reliable understanding of spatio-seasonal relationships and hydrochemistry processes (Shrestha and Kazama 2007; Simeonov *et al.*, 2004).

CA is a wide range of multivariate techniques for explanatory data analysis whose main purpose is to assemble variables into clusters based on similarities (or dissimilarities) with respect to some predetermined selection criteria (Zhao and Cui, 2009; Shrestha and Kazama, 2007). The cluster characteristics are not known prior to the analysis, but may be apprehended from the results (Singh *et al.*, 2004). PCA is designed to transform the original variables into new, uncorrelated variables (axes), called the principal components. FA is designed to reduce the contribution of less significant variables to simplify even more the data structure resulting from PCA by rotating the axis defined by PCA, according to well established rules. This process constructs new variables, so-called varifactors (VF) as the main outputs of FA. PC is a linear combination of the original observed water quality variables, whereas FA can include unobservable, hypothetical, latent variables (Helena *et al.*, 2000; Vega *et al.*, 1998).

In this study, we performed hierarchical CA technique in SPSS version 16.0 on the normalized (z-score) water quality data by the means of Ward's method using Euclidean distances as a measure of similarity. Data normalization is important to avoid miss classification, eliminate the influence of different units of measurements and render the data dimensionless (Zhao and Cui 2009; Liu *et al.*, 2003). The CA was applied on the average monthly data of six years (2005–2010). An agglomerative dendrogram was produced, elucidating the seasonal similarities, where the distance between clusters was determined by the linkage distance, denoted by $D_{\text{link}}/D_{\text{max}}$.

Meanwhile, PCA and FA were performed on the standardized full water quality dataset. Previously, Kaiser-Meyer-Olkin (KMO) and Barlett's test was performed on the datasets to examine the suitability (sphericity) of the data for PCA/FA. High value of KMO test (close to 1) normally indicates the adequacy of the data to be subjected for PCA/FA. The significance level which is 0 in this study (with KMO test value = 0.727) indicates the significant relationships among the variables. The PCA/FA was forced to extract five PCs with Eigenvalues > 1 summing almost 56% of the total variance in the datasets and the data was rotated using Varimax rotation method.

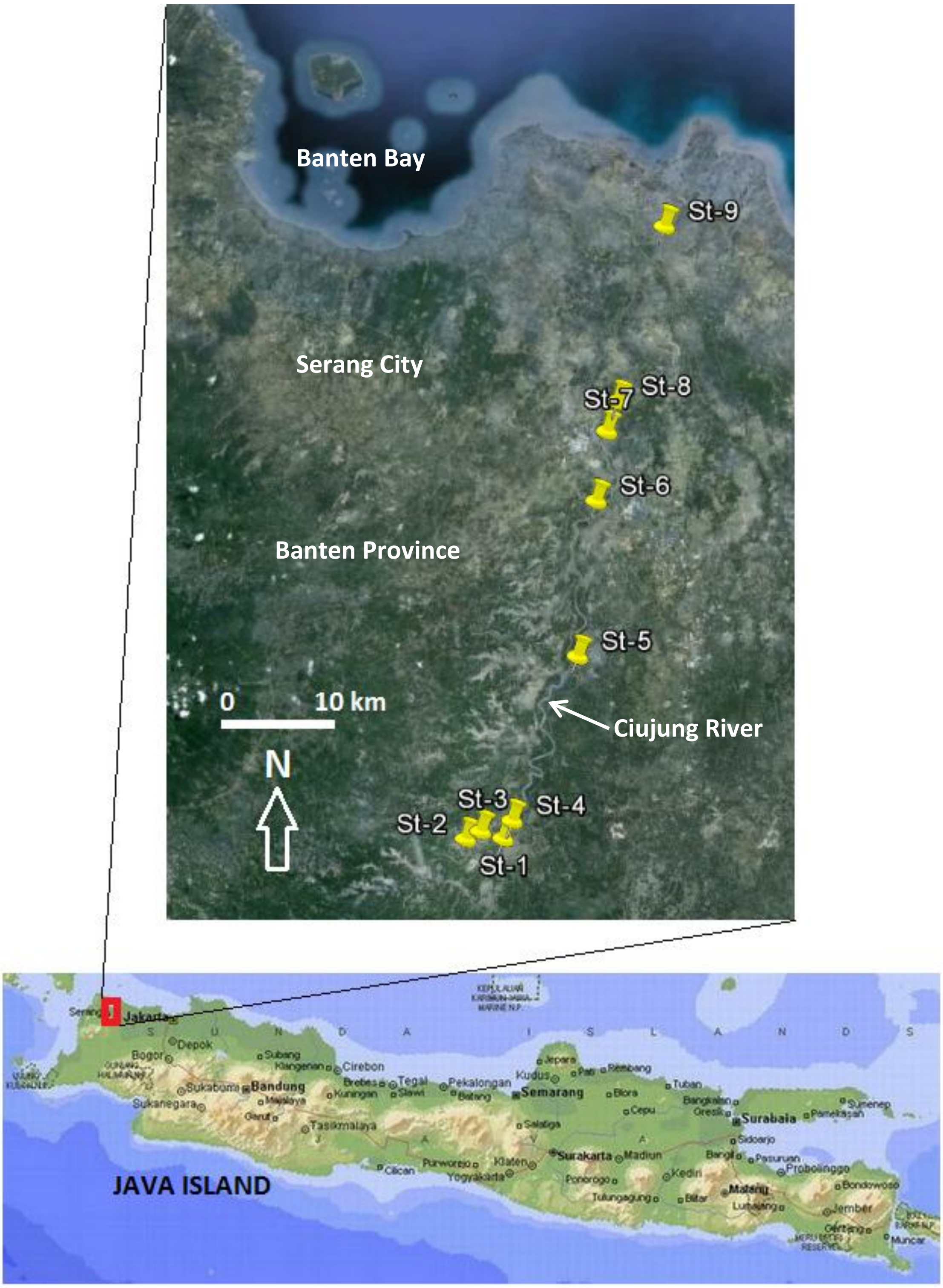


Figure 3-11: Water quality stations in Ciujung River.

Table 3-9: Minimum, maximum, mean and standard deviation of water quality parameters of Ciujung River compiled from 9 stations during 2000 – 2010.

Parameter	Unit	Min	Max	Mean	Standard deviation	Coefficient of variance (%)
Temperature	ºC	21.600	34.800	28.455	1.551	5.451
Electrical conductivity	µS/cm	7.400	9720.000	276.475	922.485	333.659
TDS	mg/l	23.00	5340.000	135.947	446.186	328.206
Salinity	%	0.000	17.600	0.165	1.037	628.485
Turbidity	NTU	2.300	722.000	111.955	135.950	121.433
pH	-	5.520	9.410	6.761	0.448	6.626
Alkalinity	mg/l $CaCO_3$	2.100	282.800	41.049	34.712	84.562
DO	mg/l	0.421	7.449	4.101	1.031	25.140
COD	mg/l	0.909	646.800	37.082	35.511	95.763
BOD	mg/l	0.168	30.210	2.426	3.509	144.641
Chloride	mg/l	0.485	5825.000	46.068	330.542	717.509
Nitrate	mg/l	0.021	18.547	2.724	2.082	76.432
Nitrite	mg/l	0.002	1.861	0.138	0.216	156.522
Sulfate	mg/l	0.024	250.478	12.143	24.383	200.799
Iron	mg/l	0.001	3.015	0.520	0.529	101.731
Copper	mg/l	0.001	0.095	0.009	0.007	77.778
Escherichia coli	Colony / 100 ml	400.000	460000.000	40629.966	44058.798	108.439
TSS	mg/l	9.500	779.500	109.387	134.054	122.550
Total hardness	mg/l	6.000	1920.000	74.751	107.633	143.989
Calcium	mg/l	0.600	262.000	18.034	22.057	122.308
Manganese	mg/l	0.061	155.520	8.436	11.359	134.649
KMnO4	mg/l	0.239	97.961	11.703	8.667	74.058
Chromium	mg/l	0.000	0.029	0.008	0.008	100.000
Lead	mg/l	0.000	0.081	0.007	0.007	100.000
Zinc	mg/l	0.002	0.968	0.038	0.146	384.211

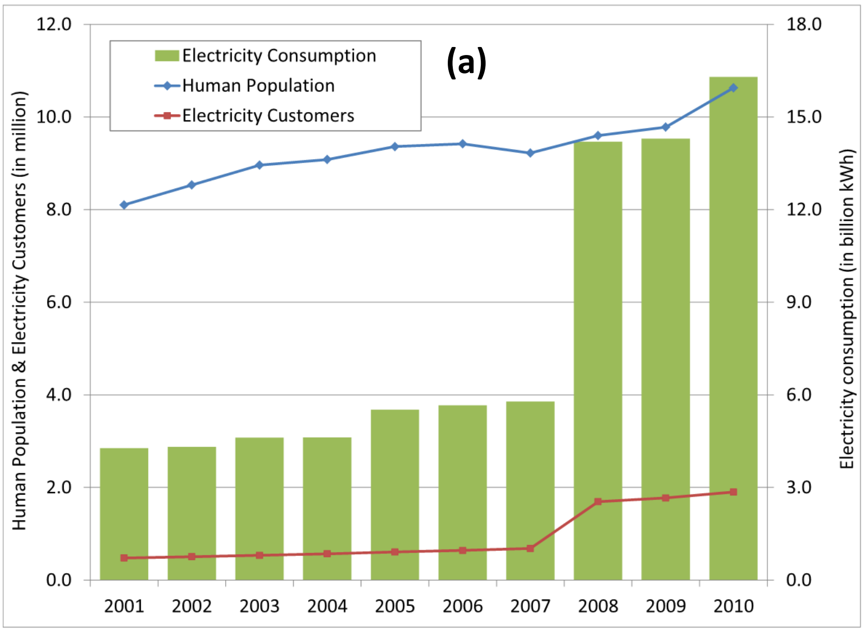
3.2.4 Results and discussion

3.2.4-1 Socio-economic development

In the last ten years, the human population in Banten Province has increased from 8 million to 10.6 million with a birth rate of 2.78 (Figure 3-12a). The population growth stimulated the production increase in agriculture sector. Figure 3-12b shows the increase in some commodities (rice, chickens and ducks). For the last decade, the production increase has reached an average of 0.18 million ton·year^{-1}, 2.82 million ton·year^{-1}, 0.71 million ton·year^{-1}, 0.35 million ton·year^{-1} and 0.11 million ton·year^{-1}, corresponding to paddy, chicken broilers, chicken broilers (native species), chicken egg layers, and ducks.

The population growth has also a positive implication in the increase of electricity customers from 444,924 to more than 1.9 million customers (Figure 3-12a). Consequently, the need of electricity consumption has risen from 4.27 billion kWh to 16.3 billion kWh, in which a significant leap occurred in 2008. Besides household consumption, the number of new established factories has given much contribution to the need of electricity.

Regional development in Banten Province has shown a good performance (Figure 3-13). The value added of industry (VAI) of Banten Province has also increased from USD 3.18 billion in 2001 to USD 9.34 billion in 2010. The VAI, also referred to gross domestic products (GDP)-by-industry, has contributed to more than 50% of the province's total GDP, which has increased from USD 5.73 billion to USD 16.22 billion during the last decade (all figures are estimated at the rate of USD 1 = Rp 9,158). In turns, the provincial GDP has contributed to approximately 14.75% of the total national budget in 2010. At the end, the prosperity of Banten people can be observed from their expenditure per capita which increased from USD 66.19 in 2001 to USD 68.56 in 2010. With these achievements, Banten Province is considered to be one of prospective provinces in Indonesia in the last decade.



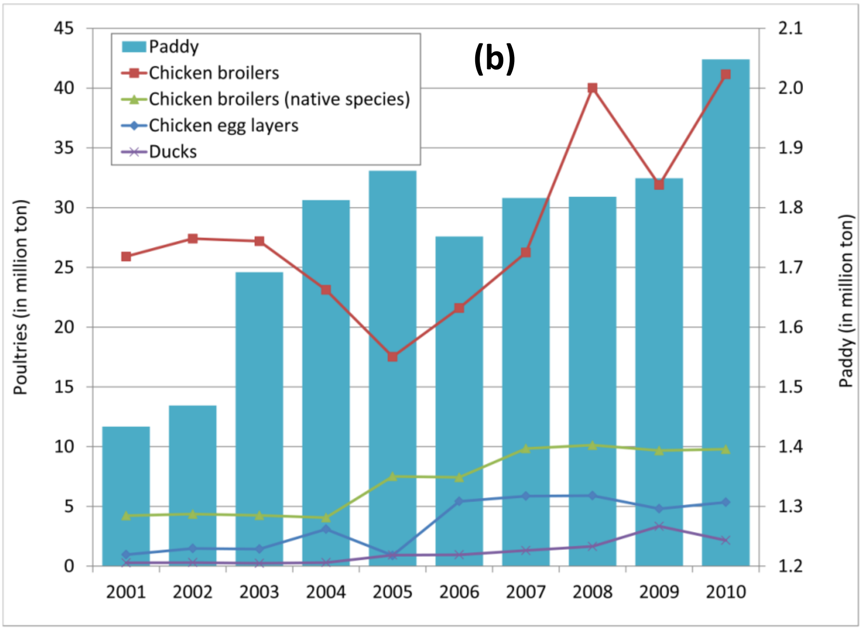


Figure 3-12: Trends of human population, electricity customers, electricity consumption (a) and some agriculture commodities (b) in Banten Province during the period of 2001 – 2010 (raw data from derived from the Statistical Office of Banten Province).

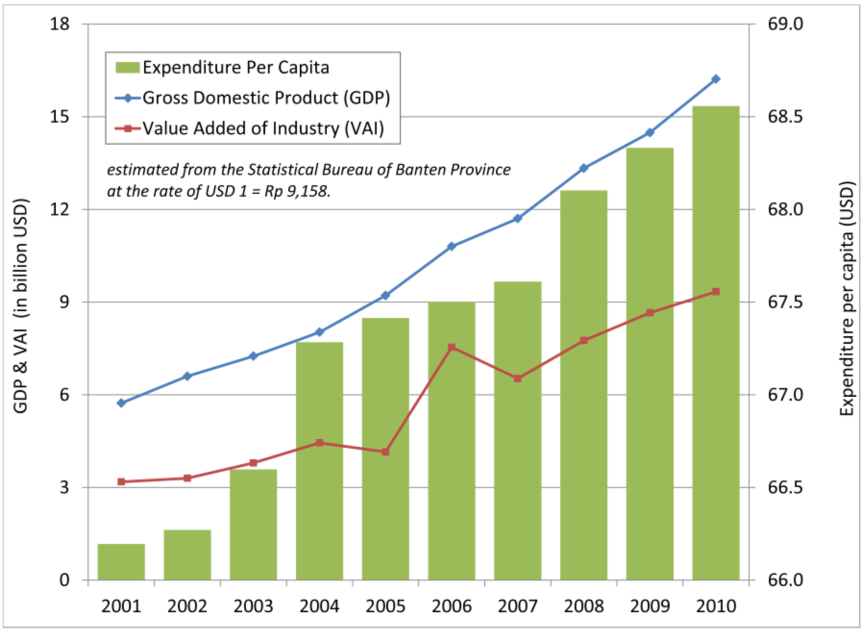


Figure 3-13: Some macroeconomic development indicators in Banten Province during the period of 2001 – 2010 (raw data from derived from the Statistical Office of Banten Province).

3.2.4-2 River water quality

All water quality stations in this study were located at the same river tributaries, hence the last station in the downstream area (Jongjing station) would receive pollutants from the upstream stations. In the first part of analysis, we therefore explored the water quality data at Jongjing station, the lower most station in the downstream area, to assess the accumulation of water pollution brought by Ciujung River and its tributaries.

3.2.4-2.a. Nonmetal elements

There were nine physicochemical parameters out of 41 which showed an increasing pattern (Figure 3-14). Turbidity and total suspended solids (TSS), two water properties related with particulates contained in a water column (Kulkarni, 2011; Najah et al., 2009; Packman et al., 1999), have shown their increasing pattern. The concentration of these variables are greatly influenced by precipitation rate through runoff (Effler et al., 2007), but it can also be induced by contaminants such as heavy metals and pesticides (Bilotta and Brazier 2008).

Turbidity refers to the cloudiness or haziness of water generally caused by invisible particles (suspended solids) (Kulkarni, 2011). The standard limit for turbidity in the Indonesian river water is 25 nephelometric turbidity units (NTU). Meanwhile, the average value of turbidity at Jongjing station was of 68.83 ± 88.33 NTU. Some large fluctuations have accounted for the high mean value and standard deviation. The highest peaks were reached in December 2008 (577 NTU) and February 2010 (546 NTU), both occurred in the rainy season.

TSS is a measure of the mass of solids (organic and inorganic) found in a volume of water that can be trapped using filter (Bilotta and Brazier 2008). The permissible limit for TSS in the Indonesian rivers is 50 mg/l. The range of TSS at Jongjing station from 10 years observation was 22 – 725 mg/l, with a mean value of 90.26 ± 107.37 mg/l. Except one peak in August 2000 (725 mg/l), the other two peaks of TSS occurred in December 2008 (615.5 mg/l) and February 2010 (577 mg/l), similar to the peaks of the turbidity.

All oxygen-related properties, *i.e.* DO, BOD and COD, have shown their intensifying trend. DO, as a relative measure of the amount of molecular oxygen that is dissolved in a given water volume (Lewis, 2006), decreased in concentration especially after 2006. BOD level, although still below its ambient value, showed some spikes in the last five years, meaning that the amount of dissolved oxygen needed by microorganisms for their oxidation process (the breaking down organic materials) (Cox, 2003) increased. Finally, the level of COD, as a measure of the oxygen amount consumed by water in the decomposition of organic matter and oxidation of inorganic matter (Moreno-Casillas *et al.*, 2007), was far above its ambient value (25 mg/l). The mean value of COD of the ten years data was 80.75 ± 85.01 mg/l. This value indicates that the amount of organic compounds contained in the water of Ciujung River was very high (Liu *et al*, 2009).

Nitrates and nitrites, two essential nitrogen-related properties frequently used for pollution indicator, also showed their magnifying concentrations. The mean concentration of nitrites (0.22 ± 0.54 mg/l) has exceeded its ambient level (0.05 mg/l). Its high concentration is also related with the high amount of organic materials in the water. The mean concentration of nitrates, although still below its ambient level, already indicated an escalating level especially in the last five years.

Salinity refers to the water’s saltiness and a measure of the mass of salts, such as carbonates, chlorides, nitrates, sulfates, potassium, sodium, magnesium and calcium, per unit mass of water (Pawlowicz, 2008). In pure fresh water, the salinity level should be close to 0.05%. In Indonesia, the ambient level in river water is determined not to exceed 0.1%. Meanwhile, the salinity at Jongjing station ranged from 0.08 to 1.60%, with a mean value of 1.24 ± 2.52%, far above its permissible level.

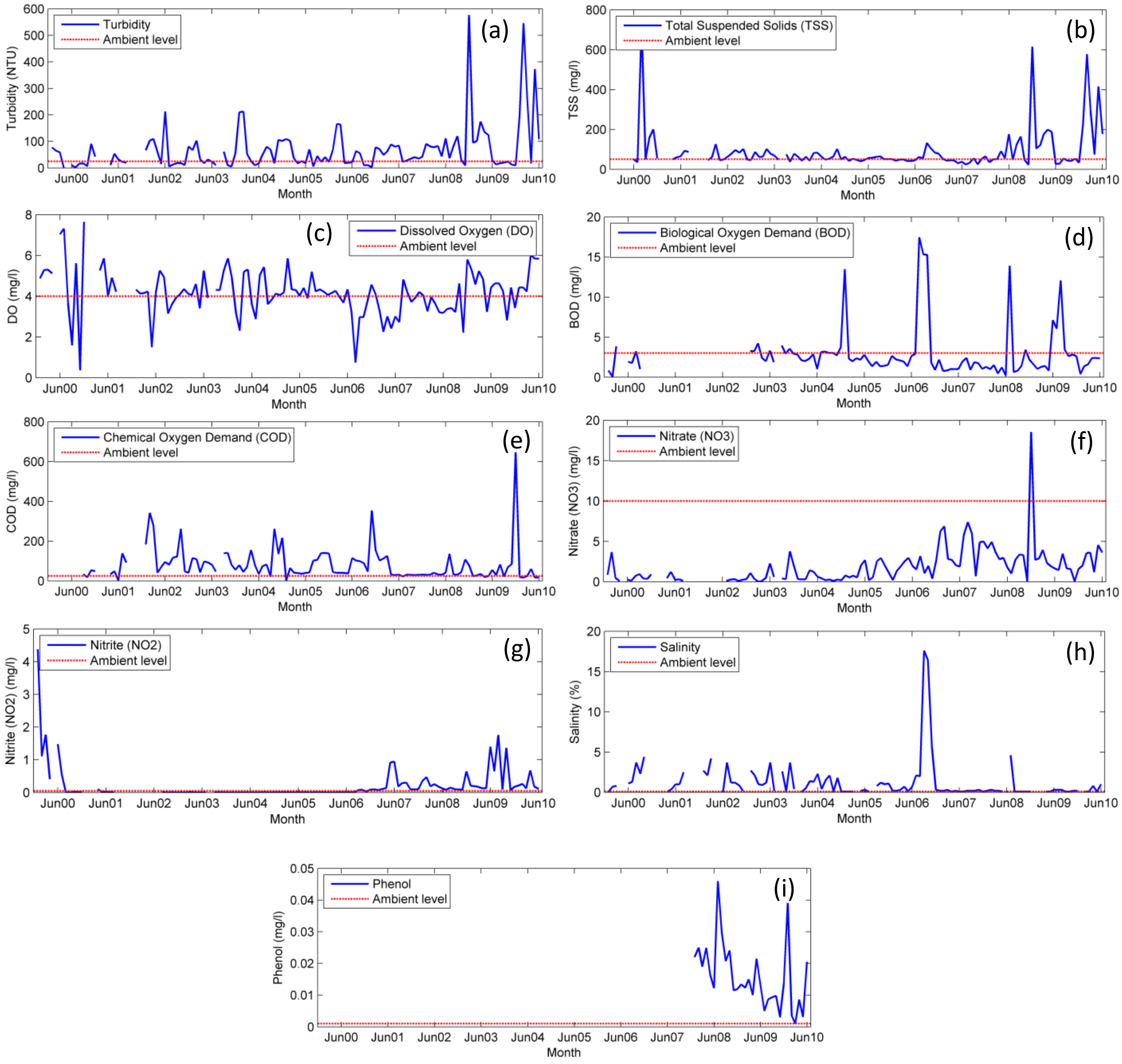


Figure 3-14: Concentration of some nonmetal elements at the lower most station in the downstream area of Ciujung River (2000–2010).

Phenol concentration has exceeded its ambient level (0.001 mg/l). The monthly concentrations of phenol, which have been measured since 2008, produced a mean value of 0.016 ± 0.01 mg/l. The high concentration of phenol in the river water may be related to the high discharge of municipal and industrial sewages, such as dyes, detergents, drugs, polymers and organic substances (Michałowicz and Duda, 2007).

3.2.4-2.b. Heavy metal elements

Heavy metals are chemical elements which at high concentration are toxic to the environment and human. Domestic and industrial products, such as detergents, surfactants, insecticides, drugs and reagents, are among their original sources (Sakan *et al*., 2009; Rule *et al*., 2006; Patnaik, 2002). The 10-year measurement at Jongjing station showed an increasing trend in the concentrations of some heavy metals, but their average concentrations were still below the threshold limits, except for iron (Figure 3-15).

Consecutively, the threshold level of chromium, manganese, lead, zinc, copper and cadmium in the Indonesian rivers are 0.05 mg/l, 0.1 mg/l, 0.03 mg/l, 0.05 mg/l, 0.02 mg/l and 0.01 mg/l. Meanwhile, their mean values at Jongjing station were 0.006 ± 0.008 mg/l, 0.018 ± 0.005 mg/l, 0.006 ± 0.006 mg/l, 0.013 ± 0.015 mg/l, 0.008 ± 0.006 mg/l and 0.008 ± 0.004 mg/l, respectively, all concentrations were still below their corresponding threshold levels. Iron was the only heavy metal element that exceeded its threshold level (0.3 mg/l) with its mean value of 0.39 ± 0.57 mg/l. Iron ions could be derived from natural sources and anthropogenic sources, such as domestic and industrial wastes.

The escalating concentration of heavy metal elements, especially in the last five years, is very alarming to the environment. The trend is very obvious that without proper management the water quality in Ciujung River is going to be more declining in the short future. The sources of heavy metals are mostly related with the industrial wastes and the use of detergents, surfactants, emulsifiers and other daily human-related appliances.

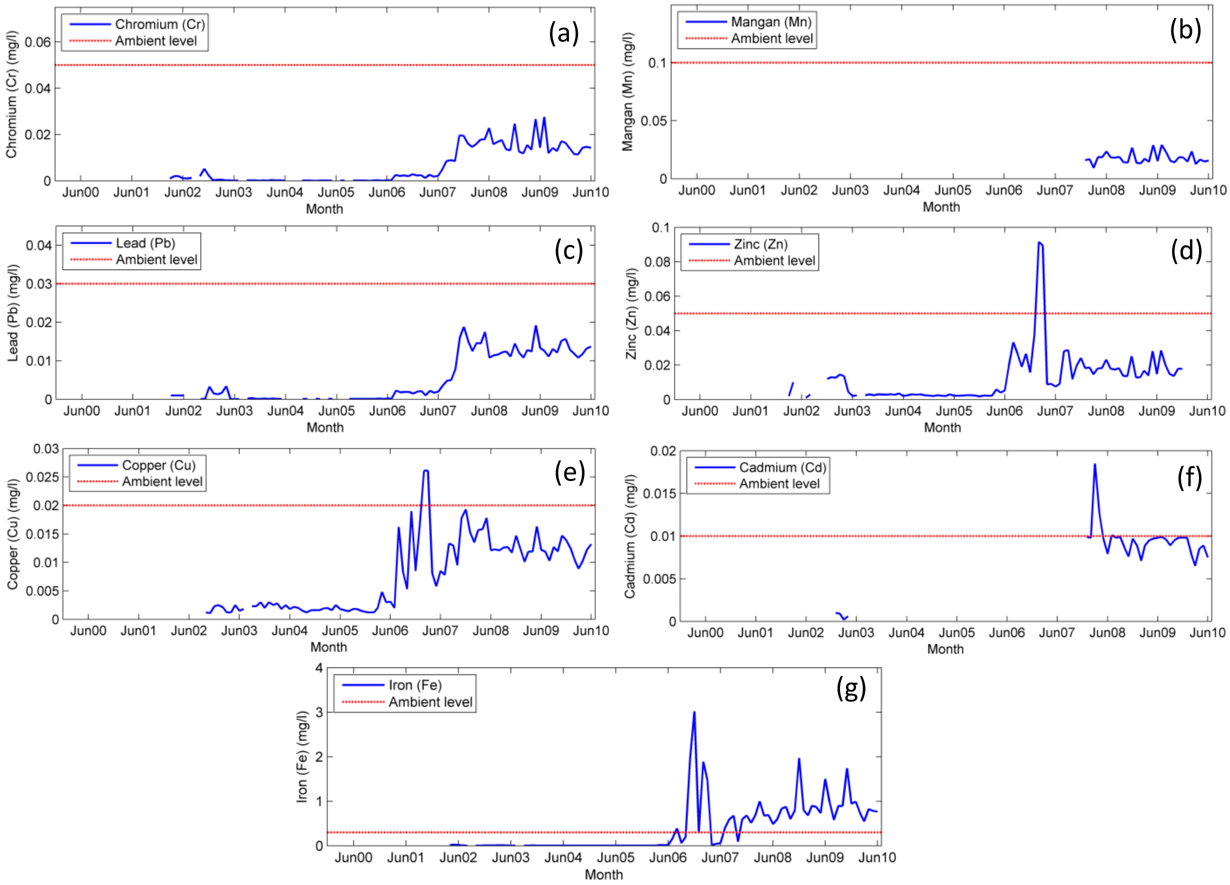


Figure 3-15: Concentration of some heavy metal elements at the lower most station in the downstream area of Ciujung River (2000–2010).

3.2.4-2.c. Organic-material-related properties

The concentration of organic materials contained in water is also determined by potassium permanganate ($KMnO_4$) value, or so-called ‘$KMnO_4$ number’, which is used to quantitatively determine the total oxidisable organic material in an aqueous sample (Patnaik, 2002). The ambient level of “$KMnO_4$ number” in the Indonesian rivers was 10 mg/l, meanwhile the $KMnO_4$ number at Jongjing station ranged from 1.2 to 66.37 mg/l, with a mean value of 16.57 ± 12.64 mg/l (Figure 3-16). The high value of $KMnO_4$ confirmed the high contents of organic materials in Ciujung River as that predicted by the high COD value.

In line with the high concentrations of $KMnO_4$ and COD, as the indication of high organic material contents, the concentration of *Escherichia coli* (*E. coli*) at Jongjing station was also remarkably high. *E. coli,* as one most essential indicator of water healthiness, can have a long-term survival rate in river water up to 265 days at a temperature range of 4–25 ºC (Flint, 1987). The expectable limit of total *E. coli* in the river water in Indonesia is 5000 colonies / 100 ml. Meanwhile, the mean concentration of *E. coli* at Jongjing station has reached 47,749 ± 28,906 colonies / 100 ml, with a range of 4,400 to 210,000 colonies / 100 ml.

The excessive concentration of *E. coli* could be related to the unhealthy culture of some local people, especially those living below the poverty level. Their retain less care on the installation of septic tank in their houses and just simply flushing all waste water away from toilets, bath rooms, washing places and livestock farming to the drainage or river without having treatment, is very common. The concentration of *E. coli* had been very high even before the decentralization policy. Fortunately, during the 8 years, the *E. coli* concentration exhibited a declining trend.

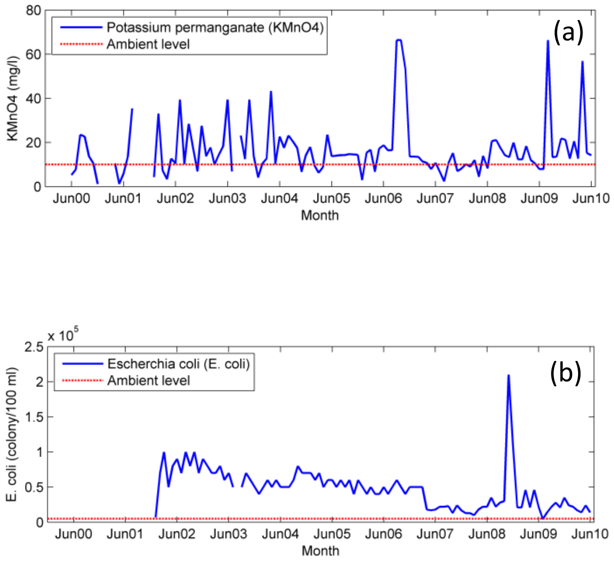


Figure 3-16: Concentration of organic-materials-related properties at the lower most station in the downstream area of Ciujung River (2000–2010).

The results may be coincident, but it could be a result of the intensive sanitation programs, such as sanitation by communities (*Sanimas*) and water and sanitation for low income communities (WSLIC) programs. Both programs have constructed a big number of public toilets and sanitary systems in some urban and rural areas in Indonesia, including in Banten Province (Buhl-Nielsen *et al*., 2009). However, many efforts are still required to reduce this pathogen bacteria concentration until below its ambient level.

3.2.4-3 Multivariate statistics analysis

3.2.4-3.a. Cluster analysis

HCA (Hierarchical Cluster Analysis) was performed to identify the similarity groups between six years monthly average water quality data. The dendrogram (Figure 3-17), as a result of HCA, illustrates the seasonal grouping of all 25 variables. The monthly average water quality data were classified into two statistically significant clusters at $(D_{\text{link}}/D_{\text{max}}) < 15$, including Cluster 1: February, March and January; Cluster 2: April, June and May; Cluster 3: July and August; and Cluster 4: September, October, November and December.

Based on Schmidt and Ferguson classification, in which rainfall intensity is used as a main factor for climatic classification, Indonesia consists of two main seasons, *i.e.,* dry season and wet/rainy season, including their transition periods. In Java, dry season usually occurs between July and September (Aldrian and Susanto, 2003), with the midpoint in August (Hendon, 2003), whereas the peak time of high rainfall intensity normally occurs in December (Aldrian and Susanto, 2003) or January (Hendon, 2003). The other months are considered as transition periods. However, those periodical classifications are sometimes slightly different from one year to another, because they are influenced by the events of El Nino and La Nina (Hamada *et al.,* 2002).

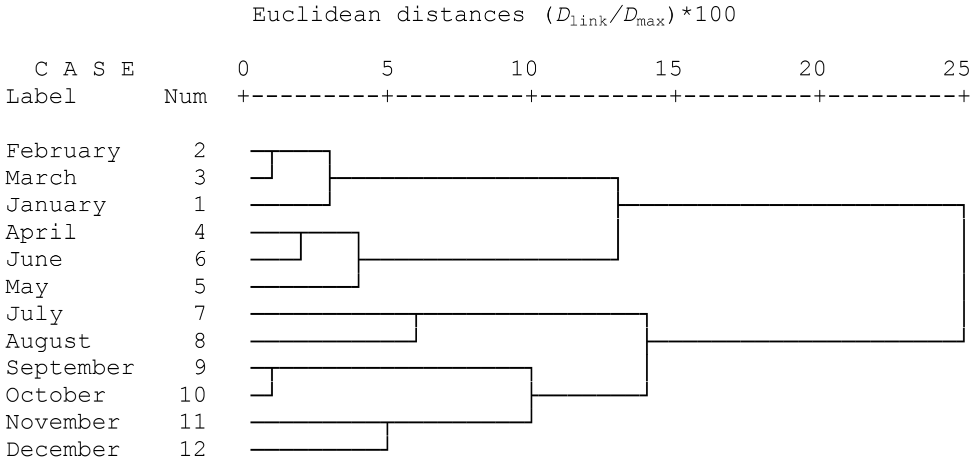


Figure 3-17: Agglomerative hierarchical clustering based dendrogram using Ward's method and Euclidean distance showing seasonal grouping.

Table 3-10: R-mode rotated varimax factor analysis of water quality parameters.

Parameter	Varifactor				
	1	2	3	4	5
TDS	.919	.072	-.051	-.050	.007
DHL	.903	.041	-.077	-.048	-.061
COD	.588	-.046	-.008	.130	-.075
Chlorida	.588	.187	.096	-.050	.184
Total_Hardness	.569	.160	.126	-.104	.549
Salinity	.551	.416	.059	.040	.207
Sulfate	.551	-.211	-.356	-.023	-.233
Calcium	.528	.483	.113	-.039	.435
Alkalinity	.132	.852	-.155	-.067	.059
BOD	.113	.753	-.142	.057	.167
DO	-.006	-.552	-.167	.283	.213
Temperatur	.006	.477	-.238	-.137	-.086
Copper	.016	-.085	.881	-.002	.018
Iron	.081	-.187	.733	.211	.067
Zinc	.041	.141	.565	-.144	-.441
Chromium	-.076	-.422	.563	.199	.469
Lead	-.079	-.412	.519	.162	.462
Nitrite	-.072	-.019	.313	.121	.164
TSS	-.007	-.158	.194	.875	.141
Turbidity	-.064	-.148	.174	.872	.000
Nitrate	-.035	-.154	.366	.525	-.037
E.coli	.076	.084	-.131	.371	-.186
Magnesium	.150	.041	.028	-.131	.614
Permanganate	.035	-.233	.019	.217	.483
pH	-.079	.147	.080	-.084	.422
Eigenvalue	4.874	3.768	2.075	1.632	1.590
Total Variance (%)	19.498	15.074	8.299	6.527	6.361
Cummulative variance (%)	19.498	34.572	42.871	49.397	55.758

It is obvious that the yielded clusters indicate that the changes of water quality in the study site were significantly affected by the seasonal variability, in this case the rainfall intensity and river water debit. This study has demonstrated that CA has an advantage in exploring some meaningful information out of the complex dataset that could not be able to be figured out by the simple statistics in the previous section.

3.2.4-3.b. Factor analysis

PCA followed with FA, was applied to the Kaiser-normalized full dataset. The rotated Varimax component matrix of five VFs was produced as that listed in Table 3-10. Based on Unmesh *et al.* (2006), the absolute loading values are classified into three classes, *i.e.,* <0.4, 0.50 – 0.75 and > 0.75, corresponding to weak, moderate and strong loads.

VF 1, accounting for 19.50% of the total variance, was strong positively loaded with TDS and EC and moderate positively loaded with COD, chloride, total hardness, salinity, sulfate and calcium. It is clear that these variables were believed to be related to mineral loads from runoff and soil erosion. The results also implied that rainfall intensity was the key factor which influences the variability of water quality in Ciujung River. The next variables, which were grouped in VF 2 and accounting for 15.07% of the total variance, including alkalinity, BOD, DO and temperature, were also believed to be related to the rainfall variability and water debit. Except for DO, which was moderate negatively loaded in VF2, alkalinity, BOD and temperature were positively loaded with the loading values ranged from moderate to strong.

Most of the water variables which were grouped in VF 3, which accounted for 8.30% of the total variance, were heavy metals and nitrite, with the loading values ranged from moderate to strong positive. These elements, whose their existence at high concentration is poisonous to the environment, seemed to be related to the anthropogenic discharges and wastes, including those coming from industry. Although their contribution to the variability of Ciujung River was still very limited, as that proved by only 8.30% of the total variance, but their emerging trend was important to be intensively monitored along with the economic development trend.

VF 4 and VF 5, each accounting for 6.52% and 6.36%, consisted of TSS, turbidity, nitrate, *E. coli*, magnesium, $KMnO_4$ and pH. Although clear explanation for the relationships between these variables could not be taken, both natural loads and organic materials as response to the rainfall intensity and anthropogenic impact may have been the reason behind these variables grouping. Again, this study has showed that FA/PCA was powerful to figure out some useful information out of the complex dataset that could not be possible to be overcome by the standard statistics.

3.2.5 Conclusions

One decade since the implementation of decentralization policy in 1999, Banten Province has achieved a considerable economic growth. In line with the population increase, the province’s GDP has also increased and contributed to approximately 14.75% of the total national GDP in 2010. The positive growth of GDP was supported by many sectors, such as agriculture, energy, industry and so on. Industrial sector has contributed to more than 50% of the provincial GDP. By these achievements, it is therefore important to assess the water quality in Ciujung River (one of the main rivers in Banten Province), in order to maintain the sustainability of the environment in harmony with the economic development. Ten years water quality data comprising of 41 water quality parameters from nine stations, collected in monthly basis by Water Resources Office of Banten Province, were used in the analysis. Beside descriptive statistics, multivariate statistics analysis including CA, FA and PCA were also applied in the study.

The analysis was done for the water quality data at Jongjing station (the lower most station in downstream area of Ciujung River, into which the water from the upper regions accumulates). The results showed that the majority of the parameters were still below their threshold values. However nine physicochemical elements, seven heavy metal elements and two organic-material-related properties have shown the increasing trends during 10 years observation.

For nonmetal elements, there were eight parameters out of 41 water parameters at Jongjing station already beyond their ambient values. Those include turbidity, TSS, COD, salinity, nitrite, phenol, $KMnO_4$ and *E. coli*. The concentration increase seemed to be related with the inputs from natural and domestic loads. Overall, this study revealed that Ciujung River is still considered to be relatively clean, but an emerging increase in heavy metals concentration could be taken as a serious warning for the local government.

The result of CA in multivariate statistics showed that the monthly average of water quality data was grouped in four clusters: Cluster 1: February, March and January; Cluster 2: April, June and May; Cluster 3: July and August; and Cluster 4: September, October, November and December. The produced clusters indicated that the changes of water quality were highly affected by seasonal variability, in which the rainfall intensity became the primary key.

The PCA/FA produced four dominant varifactors. VF 1, accounting 19.50% of the total variance, was strong positively loaded with TDS and EC and moderate positively loaded with COD, chloride, total hardness, salinity, sulfate and calcium. VF 2, accounting for 15.07% of the total variance, includes alkalinity, BOD, DO and temperature. VF 1 and VF 2 seemed to be related with the rainfall variability, runoff, soil erosion and water debit. VF 3, accounting for 8.30% of the total variance, comprises all observed heavy metals and nitrite, with the loading values ranged from moderate to strong positive. These elements, which their existence at high concentration is poisonous to the environment, seemed to be related with the emerging anthropogenic discharges and wastes, including those coming from the industry. Although their contribution to the variability of Ciujung River was still very limited, as that proved by only 8.30% of the total variance, but it is important to anticipate their future increase along with the economic development trend. VF 4 and VF 5, each accounting for 6.52% and 6.36%, consist of TSS, turbidity, nitrate, *E. coli*, magnesium, potassium permanganate and pH. Although clear explanation for the relationships between these variables could not be taken, both natural loads and organic materials as response to rainfall intensity and anthropogenic impact may have been the reason for these variables moderate positive loads in the matrix.

This study demonstrated that there were some emerging trends in heavy metals concentration, especially during the last five years, which could be a warning for the water quality in Ciujung River. The worsening condition of the water quality could be caused by the indirect impact of population growth and industrial development as consequence of the increase of economic development in Banten Province. An integrated water quality management needs to be implemented in Banten Province, parallel with the economic development strategy.

Chapter IV

Water Quality Assessment of the Jakarta and Banten Bays

This chapter discusses about water quality level in the Jakarta and Banten Bays. Jakarta and Banten Bays are the last destination for the runoff and river water coming from Ciliwung and Ciujung watersheds, respectively. Located in an urban watershed, the Jakarta Bay accumulates contaminants from the polluted rivers in Jakarta city. Meanwhile, the Banten Bay is located in a relatively rural watershed where the industrial development is still concentrated in the west side of the Bay.

In addition, a hyperspectral study using field spectroradiometer was conducted to measure the spectral reflectance response of coastal plants to the nutrient increase in the water. In this experiment, two coastal plants, i.e., seagrass (*Enhalus acoroides*) and brown algae (*Sargassum* sp.), were taken from the Banten Bay and treated with the nutrient enrichment in a laboratory scale and subjected for hyperspectral measurement.

4.1 *Escherichia coli* and biophysicochemical relationships of seawater and water pollution index in the Jakarta Bay

(American Journal of Environmental Sciences: Vol. 7(3), pp. 183-194, 2011)

4.1.1 Introduction

Like other metropolitan cities in the world, Jakarta city in Indonesia faces up some environmental problems as an impact of rapid development. Being the country’s economic, cultural and political center, Jakarta is targeted by young people to finding jobs and better carrier. The population size of Jakarta almost tripled since the last five decades from 2.9 million in 1961-9.5 million in 2010, based on the tabulation of 2010 National Census.

Rapid development of Jakarta city especially during the centralization period where Indonesian GDP reaching an incredible increase of 5.7 percent per year between 1980 and 1992 (WRI, 1996) has made Jakarta city growing very fast. With such an economic growth, Jakarta embodies many of the contradictory forces at play in rapidly industrializing megacities of the world. Of course this "engines of growth" can play a vital role in economic development, however at the same time; worsening environmental problems may threaten economic prosperity and human health (WRI, 1996).

Some issues, such as air and water pollution (Sato and Harada, 2004; WRI, 1996) and urban waste (Steinberg, 2007), are among the impact of environmental aspects being faced by Jakarta Provincial Government. Garbage such as plastics, woods, bottles and other solid wastes are easily found in the canal and river systems, worsening the water quality. The wastes are drifted to the coastal zone of the Jakarta Bay as the final destination. The massive dead of fishes in 2004 in the Jakarta Bay could be an evidence of pollution level in 13 river systems in Jakarta City (Steinberg, 2007).

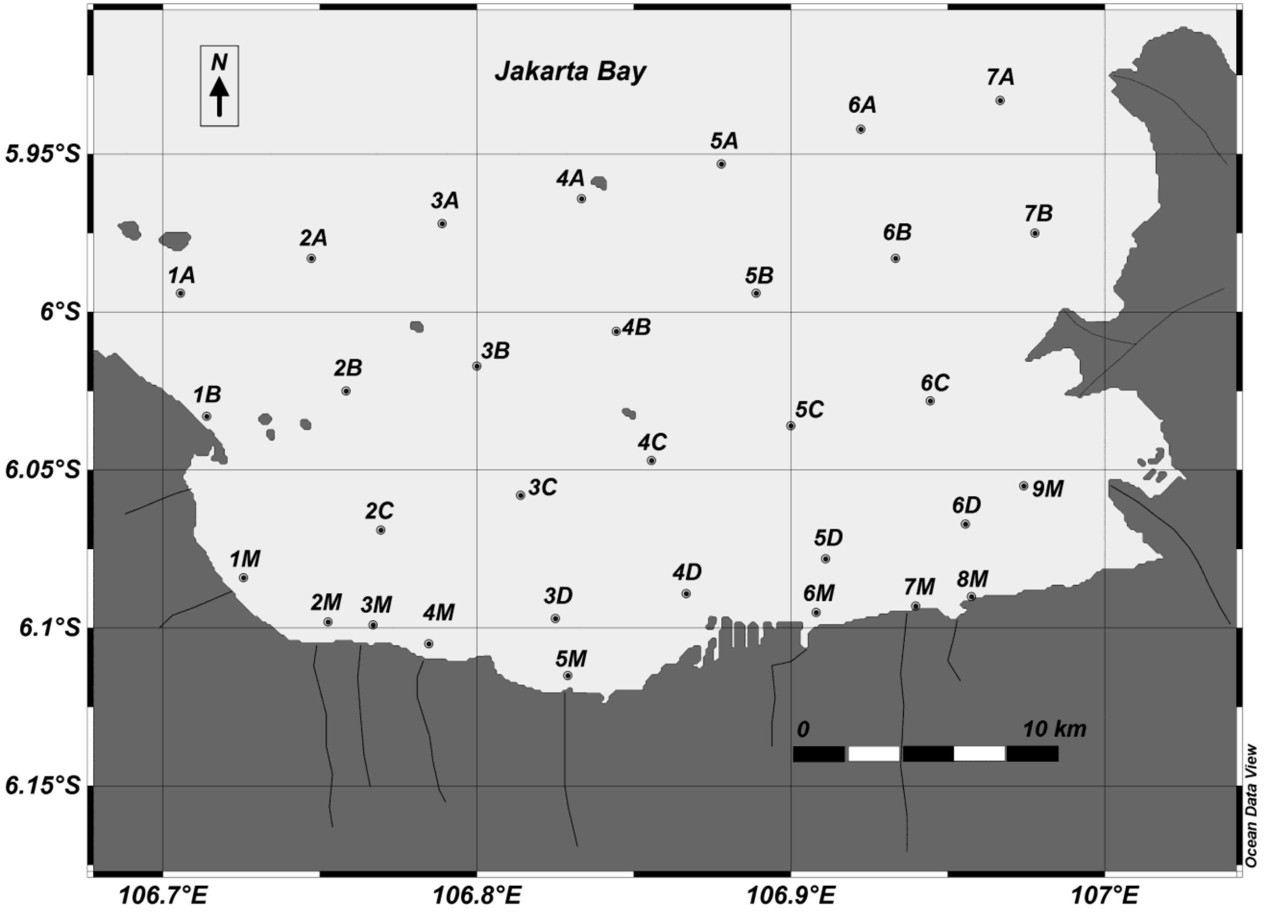


Figure 4-1: Distribution of the sampling stations in the Jakarta Bay. A, B and C are considered to be offshore stations; and M1-M9 are considered to be onshore stations.

The Jakarta Bay received two important sources of water pollution, i.e. industrial and household wastes. The condition is worsened by poor drainage systems and weak law enforcement (Colbran, 2009; Willoughby *et al*., 1997). William *et al*. (2000) reported that high concentrations of heavy metals were found in the water column and sediment bed of the Jakarta Bay. This condition threatens the population of some biodiversities in the bay, such as molluscan fauna (Van der Meij *et al*., 2009). The pollution level also puts impact on the economic loss of the fisheries in the area as described by Anna and Fauzi (2008).

There are numerous water indicators that can be used to evaluate water quality level, including physical, chemical and biological parameters. Each parameter has associations with other environmental attributes, for example salinity with precipitation, turbidity with sedimentation rate, pH with alkalinity, etc. Among these water parameters, *Escherichia coli* (*E. coli*) concentration has been widely used as bioindicator to quantify water quality condition, for example in ground water (UNESCO, 2000) river water (Yisa and Jimoh, 2010; Kido *et al*., 2009) and seawater (Costa *et al*., 2000).

E. coli is widely known as biological indicator of soil and water pollution. One type of fecal coliform, it is commonly found in the intestines of warm-blooded animals and human. Most *E. coli* strains are actually harmless, but some like O157:H7 can cause serious poisoning in human body. Besides human excrements, cattle faeces are among the important sources of this pathogen strain (Campbell *et al*., 2001). Like other bacteria, *E. coli* prefers to live in the water containing high nutrious elements and organic materials; therefore the presence in water is a strong indication of recent sewage or animal waste contamination (Jalal *et al*., 2010). One important factor that can exacerbate the high presence of *E. coli* in the environment is poor management of city sewage systems (Brussow, *et al*., 1992).

Beside single indicator such as *E. coli*, scientists developed multi-parameter pollution indicators oftenly called Water Quality Index (WQI) and Water Pollution Index (WPI). Both indices are almost similar in use. WQI is used to evaluate water condition especially for consumable water, while WPI is more applicable for evaluating pollution level of a water ecosystem. WQI/WPI is calculated from several water parameters with a set of equations and circumstances. Terrado *et al*. (2010) lists about 55 different WQI and WPI introduced by many scientists in the world.

4.1.2 Objectives

This study attempts to 1) calculate WPI in the Jakarta Bay by comparing offshore and onshore areas at different seasons and 2) analyze the relationships between *E. coli* and biophysicochemical properties of seawater at different seasons in the Jakarta Bay.

4.1.3 Materials and methods

The study site is located in the Jakarta Bay with a total area of 285 km^2, 33 km of the coastline and 8.4 m of the average water depth. There are 13 river systems flowing into the bay with the average water debit of 112.7 m^3s^{-1}. Some human activities like industries, harbors, fishing ports, marine aquaculture, tourisms, slum areas and luxury settlements are located along the coastline. For the purpose of analysis, the stations are divided into offshore stations, i.e. A, B, C and D and onshore stations, i.e. M1 - M9 (Figure 4-1).

Water quality data of the seawater was derived from the Jakarta Environmental Management Board (BPLHD Jakarta). Two series of water quality data taken in November 2007, representing the early rainy season and in August 2008, representing late dry season, were analyzed. A total of 32 stations were defined throughout the Jakarta Bay, where 30 water parameters, including 5 physical, 20 chemical and 5 biological parameters, were measured in each station, as listed in Table 4-1.

Similar to the previous study, the pollution level of the Jakarta Bay at different seasons was calculated using Nemerow-Sumitomo WPI method (see Section 5.2.3). The Nemerow-Sumitomo method became formally used for water quality analysis in Indonesia, since it has been included in the regulation of the Ministry of Environment of Indonesia No. 115/2003 regarding Water Quality Measurement Guideline; therefore it was used in this study. The pollution level is classified in four criteria as follows:

$0.0 \leq \text{WPI} \leq 1.0$ = clean water (meets the PV criteria)
$1.0 < \text{WPI} \leq 5.0$ = slightly polluted water
$5.0 < \text{WPI} \leq 10$ = moderately polluted water
$\text{WPI} > 10$ = highly polluted water

According to the Nemerow-Sumitomo WPI equation, it needs a set of PV for each parameter as an input for the equation and this PV is likely to be designed by a government regulation. Table 4-1 lists the mean value and standard deviation of all measured parameters along with their PVs in seawater designated by the regulation of Ministry of Environment of Indonesia no. 51/2004. This regulation is designed for the purpose of marine tourism activities and marine living organism. Although in total 30 water properties have been measured in the early rainy and late dry season, but only the parameters having designated PVs were inputted in the WPI equations (Table 4-1). Some parameters such as TDS, temperature, salinity, etc. were excluded from WPI calculation, because their PVs are not defined by the mentioned regulation.

Table 4-1: Means and standard deviations of the observed water properties and their permissible values (PVs) in the seawater.

	No	Parameter	Unit	Values (mean ± standard deviation)				
				Nov 07		Aug 08		PV [a]
				Offshore	Onshore	Offshore	Onshore	
Physical	1	TDS	mg/l	3.02E4 ± 2.05E3	2.22E4 ± 9.40E3	3.55E4 ± 5.32E3	2.04E4 ± 1.06E4	-
	2	TSS	mg/l	3.22 ± 1.35	24.89 ± 17.42	4.61 ± 2.19	26.33 ± 20.85	20
	3	Turbidity	NTU	1.26 ± 1.48	5.67 ± 1.80	1.87 ± 1.18	8.50 ± 7.24	5
	4	Temperature	^{o}C	30.55 ± 0.44	30.35 ± 0.81	28.25 ± 0.32	29.21 ± 0.69	-
	5	Water transparency	m	2.94 ± 1.58	0.58 ± 0.36	2.93 ± 1.05	0.74 ± 0.66	-
Chemical	6	Salinity	‰	32.04 ± 1.46	27.72 ± 6.18	31.57 ± 0.65	29.22 ± 4.16	-
	7	Ammonia (NH_3)	mg/l	0.181 ± 0.132	2.746 ± 2.685	0.013 ± 0.022	1.292 ± 2.014	0.00
	8	$KMnO_4$	mg/l	64.90 ± 19.22	51.14 ± 13.21	106.31 ± 32.75	86.57 ± 25.71	-
	9	Nitrate (NO_3)	mg/l	0.004 ± 0.019	0.027 ± 0.080	0.000 ± 0.000	0.132 ± 0.112	0.008
	10	Disovld. Oxyg. (DO)	mg/l	7.68 ± 3.11	2.86 ± 2.26	5.31 ± 0.76	3.74 ± 2.73	5
	11	Phosphate (PO_4)	mg/l	0.007 ± 0.018	0.231 ± 0.234	0.023 ± 0.028	0.428 ± 0.466	0.015
	12	Phenol	mg/l	0.016 ± 0.005	0.018 ± 0.004	0.000 ± 0.002	0.012 ± 0.004	0.002
	13	Sulfide (H_2S)	mg/l	0.000 ± 0.000	0.019 ± 0.031	0.004 ± 0.008	1.134 ± 2.941	0.00
	14	Oil and Fat	mg/l	0.083 ± 0.105	0.064 ± 0.030	0.073 ± 0.052	0.103 ± 0.182	1.00
	15	Blue Methylene	mg/l	0.076 ± 0.059	0.081 ± 0.059	0.010 ± 0.000	0.407 ± 0.638	0.001
	16	COD	mg/l	102.4 ± 14.94	76.57 ± 13.20	33.76 ± 13.06	121.25 ± 37.14	-
	17	BOD at 20^{o}C 5 days	mg/l	29.20 ± 8.45	31.05 ± 10.73	0.152 ± 0.05	34.20 ± 6.82	20
	18	pH	-----	8.11 ± 0.19	7.67 ± 0.19	8.60 ± 0.18	7.83 ± 0.32	7 – 8.5
	19	Zink (Zn)	mg/l	0.033 ± 0.047	0.014 ± 0.011	0.015 ± 0.008	0.026 ± 0.010	0.095
	20	Mercury (Hg)	mg/l	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.002
	21	Copper (Cu)	mg/l	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.005
	22	Lead (Pb)	mg/l	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	-
	23	Cadmium (Cd)	mg/l	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.002
	24	Chromium (Total)	mg/l	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.002
	25	Nickel (Ni)	mg/l	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.075
Biolological	26	*E. coli* (log)	ind/dl	2.447 ± 1.423	5.388 ± 1.604	0.512 ± 0.481	5.239±2.005	2.30103 [b]
	27	Fecal Coliforms (log)	ind/dl	1.986 ± 1.400	5.027 ± 1.678	0.365 ± 0.348	4.777 ± 1.540	3.0 [b]
	28	Phytoplankton (log)	ind/m^3	7.04 ± 0.47	7.94 ± 0.53	7.84 ± 0.91	6.35 ± 0.61	-
	29	Zooplankton (log)	ind/m^3	3.34 ± 0.37	3.94 ± 0.58	3.16 ± 0.54	2.42 ± 0.81	-
	30	Macrobenthos (log)	ind/m^3	3.08 ± 0.67	1.97 ± 0.40	2.82 ± 0.79	1.98 ± 1.29	-

[a] based on Ministry of Enviroment of Indonesia, regulation No. 51/2004 (for marine biota and tourism).

[b] values in logaritmic format.

Bivariate correlation and simple regression analysis between *E. coli* concentration and biophysicochemical properties of seawater were performed using SPSS version 16.0 (SPSS Inc., Chicato, Ill). Pearson-R correlation and *R*-squared linear coefficients were used to evaluate the magnitude and direction of the association between variables. Two-tailed test with a confidence level (α) of 0.05 and 0.1 was used to examine the significancy of the result.

Ocean Data View (ODV) software version 4.2.1 (AWI Bremerhaven, Germany) was used to create an interpolation image of water transparency distribution by applying DIVA gridding technique. DIVA gridding has been incorporated in the last version of ODV and generally produces better results than Quick Gridding in cases of sparse and heterogeneous data coverage and in cases the study area is separated by land masses (small islands), ridges or bathymetric barriers such as the Jakarta Bay.

4.1.4 Results and discussion

4.1.4-1 Biophysicochemical properties of seawater at different seasons

For comparison, the sampling stations were divided into offshore and onshore areas. Offshore area consists of 23 stations (A, B and C) and onshore area consists of 9 stations (M1-M9) as illustrated in Figure 4-1. In general, Table 4-1 shows that the mean value of biophysicochemical water parameters in the onshore area was higher (in case of DO, lower) than that of in the offshore area, both in the early rainy and late dry season, similar to the study of Koropitan *et al.*, 2009. In the onshore area (Figure 4-2), 12 parameters exceeded the PVs in both seasons, i.e. TSS, turbidity, ammonia, nitrate, DO, phosphate, phenol, sulfide, blue methylene, BOD, *E. coli* and fecal coliforms. Meanwhile in the offshore area, only five parameters in both seasons exceeded the PVs (Figure 4-3).

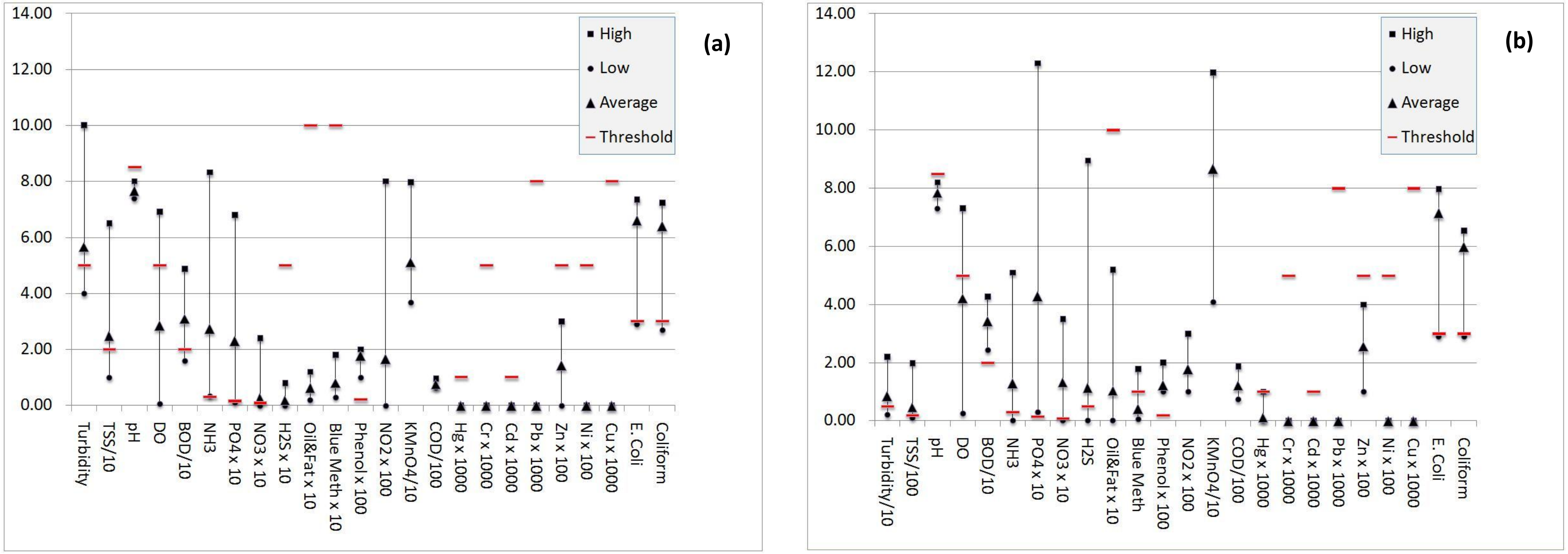


Figure 4-2: The standardized permissible value (PV), minimum, maximum and average values of water parameters in the onshore stations in the (a) early rainy season (November 2007) and (b) late dry season (August 2008).

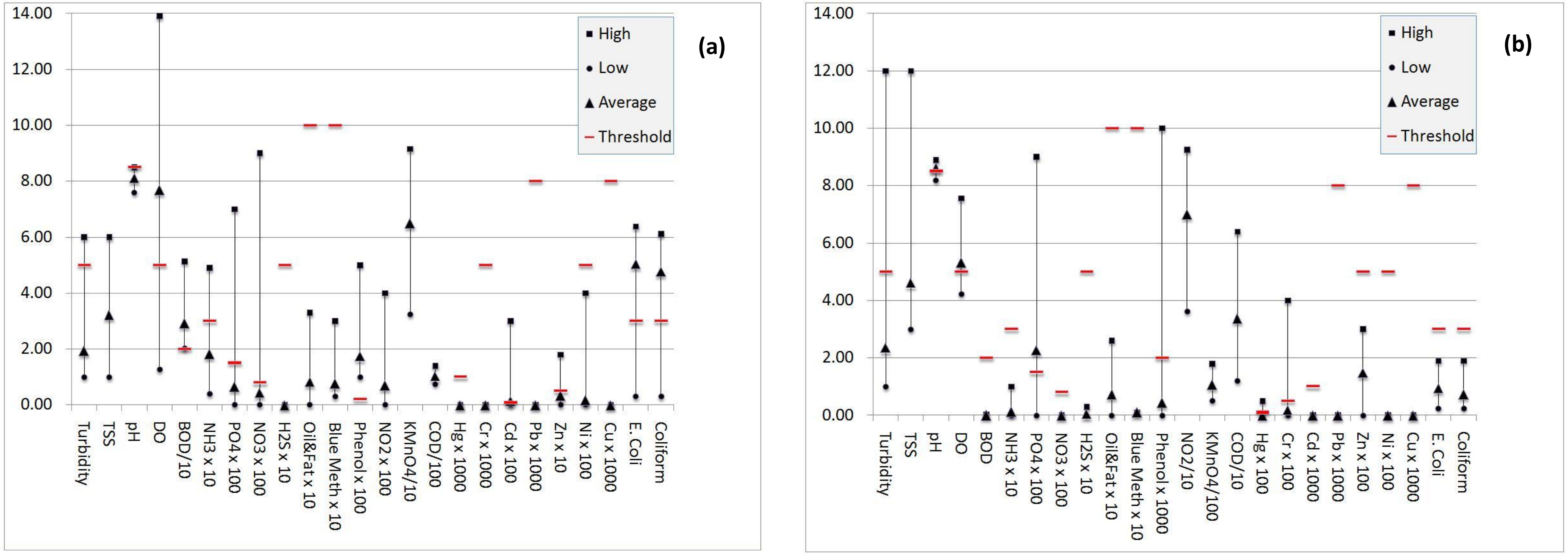


Figure 4-3: The standardized permissible value (PV), minimum, maximum and average values of water parameters in the offshore stations in the (a) early rainy season (November 2007) and (b) late dry season (August 2008).

In respect to seasonal variability, water parameters were responsive to precipitation. For example, in the early rainy season, although rainfall intensity in this period was not as much as in mid rainy season (Figure 3-5), but the presence of rainwater in this period was sufficient to slightly dilute seawater as can be observed from most of water parameters. Therefore some parameters showed relatively lower mean values than those of in the late dry season, especially in the onshore area, for example turbidity, potassium permanganate ($KMnO_4$), nitrate, salinity, phosphate, sulfide, blue methylene, TSS, Chemical Oxygen Demand (COD) and BOD.

However, at the same time, rainfall intensity has also capacity to force out the polluted river water flowing into the bay. Therefore few parameters also showed higher values, i.e. ammonia, phenol, DO, *E. coli* and fecal coliforms. The resultant of water current from rivers that meets with the waves from open sea could also be the explanatory why the polluted water was more concentrated in the coastal area.

4.1.4-2 Water pollution level in Jakarta Bay at different seasons using WPI

Table 4-2 summarized number of stations in the offshore and onshore stations in both seasons that were classified based on the WPI criteria. The results indicate that most of the sampling stations fall within “slightly polluted” criteria with 20 stations (62.5%) in the early rainy season and 16 stations (50%) in the late dry season. Overall, the water tended to be more polluted in the early rainy season with (C = 0, SP = 20, MP = 6 and HP = 6) compared to that of in the late dry season (C = 9, SP = 16, MP = 3, and HP = 4). Here, C, SP, MP and HP are clean, slightly polluted, moderately polluted and highly polluted, respectively.

Table 4-2: Results of water pollution index (WPI) in the offshore and onshore stations at different seasons.

Criteria	Early rainy season Nov 2007			Late dry season Aug 2008		
	Number of station			Number of station		
	Offshore	Onshore	Total	Offshore	Onshore	Total
Clean (C)	0	0	0	9	0	9
Slightly Polluted (SP)	18	2	20	14	2	16
Moderately Polluted (MP)	4	2	6	0	3	3
Highly Polluted (HP)	1	5	6	0	4	4
Total	23	9	32	23	9	32

Although, in general the average value of water parameters in the early rainy season was lower compared to that of in the late dry season, but in some stations the concentration was very high due to the influence of water input from river systems, producing high WPI on those stations. This was the reason why, to some extents, it became necessary to conduct a multiple-parameter pollution index, such as WPI, instead of depending only on one pollution indicator such as *E coli*. According to Terrado *et al.* (2010), the presence or absent of certain organisms in water which is used as a single bioindicator, has been introduced since 1848 in Germany. However, sometimes judging only on a single bioindicator is not sufficient because other toxicological effects and contaminant substances are also important to consider.

This first reason which supports the idea why the WPI in the early rainy season was higher than that of the late dry season is related to the supply of rainwater which started to increase in November 2007. The rainwater supply had capacity to force out the polluted water in 13 river systems entering the bay. The second reason is related to the cyclonic events in the Western Ocean Pacific which impact the coastal waters in the northern Java Island. Both reasons are explained in detail in the following sections.

Some literatures reported that most of the river systems in Jakarta have been classified into highly polluted water (Colbran, 2009; Steinberg, 2007; UNESCO, 2000). Therefore, rainwater supply in the early rainy season could be an explanatory for the increase of water pollution in the Jakarta Bay within this period. Unfortunately, the amount of water debit from all river systems in the early rainy season was unknown; hence it was difficult to statistically measure the impact of rainfall intensity to the increase of water pollution in the bay. An attempt was made by creating a water transparency distribution map from the water transparency point data using DIVA gridding interpolation technique (Figures 4-6 and 4-7).

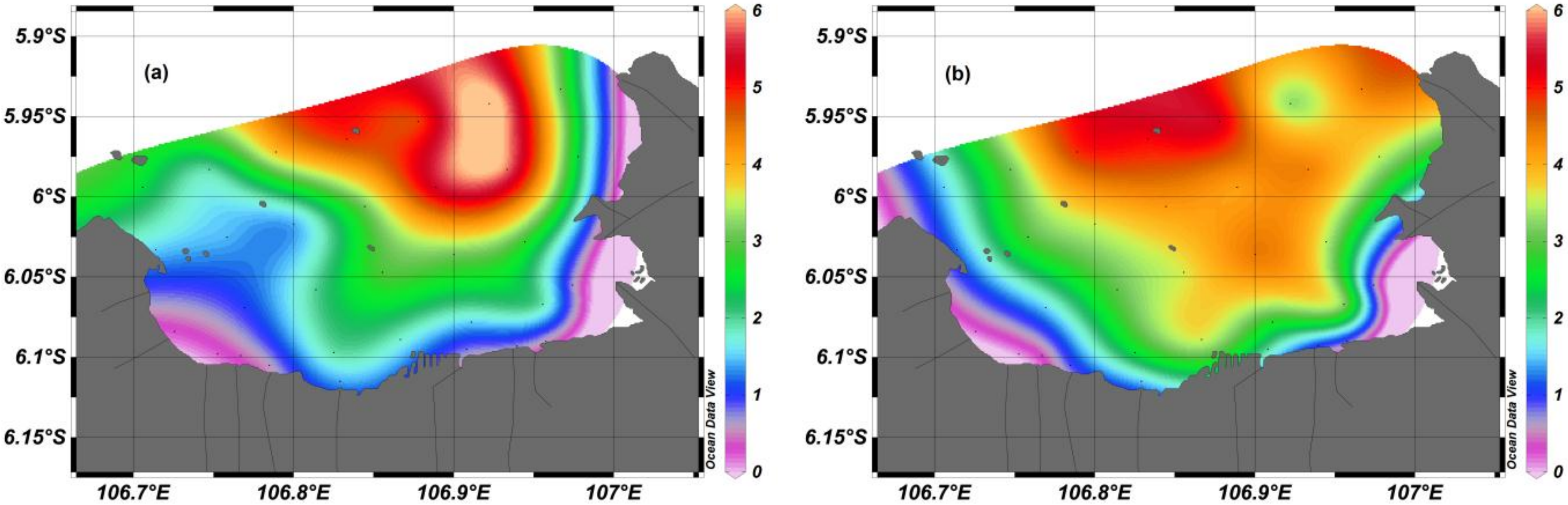


Figure 4-4: Interpolated-water transparency distribution data of the Jakarta Bay in the (a) early rainy season (November 2007) and (b) late dry season (August 2008).

It is clearly seen from the above figure, there is a significant supply of fresh water from river systems in the early rainy season (Figure 4-4), as shown by the expansion of purple and blue colors over green and orange colors. The water transparency in this season was more turbid especially in the onshore area ($\bar{x} = 0.58 \pm \sigma = 0.36$) compared to that of in the late dry season ($\bar{x} = 0.74 \pm \sigma = 0.66$).

The evidence that the water condition in Jakarta Bay was more polluted in the early rainy season has been addressed by Yanagi (2011) and was also related to the storm events in the Western Pacific Ocean which gave impacts on the Java Sea waters (Ningsih *et al.*, 2011; Ningsih *et al.*, 2010). As the Cyclones Peipah, Hagibis and Mitag hit this region in November 2007, some locations in the northern Java, including the low-lying areas of the northern of Jakarta, were severely flooded. The Cyclone Peipah event on November 9, 2007 and Cyclones Hagibis and Mitag in November 25, 2007 have caused the total sea level rose up to 5 cm and 75 cm above the mean sea level, respectively. The storm surge level in some parts of northern Java sea resulted by these cyclone events can be observed by measuring the residual water level which is obtained by removing astronomic tides from the observed tidal data. The residual water levels in Jakarta Bay at the time of the cyclones are depicted in Figure 4-5.

In turn, the flooding sea water in the northern Jakarta areas caused by these cyclones, mixed with the polluted water in the rivers. Afterwards, when the energy of the cyclones and the tidal current were reducing, the mixed polluted sea and river water was brought back to the sea by the ebb flow (the tidal current which returned the water to the sea at low tide). The study on these cyclone events has supported the reason why the Jakarta coastal water was more polluted in the early rainy season (November 2007). The strong influence of river water pollution to the water in the bay is also addressed by Koropitan *et al.*, 2009.

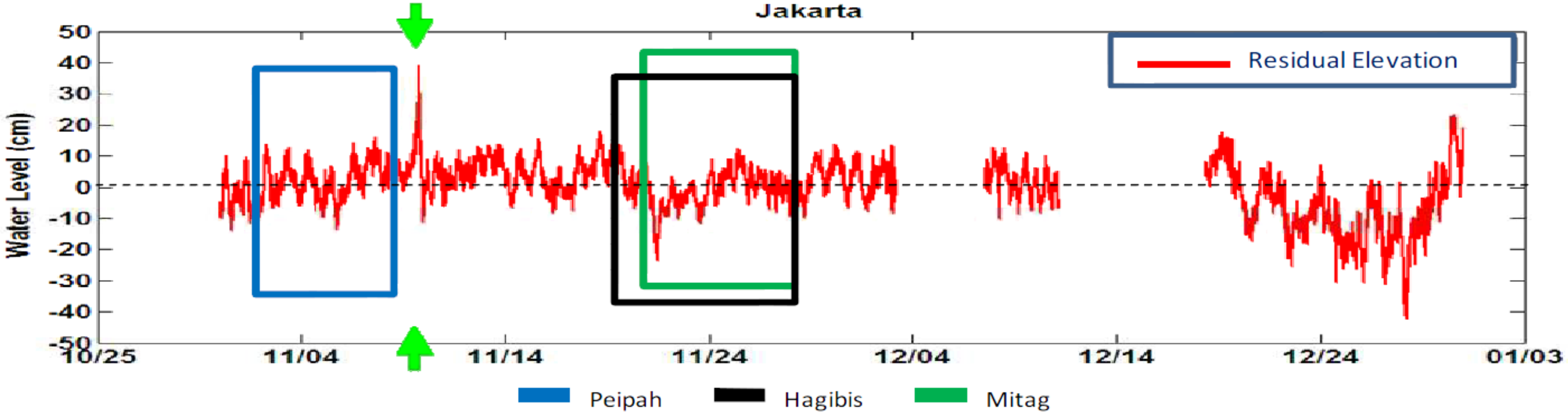


Figure 4-5: Residual sea level heights in the Jakarta coastal waters during the events of Cyclones Peipah, Hagibis and Mitag which caused flooding in the low-lying areas of the northern Jakarta (Ningsih *et al.*, 2011).

4.1.4-3 Relationship of *E. coli* and biophysicochemical properties of seawater

In this section, we focused on *E. coli* concentration and its relation to the physical, chemical and biological properties of the seawater. Table 4-3 summarizes the results of bivariate correlation and simple regression analysis between *E. coli* and other water parameters at different seasons in the Jakarta Bay.

From five physical parameters, three parameters showed moderate correlation, i.e. water transparency, TSS and turbidity, both in the early rainy season and late dry season. These parameters are associated with sedimentation rate in the water. Suspended solid in the water body provides suitable media for bacterial microorganisms, such as coliforms, to grow (Narkis *et al*., 1995). Relationship between *E. coli* and turbidity is also essential especially for the raw material of drinking water, where the median of turbidity should be below 0.1 NTU (Nephelometric Turbidity Unit) (Allen *et al*., 2008).

The impact of rainwater to the physical parameters can be observed from Figure 4-6 where the value of each parameter, in general, was lower than that of the late dry season. Temperature did not show strong correlation with *E. coli* (not shown in Table 4-3) because there was not significant difference in temperature between the early rainy season and late dry season.

Among the chemical parameters (Figure 4-7), pH exhibited a very strong correlation with *E. coli* in both seasons. Such strong negative correlation indicated that *E. coli* preferred to grow in a normal to an acidic environment. A laboratory experiment done by Jordan *et al*. (1999) proved that *E. coli* concentration was very high at pH 3.0 after 24-h incubation, and even some survivals could still be found after 3-days of experiment.

Table 4-3: Regression and correlation coefficients between *E. coli* concentration and other water parameters.

		Physical				Chemical					Biological			
		Transparency	Turbid	TSS	pH	COD	BOD	PO_4	NH_3	NO_3	Coliforms	Phytoplankton	Zooplankton	WPI
E. coli	r	-.672**	-.679**	.399*	-.697*	-.551**	-.027	.740**	.676**	.054	.984**	.566**	.526**	.605**
(Nov 2007)	Sig	.000	.000	.024	.000	.001	.883	.000	.000	.768	.000	.001	.002	.000
	r^2	.452	.461	.160	.486	.304	.001	.548	.457	.003	.968	.320	.277	.366
E. coli	r	-.729**	.581**	.644**	-.814**	.871**	.875**	.404*	.453**	.665**	.983**	-.511**	-.523**	.942**
(Aug 2008)	Sig	.000	.000	.000	.000	.000	.000	.022	.009	.000	.000	.003	.002	.000
	r^2	.531	.337	.415	.663	.759	.765	.163	.205	.443	.967	.261	.274	.886

*: significant; **: highly significant

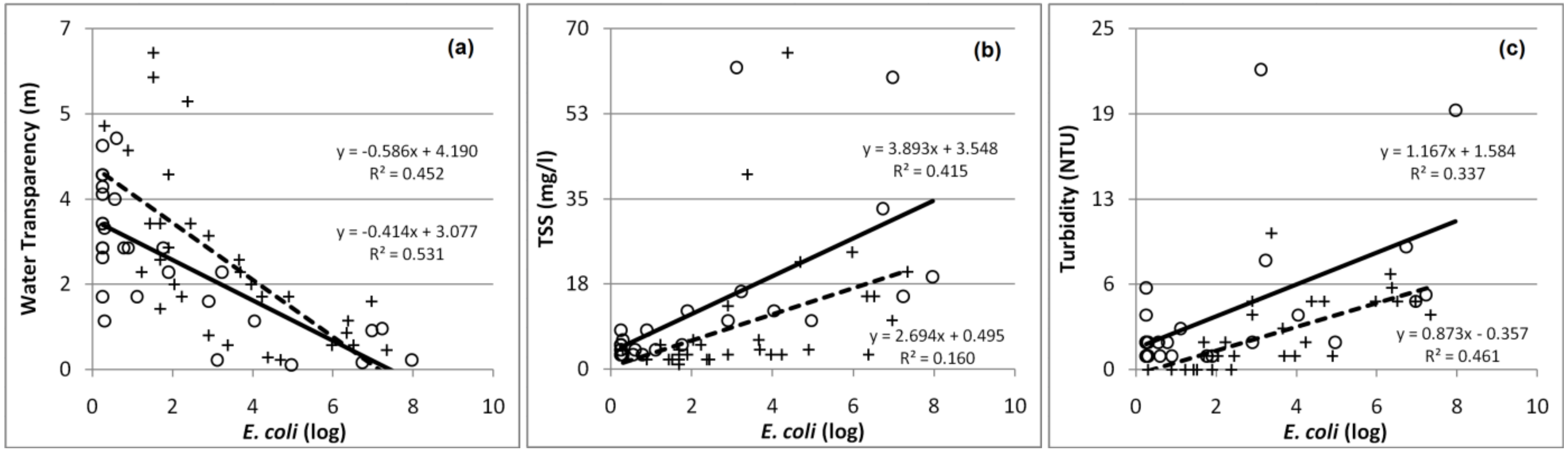


Figure 4-6: Relationships between *E. coli* and biological parameters, i.e. water transparency (a), total suspended solid (TSS) (b) and turbidity (c), in the early rainy season (+ / ---) and late dry season (○ / —).

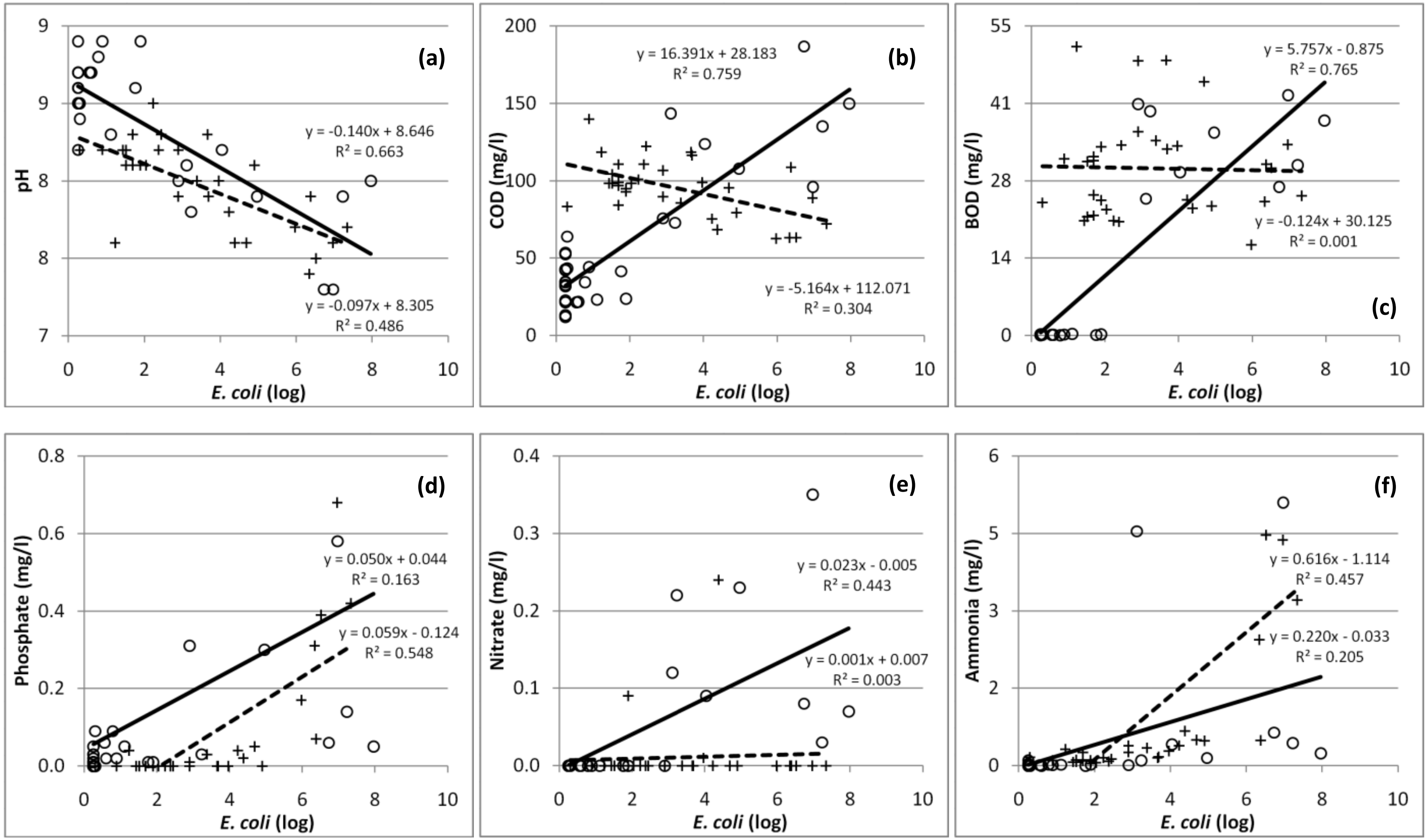


Figure 4-7: Relationships between *E. coli* and chemical parameters, i.e. pH (a), chemical oxygen demand (COD) (b), biological oxygen demand (BOD) (c), phosphate (d), nitrate (e) and nitrite (f), in the early rainy season (+ / ---) and late dry season (○ / —).

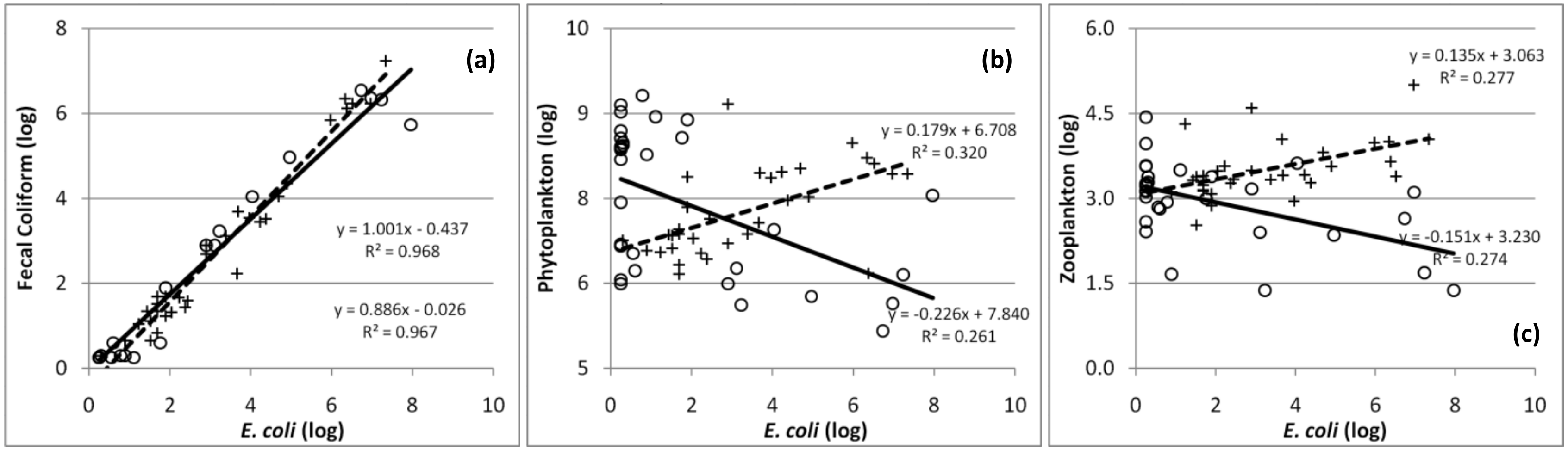


Figure 4-8: Relationships between *E. coli* and biological parameters: i.e. fecal coliform (a), phytoplankton (b) and zooplankton (c) in the early rainy season (+ / ---) and late dry season (○ / —).

Among oxygen-related parameters like DO, BOD and COD, two parameters, i.e. COD and BOD, showed high positive correlation with *E. coli* in the late dry season. COD is a very important indicator for *E. coli* growth as it measures the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as ammonia and nitrate. BOD also showed a strong positive correlation with *E. coli*. As shown in Figure 4-7, BOD and COD concentrations in the late dry season were linearly correlated. However, in the early rainy season, the relationship between *E. coli* and BOD/COD was not so clear. The relationship between COD and BOD is actually not necessarily to be linear in nature. However, the study done by Jin *et al*., (2009) concluded that in the water containing relatively high concentration of sewage contamination, a linear correlation could exist.

The relationships between *E. coli* and other chemical parameters like phosphate, nitrate and ammonia exhibited from low to moderate correlations based on pearson-r coefficients as presented in Table 4-3. The correlation of these parameters was not clearly understood and the role of rainwater to these parameters was not clear either. Suppostedly, *E. coli* should have a strong linear relationship with those three elements. The presence of high organic matter and nutrients, such as phosphorus and nitrites in the seawater can increase the bacterial colony, e.g. *E. coli*, as reported by Jalal *et al*. (2010) and Gauthier *et al*. (1993). Therefore, more field surveys are required, especially in the extreme conditions like in mid rainy and mid dry season, in order to get more precise data.

Beside physicochemical parameters, which their contibution is very important in creating a suitable enviroment for *E. coli* growth, some biological parameters were also analyzed in this study. There were three biological indicators measured during the survey, i.e. fecal coliforms, phytoplankton and zooplankton. The results revealed that *E. coli* showed strong correlations with fecal coliforms in both seasons (R^2 = 0.967–0.968, P <

0.001), because in fact *E. coli* is one type of fecal coliforms. The environmental conditions which are suitable for *E. coli* growth are also suitable for other fecal coliform bacteria, hence the relationship between those two bioindicators was nearly perfect (Figure 4-8a). On the contrary, the relationship with macrobenthos was insignificant. As organisms living on sediment, macrobenthos is not easily influenced by the changes in the seawater properties.

An interesting fact can be observed in the phytoplankton and zooplankton relationships to *E. coli*. In the late dry season, though the correlation coefficient was only 0.261 for phytoplankton and 0.274 for zooplankton, but the trend line was able to describe their association in nature. The negative linears shown in Figures 4-11b-c explain that the more the water got polluted, the less the number of phytoplankton and zooplankton was found. A study of Fachrul and Syach (2006) in the Jakarta Bay reported that biodiversity index of phytoplankton in the polluted area was around 0.26, similarity index was close to 0, and dominance index was nearly 1, meaning that only one species was dominating the polluted area.

Different situation occured in the early rainy season, where a positive correlation occurred both for phytoplankton and zooplankton. The average concentration of phytoplankton in the onshore area was higher ($\bar{x} = 7.94$, $\sigma = 0.53$) compared to the one in the offshore area ($\bar{x} = 7.04$, $\sigma = 0.47$). The same situation was performed by zooplankton, where the average concentration was $\bar{x} = 3.94$, $\sigma = 0.58$ for the onshore and $\bar{x} = 3.34$, $\sigma = 0.37$ for the offshore area.

The reason for high concentration of phytoplankton and zooplankton found in the onshore area during the early rainy season could be related with the occurrence of high precipitation. Rainfall intensity and nutrients upload from land and river systems might have triggered phytoplankton to start multiplying their population. Within this period, upwelling often occurs, nutrient enrichment takes place and sometimes this may lead to the alga bloom phenomenon (Sellner *et al*., 2003). Many studies have reported that, with this kind of circumstances, phytoplankton, and then followed by zooplankton, is very sensitive to the increase of nutrient elements introduced by rainwater (Sellner *et al*., 2003; Lee *et al*., 2009) and the growth of some phytoplankton species respond very quickly to the rainfall (Al-Homaidan and Arif, 1998).

4.1.4-4 River fluxes and hydrodynamic processes in the Jakarta Bay

Understanding of *E. coli* concentration and water pollution in the Jakarta Bay is related to the ecosystem dynamics of the bay. Unfortunately, this study did not discuss much about this part. Koropitan *et al.* (2009) has examined the ecosystem dynamics in Jakarta Bay using a three-dimensional coupled hydrodynamic–ecosystem model. The model concludes that Jakarta Bay is mainly controlled by its adjacent water (*e.g.* Java Sea). The model shows that physical processes have a direct impact on temporal and spatial distributions of the bay ecosystem. The nutrient sources from rivers are strongly influenced by rainy and dry seasons. In general, the higher concentrations of nutrients are found along the coast and near river mouths, suggesting that river flux is a major source of the nutrients. The numerical ecosystem model done by Yanagi (2011) clarifies that the biochemical characteristics of eutrophicated Jakarta Bay and the relatively pristine Banten Bay are generally higher in rainy season than in dry season. More detail explanations can be achieved in the above mentioned references.

4.1.5 Conclusions

This section presents a study on water quality assessment of the seawater in the Jakarta Bay using Nemerow-Sumitomo WPI by comparing datasets taken from different seasons, i.e. the early rainy season (November 2007) and late dry season (August 2008), with special information on *E. coli* and water parameters relationships. A total of 32 stations were taken from the Jakarta Bay, covering both onshore and offshore stations, with about 30 water parameters measured at each station. The water quality data was provided by the Jakarta Environmental Management Board.

Most of the WPI in the sampling stations fall within slightly polluted criteria, with 62.5% and 50% for the early rainy and late dry season, respectively. More polluted waters were concentrated nearby the onshore area, while the offshore area was relatively cleaner. The results also show that more polluted stations happened during in the early rainy season compared to the late dry season. Although, in general, the average value of most parameters reduced during the early rainy season, but the rainwater supply was able to wash out the polluted river water to enter the Jakarta bay, generating more polluted water in the bay.

Most of the biophysicochemical properties of seawater in the Jakarta Bay had significant correlations with *E. coli* concentration, in which some of those parameters were very essential for *E. coli* growth. The concentration level of most water parameters can also be distinguished between offshore and onshore areas; where high concentration values occurred mostly in the onshore area with some already exceeded the PVs.

The concentration of water properties was also very responsive to precipitation. The rainwater supply that flowed away from land (river systems) had two important roles in this system; one was related to its capacity in diluting seawater and the other one was related to its capacity in forcing out the polluted water in the river systems to enter the Jakarta Bay, so that the bay was more polluted during the early rainy season.

4.2 Assessment of heavy metals and nutrients status in the seawater, sediment and seagrass in Banten Bay and their distributional patterns

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4.2.1 Introduction

The Banten Bay is located northwest of Java Island, Indonesia, approximately 65 km from the Jakarta Bay. Space limitations in the Jakarta Bay have led to the industrialization of the Banten Bay and Ciujung River. Other human activities, such as paddy farming, aquaculture, settlements, and capture fisheries, also occur in the bay. Hence, the bay is very susceptible to heavy metal and nutrient contamination.

Large areas of seagrass, coral reefs, and mangroves in the Banten Bay collectively provide suitable breeding, nursery grounds and shelter for hundreds of demersal and pelagic fish species (Kiswara *et al*., 1991). Marine flora and fauna including seagrass, fish and bivalves have the capacity to absorb heavy metals and nutrients from both sediments and seawater (Nicolaidou and Nott, 1998; Stapel *et al*., 1996). Therefore, the assessment of heavy metals and nutrients is very important to ensure ecosystem sustainability in the Banten Bay.

The Banten Bay is very dynamic where seasonal monsoons and water currents play important roles in shaping coastlines (Kesumajaya, 2010), protecting coral reefs (Hoitink and Hoekstra, 2003), and distributing sediments (Hoitink and Hoekstra 2005; Helfinalis, 2002).

4.2.2 Objectives

The objectives of this section were (1) to evaluate heavy metal and nutrient concentrations in the seawater, seagrass, and sediments by conducting field experiments and (2) to understand the distributional patterns of heavy metals and nutrients in the Banten Bay using geographic information systems (GIS) technology.

4.2.3 Materials and methods

Field sampling was performed on August 24–25, 2010 in the Banten Bay (Figure 4-9 and 4-10). Seawater and sediment samples were collected from 16 stations, and seagrass samples were collected from six stations. The seawater and sediment samples were taken from the surface water (<10 cm depth) and surface sediments (<10 cm depth), respectively, whereas the seagrass samples of *Enhalus acoroides* were taken by snorkeling.

4.2.3-1 Chemical data analyses

Chemical analyses were performed at the Soil and Plant Laboratory of the Southeast Asian Regional Centre for Tropical Biology (SEAMEO-BIOTROP), Bogor, Indonesia. Table 4-4 summarizes the heavy metals and nutrients and the corresponding analytical methods used in this study.

4.2.3-2 Seawater data analyses

The concentrations of heavy metals, including iron (Fe), copper (Cu), zinc (Zn), cadmium (Cd), and lead (Pb), and an alkali metal, potassium (K), in the seawater were determined using the American Public Health Association 3111-B (APHA 3111-B) method (Clesceri *et al*., 1998). This method could detect the concentrations of these metals in an aliquot portion of stabilized hot acetic-acid extract via flame atomic absorption spectrophotometry (AAS; Analytik Jena Type Nova 300, Germany) using acetylene gas (C_2H_2) at 190–870 nm.

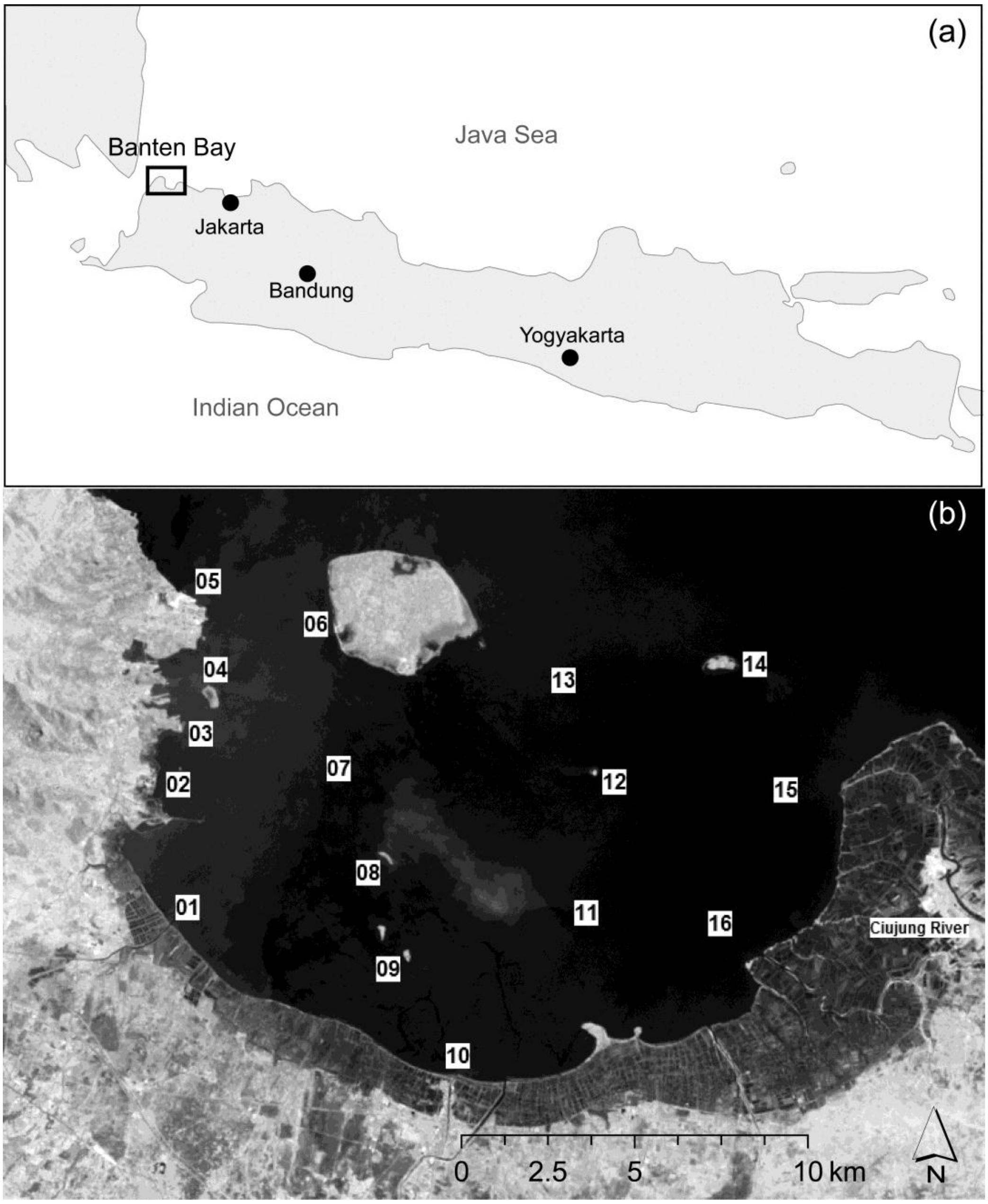

Figure 4-9: Location of the Banten Bay (a) and the sampling stations (b) for seawater and sediments (station No. 1 to 16) and seagrass (station No. 2, 3, 4, 6, 8, and 9).

Figure 4-10: Some activities during the field sampling in Banten Bay.

Table 4-4: Analytical methods used for heavy metals and nutrients in seawater, sediments, and seagrass (leaves and corms).

Element	Analytical Method	
	Seawater	*Seagrass / sediment*
Heavy metals		
Iron (Fe)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (AAS)
Copper (Cu)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (AAS)
Zinc (Zn)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (AAS)
Cadmium (Cd)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (AAS)
Mercury (Hg)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (AAS)
Lead (Pb)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (AAS)
Nutrients		
Potassium (K)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (flamephotometry)
Phosphorus (P)	APHA 4500-P E	Extract HNO_3-$HClO_4$ (spectrophotometry)
Nitrogen (N)	SNI 06-6989.52-2005	SNI 13-4721-1998

AAS: Atomic Absorption Spectrophotometry (AAS)

Phosphorus (P; in orthophosphate - PO_4 form) in the seawater was measured using the Indonesian National Standard (SNI) method No. 06-6989.31-2005, which was adopted from APHA 4500-PE. Principally, ammonium molybdate and potassium antimonyl tartrate reacted in acid medium with orthophosphate to form a heteropoly acid (*i.e.*, phosphomolybdic acid), which was reduced to intensely colored molybdenum blue by ascorbic acid. The sample was then measured using a spectrophotometer at 880 nm.

Dissolved organic nitrogen (DON) in the seawater was measured using the SNI method No. 06-6989.52-2005 that utilized macro-Kjeldahl coupled with titrimetry. The sample was treated with a digestion mixture of copper sulfate and sulfuric acid. After heating thoroughly, the sample was made alkaline with sodium hydroxide sodium. Ammonia was then distilled from the mixture, trapped in a boric acid-indicator solution, and finally titrated with sulfuric acid.

4.2.3-3 Seagrass and sediment data analyses

Previous studies focusing on heavy metal and nutrient concentrations in seagrass used different units (wet or dry weight), sample treatments (cleaned or uncleaned), and sample parts (leaf, root, corm, rhizome, and stem). Nienhuis (1986) presented the results in wet weight, whereas most studies have used dry weight. Nicolaidou and Nott (1998) separated the plants into leaves, roots and stems for both cleaned and uncleaned samples, whereas other studies handled the samples differently. In this study, the seagrass samples were divided into two parts, leaves and corms, cleaned before analysis, and measured in dry-weight units.

Fe, Cu, Zn, Cd, Hg, Pb, P and K concentrations in the seagrass and sediments were determined using the HNO_3-$HClO_4$-extraction method (Burt, 2004; Rayment and Higginson 1992). A 0.5-mm seagrass sample weighing 1.0 g was put in the digestion flask. After adding 5 ml of 65% HNO_3 and 0.5 ml of 70% $HClO_4$, the sample solution was slowly shaken and stored overnight. Later, the sample solution was placed in a digestion block at 100°C, and after the yellow steam disappeared, the temperature was increased to 200°C. The destruction process was ended when white steam appeared, and the solution in the flask remained at 0.5 ml. After cooling, the sample was diluted with 0.1 N HNO_3 until a 50-ml volume was obtained. Once it was homogenous, the sample was filtered using filter paper (Whatman-41 type) to obtain the seagrass extract.

The sediment extract was generated using the above procedure. The only difference was the utilization of distilled water instead of 0.1 N HNO_3 for diluting the sample solution. The rest of the procedure was unchanged.

After both extracts were obtained, the heavy metals (Fe, Cu, Zn, Cd, Hg and Pb) were measured using hydride-system AAS (Analytik Jena Types Nova 300 and HS 60, Germany), K was measured using flame atomic emission spectrophotometry (flamephotometry), and P was measured using simple spectrophotometry (Cecil CE 1020 scanning, England) at 693 nm.

The total nitrogen (T-N) in sediments was measured using SNI method No. 13-4721-1998. Approximately 0.5 g of the 0.5-mm sample was put into a 100-ml Kjeldahl flask, and 10 ml of concentrated H_2SO_4 solution was added to the flask. The flask was slowly shaken until the sample was fully soaked with H_2SO_4, and then 0.1 g of a selenium mixture catalyst was added to the flask. The flask was heated at 200°C for 10 min, and then the temperature was increased to 340°C and kept constant until complete destruction of the sample was confirmed. After cooling, a few drops of a phenolphthalein indicator were added by dripping. In the Kjeldahl distillation unit (Buchi K-350, Switzerland), 20 ml of 50% NaOH was gradually added into the sample until it became alkaline. During the distillation process, the distillate was collected in an Erlenmeyer flask containing 10 ml of H_3BO_3 and five drops of Conway indicator (0.3 g of bromocresol green + 0.2 g of methyl red + 20% ethanol) until a volume of 100 ml was obtained. The distillate was titrated with 0.02 N HCl until the solution color changed from green to pink. The blank solution was also titrated.

A similar procedure was applied to measure T-N in the seagrass samples. The only difference was at the step when the sample was cooled down after being heated at 340°C. In this case, the seagrass sample was diluted with 50 ml of distilled water and stirred. When a homogenous solution was obtained, the sample solution was filtered with a filter paper, and 10 ml of the concentrated solution was removed by pipette and placed in the distillation flask. From this point onward, the rest of the procedure was unchanged.

4.2.3-4 Spatial distribution maps

Ocean Data View (ODV) software version 4.2.1 (Alfred-Wegener Institute [AWI] for Polar and Marine Research, Bremerhaven, Germany) was employed to create distribution maps of the examined elements. The maps were produced from data points using the Data-Interpolating Variational Analysis (DIVA) gridding technique.

4.2.4 Results and discussion

4.2.4-1 Heavy metal and nutrient concentrations in the seawater

Table 4-5 summarizes the heavy metal and nutrient concentrations in the seawater samples from the 16 stations in the Banten Bay. Among the heavy metals, the Cd and Pb concentrations were below the sensitivity limits (<0.007 and <0.006 mg/l, respectively) at all stations. Other metals, i.e. Fe, Zn, and Cu, were detected only at some stations, but the mean concentrations were still below the maximum permissible values (PVs) as determined by the Ministry of Environment of Indonesia regulation No. 51/2004 regarding the standard quality of seawater (for marine biota).

Of the nutrients, the P (in PO_4 form) concentrations exceeded the designated PVs at almost all stations. The mean concentration of P was 0.066 ± 0.031 mg/l, which is far above its designated PV (0.015 mg/l). The oversupply of P in the coastal environment may cause eutrophication that can trigger algal blooms (Bennett *et al*., 2001). Anthropogenic sources of P include fertilizers, wastewater and detergents (Reimann and Caritat, 1998).

K concentration, although very high in seawater, may differ in each area. The mean concentration of K in the Banten Bay was 462.70 ± 183.68 mg/l, which was above its natural concentration (392 mg/l) at 3.5% salinity (Turekian, 1968). Fertilizer application is the main anthropogenic source of K (Reimann and Caritat, 1998), and K evaporites (such as KCl) are extremely soluble and can lead to high K concentrations in brines (Salimen *et al*., 2006).

Mean concentration of DON in the seawater in this study was 1.21 ± 0.33 mg/l. Organic nitrogen, including urea, amino acids, and proteins, is the main source of T-N in the seawater. It is transported to the ocean by river discharge (Seitzinger and Sanders, 1997).

4.2.4-2 Heavy metal and nutrient concentrations in the seagrass

Table 4-6 presents the results of the heavy metal and nutrient concentrations in the seagrass at the six stations. The concentrations of Pb (leaves and corms) and Cd (corms) were below the limit of detection at all stations. However, the mean concentration of Cd in leaves was 0.48 ± 0.36 ppm, which was lower than Cd concentrations found in seagrass leaves of *Cymodocea rotundata* (1.83 ± 1.12 ppm) collected from three islands near the Jakarta Bay (Kiswara *et al*., 1990) and seagrass leaves of *C. nodosa* (1.2 ± 0.2 ppm) found in Larymna Bay, Greece (Nicolaidou and Nott, 1998).

Table 4-5: Heavy metal and nutrient concentrations in the seawater of the Banten Bay.

Element (mg/l)	Station																PV
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Fe	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	0.027	0.030	0.016	0.037	0.015	*nd*
Cu	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	0.009	0.034	< *dv*	0.008
Zn	0.011	< *dv*	0.020	< *dv*	< *dv*	< *dv*	0.034	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	0.011	< *dv*	0.050
Cd	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	0.001
Pb	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	< *dv*	0.008
Hg	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	0.001
PO_4	0.16	0.05	0.05	0.07	0.06	0.04	0.07	0.07	0.04	0.05	0.04	0.10	0.09	0.04	0.05	0.07	0.015
K	554.20	480.50	582.20	591.00	506.00	*na*	*na*	541.40	515.60	545.30	508.20	514.60	545.10	454.40	540.40	523.60	*nd*
DON	1.54	1.54	1.54	1.54	0.92	1.23	1.54	0.92	0.92	0.92	0.92	0.92	1.23	0.92	1.85	0.92	*nd*

PV: permissible value, determined by the Ministry of Environment of Indonesia, regulation No. 51/2004 regarding standard quality of seawater (for marine biota)

nd: not determined by the above regulation

na: not analyzed

dv: detectable sensitivity limit: 0.009 mg/l for Fe; 0.007 mg/l for Cd; 0.006 mg/l for Cu and Pb

Table 4-6: Heavy metal and nutrient concentrations in the seagrass leaves and corms of the Banten Bay measured in dry weight based.

Element	Unit	Station No. 2		Station No. 3		Station No. 4		Station No. 6		Station No. 8		Station No. 9	
		Leaves	Corms	Leaves	Corms	Leaves	Corms	Leaves	Corms	Leaves	Corms	Leaves	Corms
Fe-total	%	0.12	0.46	0.12	0.31	0.22	0.25	0.07	0.22	0.40	0.26	0.21	0.46
Cu-total	ppm	9.08	10.18	7.12	5.62	8.80	8.59	8.84	6.34	7.07	3.97	5.43	4.91
Zn-total	ppm	195.5	103.4	72.48	57.50	94.06	102.3	98.09	90.12	74.47	76.03	51.85	76.76
Cd-total	ppm	1.05	< dv	0.73	< dv	0.47	< dv	0.28	< dv	0.26	< dv	0.07	< dv
Pb-total	ppm	< dv	< dv	< dv	< dv	< dv	< dv	< dv	< dv	< dv	< dv	< dv	< dv
Hg-total	ppm	0.027	0.034	0.096	< 0.00001	0.027	0.008	0.040	0.028	0.014	0.006	0.102	0.004
P_2O_5-total	%	0.25	0.21	0.20	0.14	0.28	0.24	0.26	0.24	0.29	0.17	0.27	0.33
K_2O-total	%	4.41	3.13	3.32	2.56	4.19	3.27	3.37	8.53	4.17	2.81	3.05	3.64
N-total	%	2.26	1.61	1.92	0.74	2.54	1.84	2.41	1.41	2.33	1.05	2.54	1.22

dv: detectable sensitivity limit: 0.007 mg/l for Cd; 0.006 mg/l for Cu and Pb

The Cu concentrations in the leaves and corms were 7.72 ± 1.44 and 6.60 ± 2.35 ppm, respectively. These concentrations were higher than those found in *C. rotundata* in the Jakarta Bay, where the mean concentrations in the leaves and corms were 6.17 ± 1.69 and 5.83 ± 1.33 ppm, respectively (Kiswara *et al.*, 1990). The concentrations were also higher than those in found in Larymna Bay (5.24 ± 0.4 and 1.10 ± 0.40 ppm, in leaves and corms, respectively; Nicolaidou and Nott, 1998).

Similarly, the mean concentrations of Zn in the seagrass leaves (97.75 ± 50.72 ppm) and corms (84.30 ± 17.64 ppm) were higher than those in the Jakarta Bay (Kiswara *et al.*, 1990) and Larymna Bay (Nicolaidou and Nott, 1998). Meanwhile, the mean concentrations of Zn were 60.83 ± 29.36 and 40.67 ± 21.95 ppm in the leaves and corms of *C. rotundata* in the Jakarta Bay and 57.5 ± 6.2 and 23.0 ± 19.5 ppm in the leaves and corms of *C. nodosa* in Larymna Bay, respectively.

The mean concentrations of Hg were 0.051 ± 0.038 ppm (leaves) and 0.016 ± 0.014 ppm (corms). As a comparison, the average Hg concentration found in two seagrass species from locations near contaminant sources in the Gulf of Mexico was 0.0231 ppm (Lewis and Chancy, 2008). The mean concentrations of Fe at the study site were 0.19 ± 0.12 and 0.33 ± 0.11 % in the leaves and corms, respectively.

Among nutrients, the T-N and P concentrations play important roles in seagrass ecosystems. Duarte (1990) compiled N- and P-content measurements from the literature for 27 seagrass species from 30 locations and found that the mean concentrations of N and P in the seagrass leaves were 1.92 ± 0.05 and 0.23 ± 0.01 % dry weight, respectively. Meanwhile, the mean concentrations of N and P in our study were 2.33 ± 0.23 and 0.26 ± 0.03 % in the leaves and 1.31 ± 0.40 and 0.22 ± 0.07 % in the corms, respectively. The mean K concentrations in the seagrass leaves and corms were 3.75 ± 0.57 and 3.99 ± 2.26 %, respectively.

4.2.4-3 Heavy metal and nutrient concentrations in the sediment

Table 4-7 lists the heavy metal and nutrient concentrations in sediment samples from the 16 stations. The minimum, maximum, and the mean ± SD concentrations of Cu were 3.29, 10.44, and 6.32 ± 2.27 ppm, respectively. These values are lower than the Threshold Effects Level (TEL) (18.7 ppm) defined in the North Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Tables (Buchman, 2008) and are also lower than values measured in the Jakarta Bay in 1982 (11.8, 82.9, and 28.59 ± 13.22 ppm, respectively; Marsh, 1992) and 2004 (0.82–74.70 ppm; Rochyatun and Rozak, 2008).

The minimum, maximum, and the mean ± SD concentrations of Pb were <0.006, 17.34, and 5.99 ± 6.17 ppm, respectively, lower than its TEL (30.2 ppm) and the Pb concentrations measured in the Jakarta Bay in 1982 (9.0, 438.0, and 41.73 ± 77.77 ppm, respectively; Marsh, 1992) and 2004 (3.64 – 53.00 ppm; Rochyatun and Rozak, 2008).

For Hg, although the concentrations in some stations exceeded the TEL, the mean concentration (0.104 ± 0.067 ppm) was below the TEL (0.13 ppm). This Hg concentration was also lower than that measured in the Jakarta Bay in 1982 (0.49 ± 0.79 ppm; Marsh, 1992) and that measured in Candarli Gulf, Turkey in 2009 (0.2 – 6.3 ppm; Pazi, 2011).

The mean concentrations of Zn and Cd were 169.17 ± 54.21 and 1.42 ± 1.15 ppm, respectively. In both cases, these values exceeded their TELs (Zn: 124 and Cd: 0.68 ppm) but were below the concentrations measured in the Jakarta Bay in 2004 (Zn: 53.87–497.53; Cd: <0.001–40.60 ppm; Rochyatun and Rozak, 2008). However, the concentration of Zn was higher than that measured in the Candarli Gulf (55–119 ppm; Pazi, 2011).

Table 4-7: Heavy metal and nutrient concentrations in the sediments of the Banten Bay.

Element	Station No.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Fe-total [a]	6.37	0.96	3.42	0.8	3.69	0.41	5.27	10.58	0.99	6.42	5.11	5.66	5.61	0.71	5.60	6.05
Cu-total	9.82	5.05	6.92	4.48	4.68	4.28	8.47	5.22	4.62	10.44	7.34	8.07	8.72	3.29	6.29	3.44
Zn-total	198.9	152.4	135.0	94.5	186.1	78.6	224.8	190.1	104.62	233.8	204.4	217.7	232.4	81.8	182.8	188.8
Cd-total	0.27	2.86	1.63	2.82	2.13	3.13	0.43	1.05	2.76	0.43	0.49	0.54	0.47	2.95	0.42	0.30
Pb-total	16.20	17.34	10.36	13.32	10.07	9.87	2.42	4.62	7.09	4.5	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006
Hg-total	0.094	0.039	0.050	0.047	0.051	0.043	0.174	0.201	0.069	0.124	0.150	0.191	0.235	0.056	0.102	0.037
P_2O_5-total	951.3	491.1	715.1	518.7	746.9	410.9	802.7	2,558	676.0	1,109	771.0	1,373	966	606.0	997.0	805.0
K_2O-total [a]	0.77	0.68	0.56	0.51	0.46	0.38	1.07	1.28	0.53	0.84	1.18	1.10	1.10	1.36	2.67	2.67
N-total [a]	0.67	0.38	0.64	0.32	0.27	0.24	0.47	0.44	0.36	0.79	0.71	0.66	0.78	0.26	0.27	0.49

All concentrations are given in parts per million (ppm) dry weight, unless specified otherwise.
[a] indicates percentage dry weight.

Regarding comparisons with other regions, the mean concentrations of Cu, Pb, Hg, Zn and Cd in sediments measured in this study were higher than those measured in Gökova Bay, Turkey (Balkis *et al*., 2010), as well as those found in seven seagrass beds in Florida (but excluding the concentrations of Cu and Pb in the seagrass-vegetated area of Little Sabine Bay, Florida) (Lewis *et al*., 2007).

Zn, Cu, Hg, Cd, and Pb are very important and widely used in many industrial activities including mining, coal and waste combustion, steel processing, and paint, rubber, and dry batteries production (Salimen *et al*., 2006); some of those industries do exist in the Banten Bay. Industrial expansion, coupled with many other human activities in the western part of the Banten Bay, has put the ecosystem under heavy pressure (Hoekstra *et al*., 2003).

The maximum *PV* of Fe is not specified in the NOAA table; however, the background concentration in the table is 0.99–1.8 %. Meanwhile, the mean concentration of Fe in the study site was 4.23 ± 2.85 %, which was higher than the given background level. It was also higher than that found in the Candarli Gulf (1.62–3.60 %; Pazi, 2011).

The mean concentration of total P (P_2O_5) was 906.06 ± 504.17 ppm, which was higher than the mean concentrations of 628.1, 676.3, and 682.6 ppm found in the Zhuyuan, Bailonggang (both in Chanjiang Estuary), and Xinghuo outfalls (Hangzhou Bay), China, respectively (Li *et al*., 2003). Steel processing is one of the anthropogenic sources of Fe in the environment (Reimann and Caritat, 1998). Fertilizers and herbicides may also contain Fe in the form of iron sulfate (Reimann *et al*., 2003).

The mean K (K_2O) concentration was 0.963 ± 0.551 %, which was lower than the median concentration of K_2O (1.71%, N = 4905) found in Japan's coastal sea sediments (Ohta and Imai, 2007). The T-N concentration of the study sites was 0.484 ± 0.196 %. For comparison, the T-N concentration in the surface sediment off the Tokai area in Japan ranges between 0.10 and 0.30 % (Maekawa and Komiya, 1999). The uses of N, P and K in fertilizers and detergents are among the most important anthropogenic sources of those elements in the environment (Reimann and Caritat, 1998).

4.2.4-4 Spatial distributions pattern of heavy metals and nutrients in the sediment

Spatial distribution maps for heavy metals (Figure 4-11) and nutrients (Figure 4-12) in the sediment of the Banten Bay were shown in. The spatial distributional patterns demonstrated the tendency of some heavy metals and nutrients (such as total Fe_2O_3, Zn, Cu, Hg, N, and P_2O_5) to be deposited in the center of the Banten Bay. In addition to the center of the bay, high concentrations of some elements (such as total Fe_2O_3, Zn, Cu, P_2O_5 and most prominently T-N) were also found near the river mouths. It was evident that organic and inorganic materials transported by river were deposited near the river mouths. In turn, the coastal waves and currents dynamically redistributed the pollutants to the middle of the bay.

The other three elements (*i.e.*, Cd, Pb, and K), exhibited different distribution patterns. The highest concentrations of total Cd and Pb were mostly localized near the industrial zone in the western part of the bay. Meanwhile, the highest concentration of K was localized in the eastern part of the bay (close to the mouth of the Ciujung River) in an area where a large part of the land is occupied by paddy farming. Although more evidence is required, the different distribution patterns exhibited by the above elements may be related to the sources of pollutants in the surrounding areas.

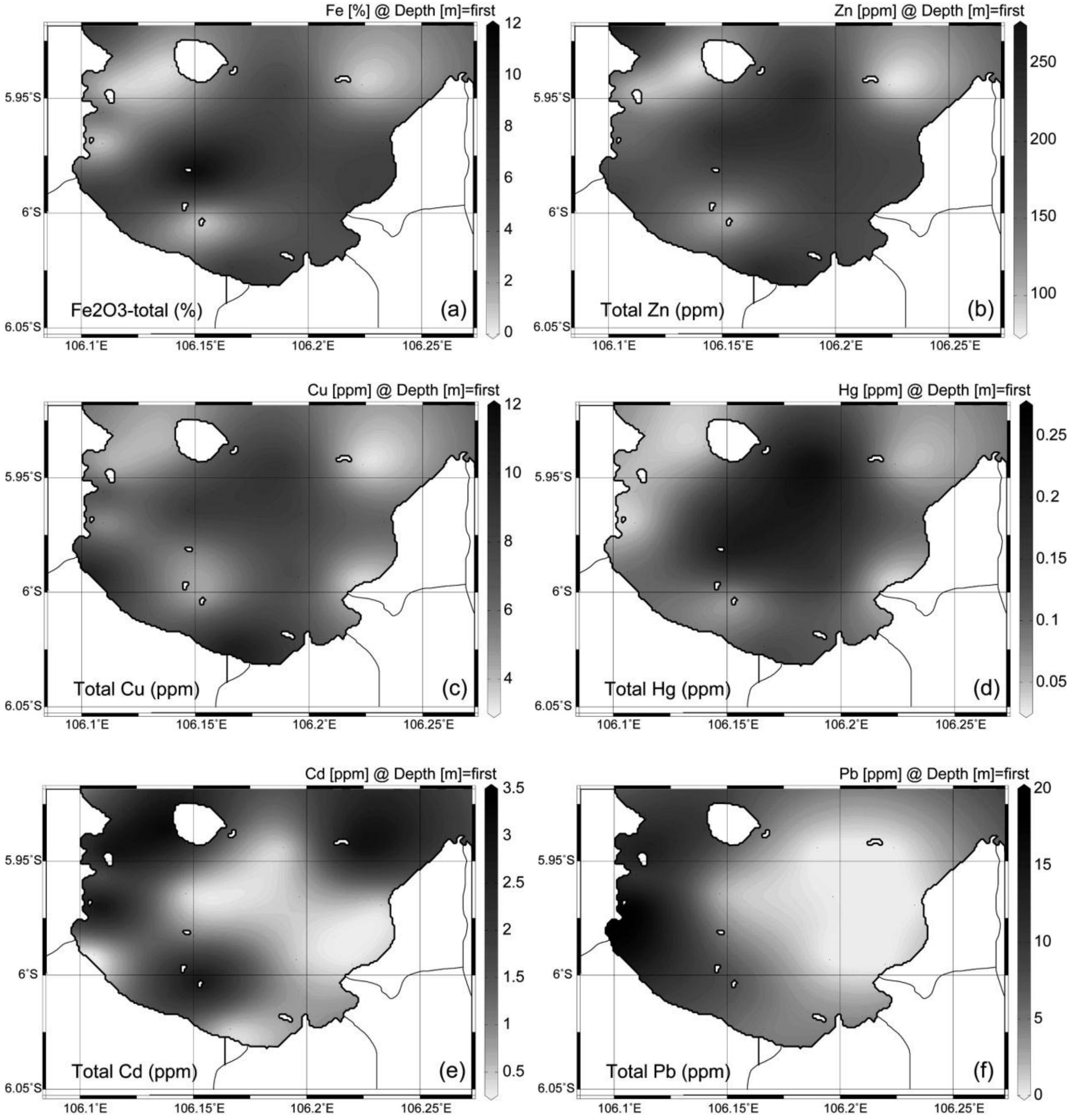

Figure 4-11: Spatial distribution patterns of heavy metals: i.e. total Fe_2O_3 (a), total Zn (b), total Cu (c), total Hg (d), total Cd (e) and total Pb (f), in the Banten Bay, interpolated from point data using data-interpolating variational analysis (DIVA) gridding method.

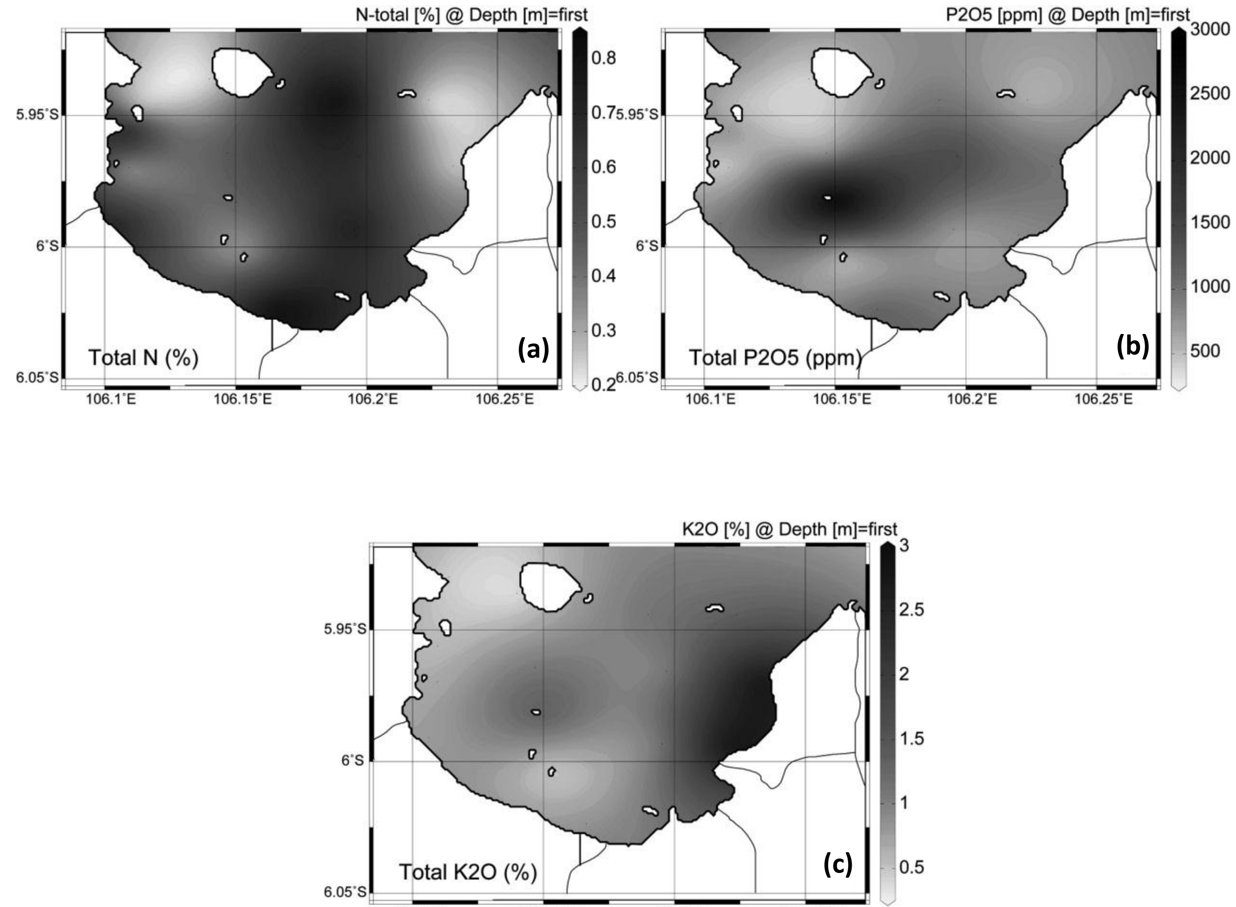

Figure 4-12: Spatial distribution patterns of nutrients: i.e. total N (a), total P_2O_5 (b) and total K_2O (c), in the Banten Bay, interpolated from point data using data-interpolating variational analysis (DIVA) gridding method.

4.2.4-5 Sediment fluxes and energy forces in the Banten Bay

The fact that high concentrations of heavy metals and nutrients (excluding Cd, Pb and K) were concentrated in the center of the bay was quite interesting. The Banten Bay is influenced by seasonal variations of the northwest and southeast monsoons, combined with bidirectional asymmetric diurnal tidal flows. These seasonal couplings between waves, wind-driven throughflow (Figure 4-13), river discharge and asymmetric tidal cycles (Figure 4-14) can generate a certain mechanism that leads to sediment deposition in the center of the bay (Hoitink and Hoekstra, 2003). This complex water current mechanism can help explain the distribution patterns of heavy metals and nutrients in Banten Bay. A study by Helfinalis (2002) also revealed a fluctuative sediment distribution in Banten Bay during four observation periods in 2001.

Hoitink (2003) elucidates that the Banten Bay is influenced by a typical monsoonal climate, resulting in clear seasonal cycles of wind and precipitation. As a result of the irregular topography and mixed diurnal-semidiurnal tidal motion, flow patterns in the Banten Bay are complex in space and time. Both tidal and subtidal currents are influenced by the exchange of seawater and tidal energy between the Java Sea and the Indian Ocean, which are interconnected by the Strait Sunda.

Hoitink and Hoekstra (2003) explain that during the westward tidal flow, sediment resuspended from the area of Ciujung river mouth is likely to settle in the center of the bay, because of the decrease in the sediment transport capacity of decelerating water mass as a result of the settling-lag/scour-lag mechanism. Analogous to the shoreward fining of bottom sediment in tidal inlets, which is associated with a shoreward decrease in tidal amplitude, this mechanism may explain why seafloor sediment in the center of the bay is significantly finer than in front of the inactive Ciujung delta. So far, this is the best research which can help elucidating the dynamic of sediment flux in the Banten Bay.

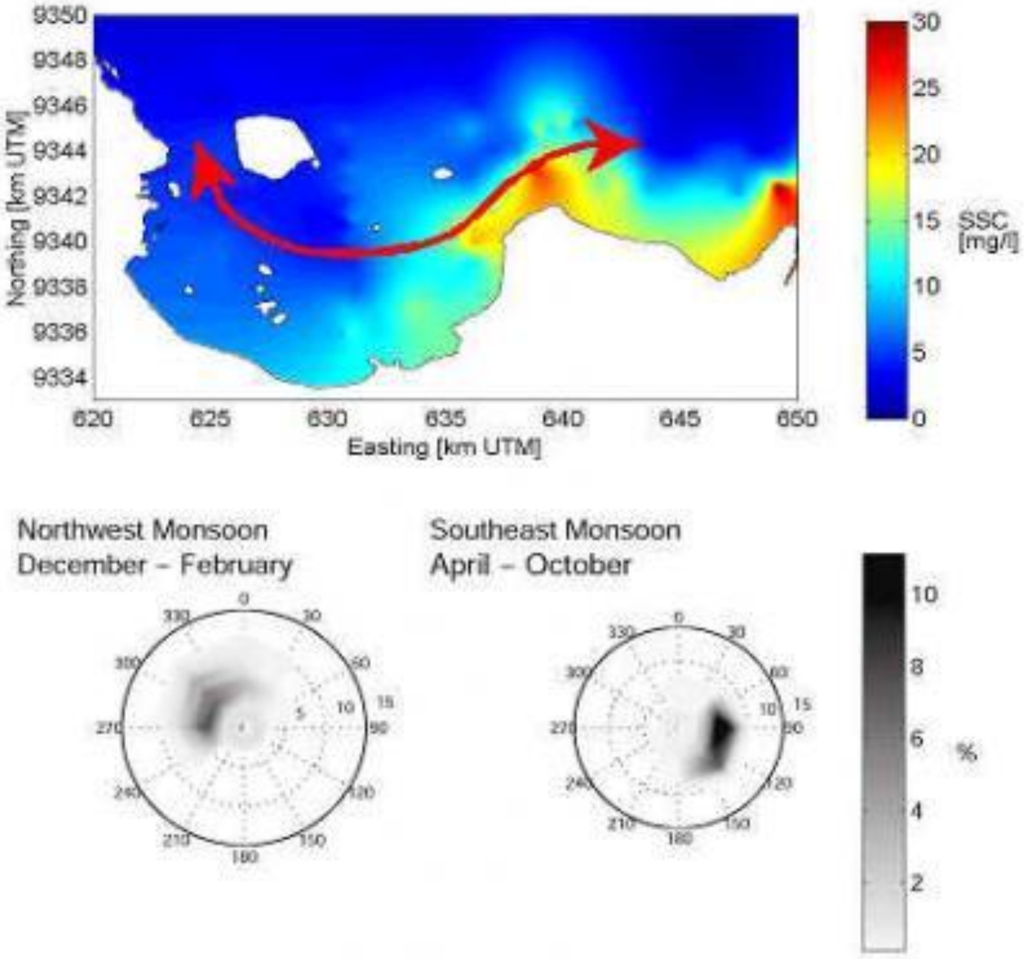

Figure 4-13: Monsoon driven throughflow in Banten Bay (Hoitink and Hoekstra, 2003).

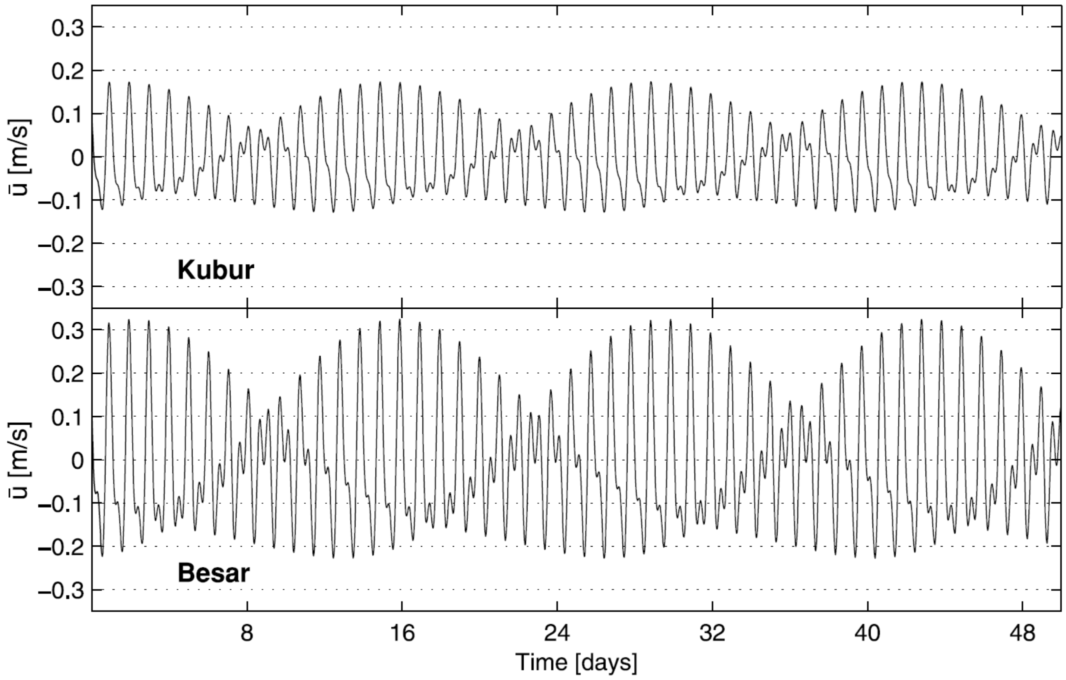

Figure 4-14: Asymmetric tidal cycles induced raise levels of suspended sediment concentration in Banten Bay (Hoitink and Hoekstra, 2003).

4.2.5 Conclusions

This section presents the concentrations of heavy metals and nutrients in the seawater, seagrass and sediment of the Banten Bay, based on field sampling data which was taken on August 24–25, 2010. Seawater and sediment samples were collected from 16 stations, and seagrass (*Enhalus acoroides*) samples were collected from six stations.

The results revealed that in general, the seawater in the Banten Bay was less polluted than that in the Jakarta Bay, although some elements were present at higher concentrations. Most of the heavy metal concentrations in the seawater were below detection limits.

All heavy metal concentrations in the sediment were also lower than those found in the Jakarta Bay and Gökova Bay, Turkey. Excluding total K, the mean concentrations of total P and N were also higher than those found in China and Japan, respectively.

In the seagrass, the concentrations of Fe (iron), Cu (copper), Zn (zinc), Hg (mercury), P (phosphorus), K (potassium), and N (nitrogen) were higher than those found in Seribu Islands (located in the northern area of the Jakarta Bay), Larymna Bay (Greece), and the Gulf of Mexico (concentrations of cadmium and lead were not). The distribution patterns of elements, such as Fe, Zn, Cd (Cadmium), Cu, Hg, N, and P, exhibited strong tendencies to accumulate in the center of the bay as a result of oceanographic processes. These results suggest that the combination of the northwest and southeast monsoons, bidirectional asymmetric diurnal tidal flows, wind-driven throughflow, and river discharge play important roles in sediment distribution in the Banten Bay.

Chapter V

General Discussion

5.1 Preamble

Ciliwung and Ciujung watersheds were taken as examples of urban and rural watersheds in Indonesia. This study focuses on the water quality assessment in both watersheds, including in the two river systems (Jakarta rivers and Ciujung River) and two bay ecosystems (Jakarta Bay and Banten Bay).

This study also includes the utilization of advance technology (hyperspectral spectroradiometer) to detect nutrients concentration contained in the leaves of two submerged coastal plants, i.e. seagrass (*Enhalus acoroides*) and brown algae (*Sargassum* sp.) at laboratory scale. The introduction of this technology in the water quality science can be combined with traditional chemical methods to improve the analysis.

Additionally, the problem in the watershed boundary and accuracy of some digital elevation models (DEMs) are also elaborated in this study. Finally, coupled with HSPF in the creation of hydrological simulation models could help enhance the analysis of this study.

5.2 The problem of watershed boundary

As a necessity in any ecology study and its components to have a boundary of the study area, hence it was important to have an accurate watershed boundary because this study was focusing on the water quality in two different watersheds. Therefore it was necessary to conduct this study since no standard and accurate watershed boundary was available. Of course some departments in Indonesia might have tried to use the same DEM sources for producing watershed boundaries for their own purpose, but at the time of the study there was no national-level consensus on which product we will deal with. The accuracy assessment of these DEMs to be used as sources for watershed boundary delineation was also unavailable for our region. Therefore, this study was very much essential to enrich the accurate information for the development of watershed boundary delineation in Indonesia.

In this study, we investigated the accuracy of watershed delineation in Ciujung watershed, Indonesia, using the ASTER GDEM compared with SRTM DEM and Topo-DEM. This study concluded that subwatershed boundaries produced from the ASTER GDEM, SRTM and Topo-DEM were highly congruent, especially in the high terrain areas. The accuracy of SRTM DEM was higher than ASTER GDEM, because it produced lower RMSE values than ASTER GDEM. Regarding the vertical accuracy, the three DEMs also showed significant correlations with the RTK-DGPS data. Again, SRTM DEM was vertically more accurate that ASTER GDEM. Their high accuracies supported that the idea that all these DEMs are adequate for hydrological studies. The results also indicate that the elevation values of ASTER GDEM and SRTM data are influenced by the presence of high objects.

The release of ASTER GDEM version 2 (GDEM2) in October 2011 (http://asterweb.jpl.nasa.gov) was expected to improve its previous version. However, this study proved that the vertical accuracy of GDEM2 was found to be lower than that of GDEM1 and the other DEMs. This lower accuracy was caused by the undulating effects, which were found in all observed stations. It was believed that the undulating effects might have been introduced during the validation process, perhaps due to cloud effect removal, land cover classification or other factors that are unknown to the authors.

5.3 Water quality in the urban and rural rivers

The first section of this river-water-quality study is about the investigation of the spatio-seasonal patterns of river- and groundwater quality in the city of Jakarta, Indonesia. This study is very important because many residents still heavily depend on groundwater resources, which they extract by direct self-pumping; hence, continuous consumption of this water may introduce some health risks. This study has proved that the river water in Jakarta was indeed highly polluted and that most of the stations were already beyond the critical level. The groundwater conditions were better, but some stations were already highly polluted. The water pollution of river- and groundwater appeared to be higher toward the northern region especially in the dry season. Therefore, it is recommended that the city residents be more careful about their consumption of water from groundwater aquifers extracted by self-pumping, especially in the northern regions and during the dry season.

On the contrary, the river water quality in Ciujung River was still cleaner compared to those in 13 rivers in Jakarta city. The analysis of Jongjing station (the most downstream station in Ciujung River) showed that most of water parameters were still below their ambient levels. Out of 41 water parameters, only nine parameters have shown their intensifying trends. Some even exceeded their corresponding ambient levels: turbidity, total suspended solids (TSS), chemical oxygen demand (COD), salinity, nitrite, phenol, potassium permanganate ($KMnO_4$) and *E. coli*. The high concentration of these parameters seemed to be related to the inputs from natural and domestic loads. Among the heavy metals, only iron which the mean concentration has reached 0.39 ± 0.57 mg/l, whereas its ambient level is 0.3 mg/l. The other concentrations of heavy metals were still below their ambient levels; however they exhibited the increasing trends during 10 years observation. The increasing heavy metal elements include chromium, lead, zinc, copper, cadmium and iron. Overall, this study has revealed that the water quality in Ciujung River is still relatively clean compared to Ciliwung River in Jakarta city.

The multivariate statistics analyses also supported the above idea that Ciujung River was still relatively clean. The results of cluster analysis (CA) have grouped the monthly average water quality data based on their seasonal variability. It is obvious that the produced clusters indicate that the changes of water quality in the study site were still highly affected by the seasonal variability, in this case the rainfall intensity and river water debit, rather than by the domestic or industrial waste. Another multivariate statistics analysis, principal component analysis (PCA) followed with factor analysis (FA), also concluded that the first and the second varifactors (VF1 and VF2) seemed to be related to the rainfall variability, runoff, soil erosion and water debit, instead of being related to domestic or industrial influences. VF 1, accounting 19.50% of the total variance, was strong positively loaded with TDS and EC and moderate positively loaded with COD, chloride, total hardness, salinity, sulfate and calcium. VF 2 accounted for 15.07% of the total variance, including alkalinity, BOD, DO and temperature. Only then, the effects of domestic and industrial were shown by the next varifactor (VF 3), accounting for 8.30%

of the total variance, comprised all observed heavy metals and nitrite, with the loading values ranged from moderate to strong positive.

Although generally, the seasonal variability (rainfall intensity) still played an important role in the variability of water quality in Ciujung River, the increase of domestic inputs within the last five years has to become the serious concern of the local government of Banten Province. The high water pollution level in Jakarta city has to become important lesson for Banten Province in order to manage their water resources and control the pollution level; otherwise rehabilitation process will be come too late.

5.4 Water quality in the urban and rural bays

As a consequence of having polluted river water in Jakarta city, the condition of seawater in the coastal area of the Jakarta Bay is ascertainable. This study has revealed that most of the sampling stations in the bay fell within slightly polluted criteria, with 62.5% and 50% in the early rainy and late dry season, respectively. More polluted waters were found close to the onshore area, while the offshore area was relatively cleaner. This study also proved that the impact of rainfall intensity to the pollution level was very clear. More polluted stations happened during in the early rainy season compared to the late dry season; because during the early rainy season, the polluted river water was washed out from the river systems to enter the bay ecosystem.

In relation to *Escherichia coli* (*E. coli*), most of the biophysicochemical properties of seawater in the Jakarta Bay showed significant correlations with *E. coli* concentration. In fact, some of those parameters were very essential for the *E. coli* growth. From five physical parameters, three parameters showed moderate correlation, i.e. water transparency, TSS and turbidity, both in the early rainy and late dry seasons. Among the chemical parameters, pH exhibited a very strong correlation with *E. coli* in both seasons. Such strong negative correlation indicated that *E. coli* preferred to grow in a normal to an acidic environment. COD and BOD were also positively correlated with *E. coli*, especially in the late dry season.

On the contrary, the seawater condition in Banten Bay in general was considerably less polluted than that of the Jakarta Bay. Most of the heavy metal concentrations in the seawater were below detection limits. All heavy metal concentrations in the sediment were also lower than those found in the Jakarta Bay. In the seagrass, the concentrations of iron, copper, zinc, mercury, phosphorus, potassium, and nitrogen were higher than those found in the Seribu Islands (located in the northern area of the Jakarta Bay), Larymna Bay (Greece), and the Gulf of Mexico (concentrations of cadmium and lead were not).

The distribution patterns of elements, such as iron, zinc, cadmium, copper, mercury, nitrogen and phosphate, exhibited strong tendencies to accumulate in the center of the Banten Bay as a result of oceanographic processes. These results suggest that the combination of the northwest and southeast monsoons, bidirectional asymmetric diurnal tidal flows, wind-driven throughflow, and river discharge play important roles in sediment distribution in the bay.

5.5 Future perspective of the research

This water quality study by comparing urban and rural watersheds, *i.e.*, Ciliwung and Ciujung watersheds, is important not only for Jakarta city and all other cities locating in Ciliwung watershed in combating their water pollution problems but also for Banten Province to take lessons from what has happened in their neighboring watershed. It has to be considered that regional development without a proper management of river water, ground water and sewage systems will create water resources disaster and pollution in the future. In turns, the pollution will cause the environmental degradation and reduce biodiversity. In long process, the human health may also be affected and more budgets will be required to solve the problem. Following this study, a managerial and technical study is necessary to overcome the situation, both for Jakarta and Banten Province.

The use of hyperspectral equipment for water quality study is also challenging. This study has introduced the utilization of hyperspectral spectroradiometer to detect nutrient contents in the aquatic plants. Although the study was still at a laboratory scale, but the possibility to apply this technique in the field is widely open. At the first step, this study has revealed scientific evidence that hyperspectral reflectance measurement can be used to detect nutrient contaminants in the coastal aquatic vegetation more quickly than traditional analytical chemistry. Before applying to the field, it is necessary to do more experiment at laboratory scale with more comprehensive and more precise measurement. It is fundamental to understand the spectral behavior and the sensitivity of aquatic species to small increments of nutrient concentrations. More aquatic species are also indispensable to be investigated.

The issue regarding watershed boundary and accuracy assessment of DEMs is also another concern that needs better improvement. It is crucial to have a standard watershed boundary approved by all institutions, instead of having so many versions with different formats and accuracies. This study has proved that either SRTM DEM or ASTER GDEM can be used for creating watershed boundary with a satisfying accuracy with only limited budgets. Of course more expensive effort such as airborne mapping can create better accuracy, but it will require huge budgets. However, it is important to note that using SRTM DEM or ASTER GDEM version 1 for watershed boundary creation has some limitations, especially for lower terrain area. It is therefore possible, if the budget is available, to combine these “free of charge” dataset with the airborne surveying concentrating on the lower terrain area. The combination of both remote sensing techniques will create more considerably accurate watershed boundaries. At last, it is also necessary to mention that the accuracy of ASTER GDEM version 2 is still under investigation. Although the report released by ERSDAC saying that the accuracy of GDEM version 2 is better than GDEM version 1, but this study proved differently. GDEM version contains more undulating effects that may be introduced during validation process. Although, this phenomenon may be site specific, but a clear explanation from the ASTER GDEM authority is needed. A similar study to be conducted in other locations is also necessary.

In addition, this study has also shown the capabilities of BASINS 4 (including HSPF package) for hydrological modeling purposes. The software is very powerful not only to explain the hydrodynamic events occurred in the past (such as precipitations, floods and storms), but also to predict the future climatic changes in a watershed and regional scale. The use of this software in the future study is very much challenging.

5.6 Scientific contributions of this study

It is very glad to mention that this study produced several scientific contributions to science. As any doctoral dissertation is expected to find something new in its field, this study could deliver several interesting findings, from which the author can consider them as novelties. We believe that some findings are relatively new in its field and some other are kind of confirmation to the previous scientific publication and reports. If these findings are listed from the most important aspect to the least one, the sequence may be as that listed in the following order:

1. **The lower vertical accuracy of GDEM2 compared to GDEM1.**

When the ASTER GDEM2 was released in October 2011, immediately we downloaded the data and analyzed its accuracy. Soon after the analysis, we found a surprising result that GDEM2 accuracy was lower than that of GDEM1 because it contains more undulating effects on the data. This result is contradictory to what the ASTER Validation Team has reported. Although the result may be site specific, but this finding is an essential contribution to the Validation Team for the next validation effort, especially for the improvement of the datasets in the study area.

2. **The introducing of hyperspectral for analyzing coastal plants and water quality.**

Up to recently, the utilization of hyperspectral technology is still limited to the land vegetation, agriculture plantation and grassland science. Hundreds of publication and reports have been focused on the above scientific fields. However, the application of this equipment for submerged coastal plants and water quality assessment still received a little attention. This study has enriched its contribution to this challenging area by successfully detecting the nutrient increase in the water by measuring the spectral reflectance response given by the coastal plants as response to the fertilizer treatment at a laboratory scale. Of course the application of this equipment to the direct measurement in the filed still needs some time, but an intensive research in this field can accelerate its possibility. This study brings a novelty of the implementation of this methodology to the coastal research field.

3. SRTM DEM has a better accuracy than ASTER GDEM.

It is a big discussion in the remote sensing society whether ASTER GDEM has better accuracy than SRTM DEM or the opposite. In fact, ASTER GDEM was released 9 years after SRTM DEM and it has a better spatial resolution than SRTM DEM (1 pixel of ASTER GDEM = 30 m; 1 pixel of SRTM DEM = 90 m). Therefore, ASTER GDEM was actually expected to have better accuracy than its predecessor SRTM DEM. However, a number of studies done by many different researchers in various places in the world have found that instead of having lower spatial resolution but SRTM DEM has better accuracy than ASTER GDEM. Our study, which was done in Ciujung watershed (Java Island) where no one had previously done it at the same site - , has confirmed the same result. We could contribute to the remote sensing society by confirming that SRTM DEM has indeed better accuracy than ASTER GDEM.

4. The alarming condition of groundwater quality in the Jakarta City.

It is well known that the river water in Jakarta is highly polluted. However, the information regarding the groundwater quality has not much found in the publication. This study has, therefore, a significant contribution to public, especially to the residents of Jakarta City – who still heavily depend on the direct pumping from the ground – to be carefully utilizing the groundwater, particularly for those living in the northern Jakarta and specifically during the dry season, because the water has been polluted.

5. The decreasing trend of water quality in Ciujung River in line with the better economic growth of Banten Province.

This study could be the first research regarding water quality in Ciujung River in related with the economic development of Banten province, one decade after the establishment of Banten Province. The results revealed that nine physicochemical water parameters, seven heavy metal elements and two organic-material-related properties have shown increasing trends in their concentrations. However, their changes in water quality were still influence by the seasonal variability. The industrial and anthropogenic impacts (in this case: heavy metals) have just shown their initial influence on water quality, as indicated by the results of multivariate statistics. This study provides essential information for the local government to set up an applicable water quality management planning to prevent and reduce the decreasing trend of the river water quality along with the increasing number of human population and economic development.

6. The high concentration of heavy metals in the seagrass in Banten Bay.

Most of the results coming out from the study regarding water quality in the Banten Bay and Jakarta Bay are actually just a confirmation to other publications that the Jakarta Bay is indeed polluted as an effect of polluted river water in Jakarta city and that the water quality in Banten Bay is relatively cleaner than that of Jakarta Bay. Nothing is special on these results. However, the finding that the heavy metal concentration contained in the seagrass tissues in the Banten Bay is higher than that contained in the seagrass in Seribu Islands, Larymna Bay and the Gulf of Mexico, is quite new information. Meanwhile, we know that Banten Bay is known as one seaweed cultivation area in western Java. Although the locations of the heavy-metal-polluted seagrass and the locations of seaweed cultivation are a little far, but in a long process it may also threaten the seaweed production and human consumption. This is a little part of what this study can contribute to the coastal science.

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Appendix A: Abbreviations and Acronyms

AAS	:	Atomic Absorption Spectrophotometry
ANOVA	:	Analysis of Variance
APHA	:	American Public Health Association
ASTER GDEM	:	Advanced Spaceborne Thermal Emission and Reflection – Global Digital Elevation Model
AWI	:	Alfred-Wegener Institute of Polar and Marine Research
BAKOSURTANAL	:	Indonesian National Mapping Coordination Agency
BASINS	:	Better Assessment Science Integrating point & Non-point Sources
BOD	:	Biological Oxygen Demand
BPLHD	:	*Badan Pengelolaan Lingkungan Hidup Daerah* (Environmental Management Board/Office)
CA	:	Cluster Analysis
CGIAR-CSI	:	Consultative Group on International Agriculture Research-Consortium for Spatial Information
COD	:	Chemical Oxygen Demand
DEM	:	Digital Elevation Model
DIVA	:	Data-Interpolating Variational Analysis
DO	:	Dissolved Oxygen
DON	:	Dissolved Organic Nitrogen
DOP	:	Dilution of Precision
DTM	:	Digital Terrain Model
EC	:	Electrical Conductivity
EGM96	:	Earth Gravitational Model 1996
ERS	:	Early Rainy Season
FA	:	Factor Analysis
FDR	:	First Derivative Reflectance
GDP	:	Gross Domestic Product
GIS	:	Geographical Information Systems
GNSS	:	Global Navigation Satellite System
GPS	:	Global Positioning Systems
HCA	:	Hierarchical Cluster Analysis
HDI	:	Human Development Index
HDOP	:	Horizontal Dilution of Precision

HSD	:	Honestly Significant Different
HSD	:	Honestly Significance Difference
HSPF	:	Hydrological Simulation Program-Fortran
KMO test	:	Kaiser-Meyer-Olkin test
LDS	:	Late Dry Season
LEI	:	Life Expectancy Index
LIDAR	:	Light Detection and Ranging
LZSN	:	Lower Zone Storage Nominal
MCARI	:	Modified Chlorophyll Absorption Ratio Index
MCL	:	Maximum Contour Level
METI		Japanese Ministry of Economy, Trade and Industry
MSL	:	Mean Sea Level
NASA	:	National Aeronautics and Space Administration
NGA	:	National Geospatial-Intelligence Agency
NOAA	:	North Oceanic and Atmospheric Administration
NS - EW	:	North South – East West
NTU	:	Nephelometric Turbidity Units
ODV	:	Ocean Data View
PCA	:	Principal Component Analysis
PDOP	:	Positional Dilution of Precision
PV	:	Permissible Value
PV	:	Permissible Value
RMSE	:	Root Mean Square Error
RTK-DGPS	:	Teal-Time Kinematic Differential Global Positioning Systems
SD	:	Standard Deviation
SEAMEO-BIOTROP	:	Soil and Plant Laboratory of the Southeast Asian Regional Centre for Tropical Biology
SN	:	Stack Number
SNI	:	*Standar Nasional Indonesia* (Indonesian National Standard)
SPSS	:	Statistical Package for the Social Sciences
SRTM DEM		Shuttle Radar Topographic Mission - Digital Elevation Model
SV	:	Satellite in View
TCARI	:	Transformed Chlorophyll Absorption Ratio Index
TDOP	:	Time Dilution of Precision
TDS	:	Total Dissolved Solids
TEL	:	Threshold Effects Level
TIN	:	Triangulated Irregular Network

Topo-DEM	:	Topographic-map-derived DEM
TSP	:	Triple Super Phosphate
TSS	:	Total Suspended Solids
US EPA	:	United States Environmental Protection Agency
USGS	:	United States Geological Survey
UZSN	:	Upper Zone Storage Nominal
VAI	:	Value Added Industry
VDOP	:	Vertical Dilution of Precision
VF	:	Varifactor
VI	:	Vegetation Index
WGS84	:	World Geodetic System 1984
WPI	:	Water Pollution Index
WQI	:	Water Quality Index
WRI	:	World Research Institute
WSLIC	:	Water and Sanitation for Low Income Communities

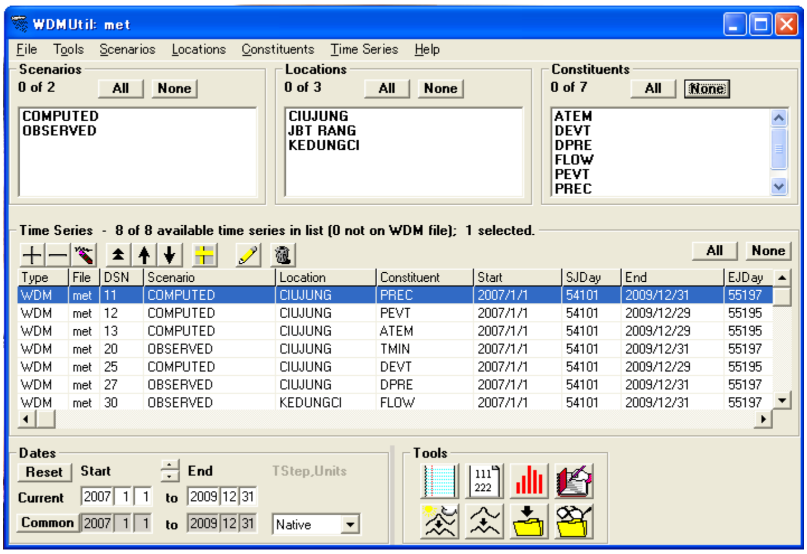
Appendix B: HSPF Model

A. Software packages

To build the hydrological simulation model, we used four hydrological modeling packages which were bundled in one BASINS version 4.0 software. The software is freely downloadable from the website: http://water.epa.gov/scitech/datait/models/basins/index.cfm.

1. The core component of BASINS can be used for many purposes. For this model, the core component was used to define watershed boundary (in this case the watershed boundary resulted from Chapter 2 is used), import land use and segmentation, define segment parameters, develop reach segment parameters, define meteorological input time series data and enter mass links to define transformations from BASINS to reach develop an HSPF User Control Unit (UCI).

2. Watershed Data Management Utility (WDMUtil) version 2.27 was used to retrieve or import the available meteorological data into WDM file format and undertake necessary operation, such as computing, editing, aggregating/disaggregating and filing missing data. These procedures were required to create the input time series data for further analysis in HSPF simulation.



Scenarios 0 of 2
COMPUTED
OBSERVED

Locations 0 of 3
CIUJUNG
JBT RANG
KEDUNGCI

Constituents 0 of 7
ATEM
DEVT
DPRE
FLOW
PEVT
PREC

Time Series - 8 of 8 available time series in list (0 not on WDM file); 1 selected.

Type	File	DSN	Scenario	Location	Constituent	Start	SJDay	End	EJDay
WDM	met	11	COMPUTED	CIUJUNG	PREC	2007/1/1	54101	2009/12/31	55197
WDM	met	12	COMPUTED	CIUJUNG	PEVT	2007/1/1	54101	2009/12/29	55195
WDM	met	13	COMPUTED	CIUJUNG	ATEM	2007/1/1	54101	2009/12/29	55195
WDM	met	20	OBSERVED	CIUJUNG	TMIN	2007/1/1	54101	2009/12/31	55197
WDM	met	25	COMPUTED	CIUJUNG	DEVT	2007/1/1	54101	2009/12/29	55195
WDM	met	27	OBSERVED	CIUJUNG	DPRE	2007/1/1	54101	2009/12/31	55197
WDM	met	30	OBSERVED	KEDUNGCI	FLOW	2007/1/1	54101	2009/12/31	55197

	Start				End			TStep,Units
Current	2007	1	1	to	2009	12	31	
Common	2007	1	1	to	2009	12	31	Native

Figure A-1: The main window of Watershed Data Management Utility (WDMUtil).

WDMUtil provides algorithms for computing potential evapotranspiration (PET) which is required for HSPF simulation based on existing meteorological data. The equation generates daily potential evapotranspiration (inch) estimated from air temperature, a monthly variable coefficient, the number of hours of sunshine (depends on latitude) and absolute humidity (estimated from air temperature). The Hamon PET equation (Hummel *et al.* 2001) is defined as:

$$\text{PET} = \text{CTS} \times \text{DYL} \times \text{VDSAT} \quad \text{(A1)}$$

Where:

PET = daily potential evapotranspiration (inch)

CTS = monthly variable coefficient (constant value of 0.0055)

DYL = possible hours of sunshine, in units of 12 hours, estimated as a function of latitude and time of year

VDSAT = saturated water vapor density (absolute humidity) at the daily mean air temperature (g/cm^3)

$$\text{VDSAT} = (216.7 \times \text{VPSAT}) / (\text{TAVC} + 273.3) \quad \text{(A2)}$$

Where:

TAVC = mean daily air temperature, calculated from the daily max-min data (°C)

$$\text{VPSAT} = 6.108 \times \exp((17.26939 \times \text{TAVC}) / (\text{TAVC} + 273.3)) \quad \text{(A3)}$$

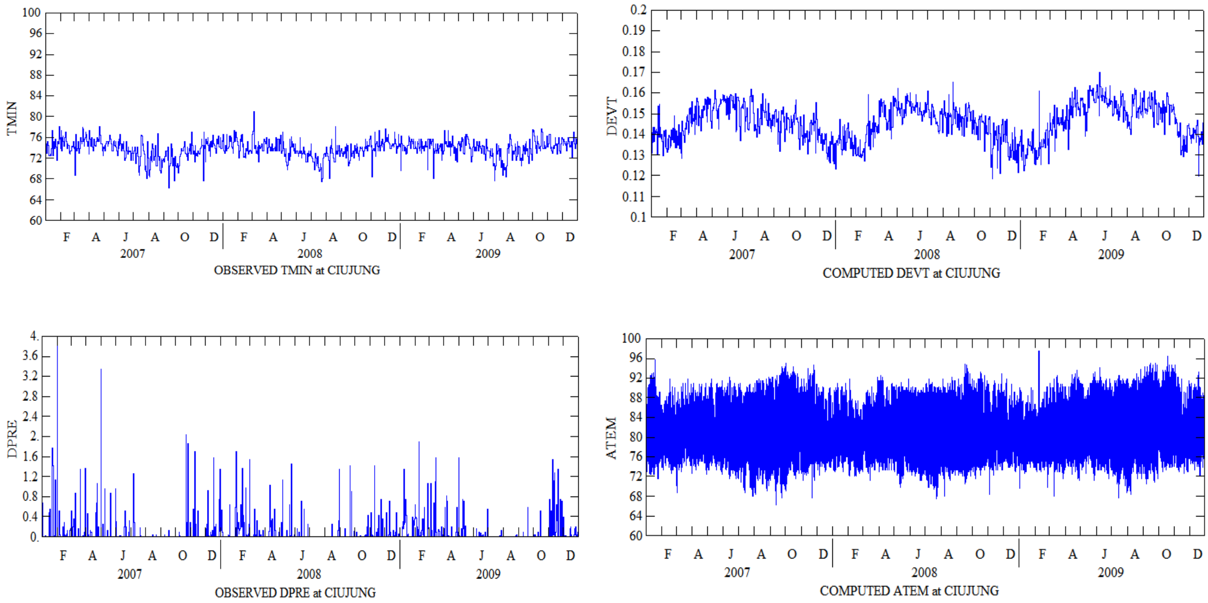
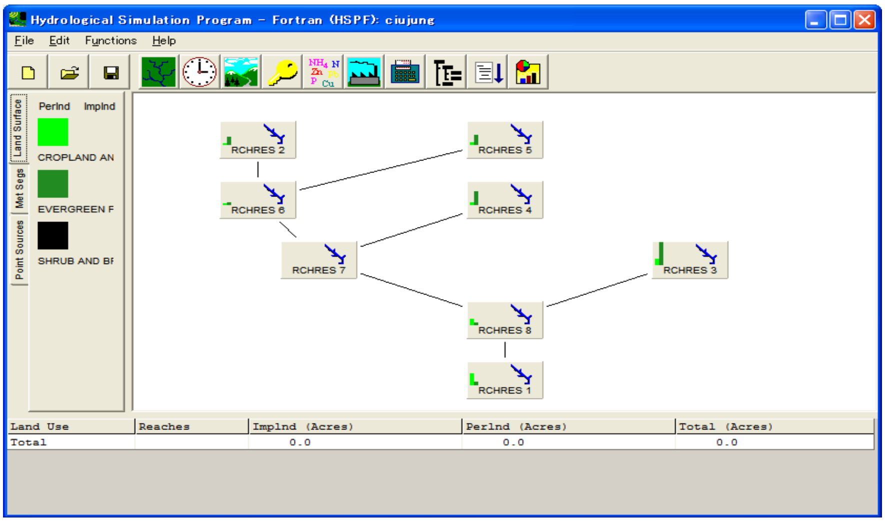


Figure A-2: Some meteorological data used for hydrological simulation model.

3. WinHSPF version 2.3 was used to run the simulation model. Object design was key in development of WinHSPF. An object was created to store all of the information that is normally contained within the UCI file. This UCI object is accessible throughout WinHSPF, and enables the software to easily access model parameter values. All of the data traditionally stored in the UCI file are now stored in the UCI object in memory. When the user accesses an existing UCI file, the UCI file is read and

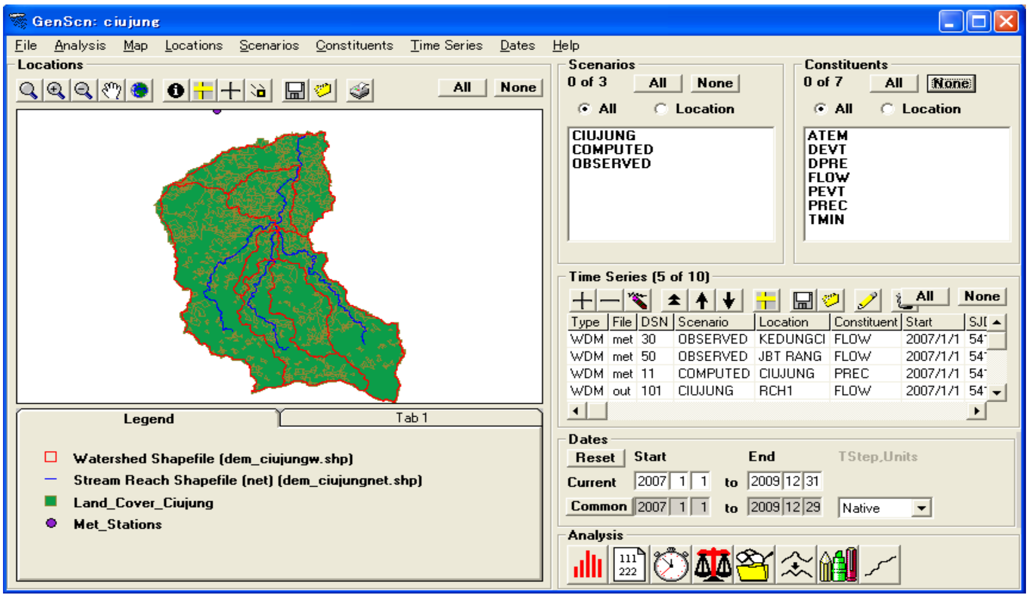
translated into the UCI object. WinHSPF then uses this UCI object throughout the program. When the UCI information is saved, the contents of the UCI object are translated back into the UCI file format. The HSPF model code was compiled into a dynamic link library (dll) for access by WinHSPF. A small set of subroutines was developed to interface between the Visual Basic code and the existing HSPF Fortran routines. Similarly, the timeseries data objects within WinHSPF use some calls to the Watershed Data Management (WDM) Fortran library of subroutines for time-series management. This scheme allowed the well-tested and well-documented WDM code to be preserved. The main Graphic User Interface (GUI) of the WinHSPF is shown like the following figure.



Land Use	Reaches	Implnd (Acres)	Perlnd (Acres)	Total (Acres)
Total		0.0	0.0	0.0

Figure A-3: The main window of Hydrological Simulation Program-Fortran (HSPF).

4. Scenario Generator (GenScn) version 2.3 was used to compare and analyze the HSPF simulation result in calibration process. Analyzing and managing the high volumes of input and output of complex river basin models is a major task. These models are used to simulate water quantity and quality for numerous scenarios involving changes in land use, land-use management practices, and water-management operations. To assist with that process, an interactive computer program, GENeration and analysis of model simulation SCeNarios (GenScn), was developed to create simulation scenarios, analyze results of the scenarios, and compare scenarios. Although other models can be adapted to use GenScn, this report describes the system as adapted for the Hydrological Simulation Program-Fortran (HSPF). HSPF is a highly versatile model capable of simulating mixed-land-use watersheds (urban and rural). It includes land surface and instream water quantity and quality components.



CIUJUNG
COMPUTED
OBSERVED

ATEM
DEVT
DPRE
FLOW
PEVT
PREC
TMIN

Type	File	DSN	Scenario	Location	Constituent	Start	SJ
WDM	met	30	OBSERVED	KEDUNGCI	FLOW	2007/1/1	54
WDM	met	50	OBSERVED	JBT RANG	FLOW	2007/1/1	54
WDM	met	11	COMPUTED	CIUJUNG	PREC	2007/1/1	54
WDM	out	101	CIUJUNG	RCH1	FLOW	2007/1/1	54

	Start		End
Current	2007 1 1	to	2009 12 31
Common	2007 1 1	to	2009 12 29

Native

🟥 Watershed Shapefile (dem_ciujungw.shp)
— Stream Reach Shapefile (net) (dem_ciujungnet.shp)
🟩 Land_Cover_Ciujung
● Met_Stations

Figure A-4: The main window of Scenario Generator (GenScn).

B. Model calibration

The goal of calibration is to "tune" the model so that the simulated flow resembles the observed flow data as closely as possible. This is accomplished by adjusting various input parameters within WinHSPF. The calibration procedure typically involves a sensitivity analysis to identify key parameters and parameter precision required for calibration (Ma *et al*. 2000). There are many parameters subjected for calibration, however in this study, the calibration was done only by adjusting the total runoff volume between the observed values and the simulated output. Technically, the total runoff volume error can be examined for the following time periods: annually, seasonally, monthly and during storm periods.

The total runoff volume error can be estimated by comparing the total water volume of water passing through a reach according to the gage data (observed data) with the output volume simulated by WinHSPF model (simulated flow).

$$\text{Volume} = \Sigma\, Q \times \Delta t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (A4)$$

Where:

Q = river discharge (m3/s)
T = time periods

In this study, once the simulated and observed volumes have been calculated and compared, the values of calibration parameters were adjusted until the total annual simulated volumes are very close to the total annual observed volumes. Losses in the watershed can be accounted for by quantifying flow diversions, evapotranspiration losses, and losses due to deep percolation. In this model, we only assumed that all flow diversions and losses were due to evapotranspiration and adjust parameters that are associated with evapotranspiration.

LZSN (lower zone storage nominal) is related to precipitation and soil characteristics in the watershed. Increasing the value of LZSN increases the amount of water stored in the lower zone and therefore, increases the opportunity for evapotranspiration. This decreases flow rates by providing greater opportunity for evapotranspiration. Decreasing the value of LZSN increases the flow rates in the reach.

UZSN (upper zone storage nominal) is related to land surface characteristics, topography, and LZSN. This parameter can change over the course of a growing season. Increasing UZSN increases the amount of water retained in the upper zone and available for evapotranspiration, allowing less overland flow. Some values of UZSN suggested by the manual of BASINS software are:

- 0.06*LZSN – steep slopes and limited vegetation
- 0.08*LZSN – moderate slopes and vegetation
- 0.14*LZSN – mild slopes and heavy forest cover

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