Bachelor Thesis

WATER QUALITY IN THE BANDUNG BASIN

TOWARDS A BETTER UNDERSTANDING OF THE WATER QUALITY IN THE UPPER CITARUM RIVER BASIN

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Deltares
Enabling Delta Life

UNIVERSITY OF TWENTE.

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Submitted by

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PREFACE

Het is inmiddels al weer meer dan een jaar geleden dat ik in Utrecht op gesprek kwam bij Daniël, om te overleggen over een eventuele opdracht in Indonesië. Mijn inzet: 'iets met overstromingen van Jakarta'. In januari 2015 was het dan eindelijk zover: ik begon aan mijn vijf maanden durende opdracht in Bandung. Niet over waterkwantiteit, maar over het waterkwaliteitsprobleem van de Upper Citarum River Basin, ookwel: de 'Bandung Basin'. Het bleek een enorm interessant onderwerp te zijn, en al snel werd ik helemaal meegezogen in de vele aspecten die daarbij een rol spelen. Het verslag dat voor u ligt is samen met mijn stakeholderanalyse het resultaat van ruim 5 maanden hard werken: veldobservaties, dataverzameling, urenlange interviews, stakeholdermeetings, lange autoritten, dagen filmmateriaal, skypegesprekken, ritjes achterop de Ojek en talloze uren kantoorwerk in het Deltareskantoortje binnen PusAir.

De opdrachtgever en belangrijkste gebruiker van deze thesis is de Alliance of Water, Health and Development: een samenwerking tussen Deltares, de Radboud Universiteit, Institut Teknologi Bandung en Padjadjaran University. Een leuke groep mensen, gedreven door een relevante doelstelling: onderzoek doen naar de relaties tussen water, gezondheid en ontwikkeling om daarmee praktische oplossing voor problemen in de Bandung Basin leveren. Ik ben er trots op dat ik hier 5 maanden lang een bijdrage aan heb kunnen leveren.

Daarom wil ik jullie allereerst bedanken: Gertjan, jij bent ongetwijfeld mijn grootste motivatie- en inspiratiebron geweest. Bedankt voor je positieve feedback, je enthousiasme en de leuke gesprekken. Ook alle anderen van de vakgroep: bedankt voor alle ideeën en de excursies, het was erg leuk dat jullie ook naar Bandung kwamen!
Vanuit de UT wil ik Denie hartelijk bedanken voor de degelijke begeleiding. Ik denk niet dat er veel begeleiders zijn die een verslag zo grondig doorlezen dat zelfs een spellingsfout in de naam van één van de geïnterviewden hen opvalt. De feedback bood altijd weer structuur in de chaos die het werken in Indonesië met zich meebrengt. Ook voor Gül: bedankt voor het kritische maar opbouwende commentaar, het is het wetenschappelijke gehalte van mijn thesis en artikel zeker ten goede gekomen.
Daniël, bedankt voor de praktische begeleiding in Indonesië. Ook al is waterkwaliteit niet je favoriete onderwerp, je hebt er voor gezorgd dat mijn opdracht in alle opzichten goed gefaciliteerd was. Door jou en Neeltje heb ik veel geleerd over het waterbeheer in Indonesië, heb ik mijn gereedsschapskistje met Python aangevuld en heb ik vooral een super leuke tijd gehad.
Familie en vrienden in Nederland, heel erg bedankt voor jullie support. Een tijdje weg zijn is misschien wel de beste manier om te ontdekken hoe waardevol jullie zijn. Ma, bedankt voor alle telefoongesprekken, ik wilde dat ik u die prachtige tropische tuinen had kunnen laten zien. Pa, leuk dat u mij bent komen opzoeken!

A few English words for all my Indonesian colleagues and friends: Lufiandi, thanks for all the time and energy you spent in showing me the Bandung Basin and introducing me into your network. I hope my thesis will be useful for your research, see you at the Radboud when you take your doctoral degree! Meli, thank you for arranging so many things for me! Ifan and Lina, you showed me why Indonesians call their colleagues friends. I will never forget all the nice adventures and dinners we had together. Friends from the First Baptist Church: thank you so much for all the wonderful services, meals and studies together.

Relation with other research

Simultaneously with this BSc-research, I studied the social-governmental aspects of the water quality monitoring for the Minor Sustainable Development in Developing Countries. This involved an analysis of the stakeholders concerned with water quality monitoring in the Bandung Basin. The findings of this research are written in the conference paper *Water quality monitoring in the Upper Citarum River Basin – rethinking the role of stakeholders* (Van Ginkel, 2015), to be presented at the 5th Environmental Engineering and Management Conference in November 2015, Bandung. The reader of this BSc-thesis might also be interested in reading this article, because it gives a complete overview of the monitoring stakeholders in the Bandung Basin and also gives insight in the organization of water management in Indonesia after two decades of reforms.

The size of this thesis exceeds the target length of 30 pages. The reader should keep in mind that due to the combination of minor and B-thesis, I worked on the topic for twenty instead of ten weeks. Moreover, the data collection with the Levelogger devices was part of the Field Work for the Minor Sustainable Development, but has been reported in this thesis. Therefore, the full extent of this thesis is 16 + 7.5 = 23.5 EC instead of the customary 16 EC, see table below:

ECS FOR THE BSC-THESIS, MINOR AND PER OUTPUT PRODUCT

BSc-thesis	**Minor Sustainable Development**	**Output products**
Water quality research 16 EC	Datacollection 7.5 EC	BSc-thesis: 23.5 EC
	Stakeholder analysis 7.5 EC	Conference article: 7.5 EC
16 EC	15 EC	31 EC

Video

This BSc-thesis is accompanied by a 10-minute video about the water quality in the Bandung Basin. The reader is recommended to watch this video when reading the thesis, because it will strongly contribute to his/her understanding of the problem. References to the video in the thesis are indicated with a camera symbol in the left margin.

Short link to video: tiny.cc/BandungBasin
Permanent link: http://youtu.be/039PfqWQVjU

Further, an impression of the field work can be found on my videoblog: https://youtu.be/2IV4tV74wkU

FERRY IN THE CITARUM RIVER, NEAR DAYEUH-KOLOT (7/3/2015)

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SUMMARY

The Alliance of Water, Health and Development is developing a water quality model for the Upper Citarum River Basin, or Bandung Basin, located in West Java, Indonesia. This thesis aims to increase the understanding of the water quality problem of the Bandung Basin and the available data, in order to support the development of this model. Four succeeding steps give insight in the current condition of the basin.

1. Six drivers of the water quality problem of the basin were identified using system analysis.
    1) The natural conditions of the basin, a large floodplain surrounded by eroding volcanic mountains, contribute to high concentrations of suspended solids in the river water. Dilution as a result of rainfall-runoff is an import determinant of observed concentrations.
    2) Industrial effluents, mainly originating from abundant textile industry, highly contribute to the pollution as a result of inadequate wastewater treatment.
    3) Large quantities of solid waste end up in the water system as a result of insufficient refuge collection.
    4) On many places sewage is discharged to the river water, because there is a lack of sanitation infrastructure.
    5) As a result of crop farming practices, large amounts of sediments, pesticides and fertilizers are flushing to the river water.
    6) Practically all manure originating from stockbreeding activities is directly discharged to the surface water.

    All these factors can be traced back to insufficient social and governmental institutions. The pollution of the basin is a threat to the environment and the health of the citizens: the reservoir downstream of the basin is heavily polluted, many citizens are directly exposed to polluted river water, wells are contaminated because water infiltrates in aquifers and heavy metals accumulate in fish consumed by the citizens.

2. The current monitoring activities and the data obtained with it were investigated. Monitoring of polluting sources is very scarce, and inadequate. Therefore, emissions for modelling purposes have to be estimated based on literature and spatial data. Rainfall data can be obtained from measuring stations or satellite images. Recent discharge data is scarce, inconsistent and often unreliable. River water quality data is obtained from five different organizations. The number of locations, sampling frequency, measured parameters and the timing is very different for every dataset. Validation of the data shows that there are inconsistencies between certain datasets, so that data should be checked before use. However, the data can certainly be used to develop and validate a baseline scenario for the current water quality of the Citarum.

3. Three Levelogger sensors were installed to collect continuous temperature, water level and conductivity data. The design of the sensor frame and the collaboration with the local community was successful. However, the large amounts of solid waste clogging to the devices reduce the reliability of the obtained data, especially the conductivity measurements. The obtained data revealed that river water originating from a catchment dominated by textile industries is characterized by high water temperatures (5 - 10 ºC above normal conditions) and high specific conductivity (1000 - 2000 μS/cm). In contrast, in the river water from a catchment dominated by agricultural activities and small settlements normal temperatures and very low specific conductivity (around 200 μS/cm) were found. TRMM-satellite rainfall data is clearly linked with the observed water level data, indicating that the satellite data can be used for analyzing the water quality data. In contrast to the expectations, no differences between day and night or working days and weekends were found in temperature or

specific conductivity of the industry dominated river water. However, clear correlations were found between conductivity and water level in both rivers.

4. The data obtained in the second and third step was converted to a format suitable for data analysis and import in database software. The data was analyzed using qualitative and quantitative methods which revealed the following about the water quality in the Bandung Basin:
    - The water quality in the basin exceeds the governmental standards for almost all parameters at most locations during the whole year.
    - Stockbreeding activities in the first 28 km of the Citarum lead to high nitrate concentrations and large quantities of fecal coliform bacteria.
    - The most obvious deterioration of water quality in the Citarum is due to the industry clusters in the basin. Industrial emissions account for high pH, temperature, TDS, BOD, COD and [Zn] of the water.
    - Domestic areas are another important source of pollution in the basin, mainly correlating with zinc and fecal coliform, but also with BOD and COD.
    - The parameters currently monitored do not give insight in emissions from crop growing.
    - In general it can be said that the water quality during the dry season is worse compared with the wet season; as a rule of thumb the TDS, BOD and COD are two times higher during the dry season. However, some parameters like TSS show an opposite pattern.

The Alliance should start the modelling with the parameters BOD, COD, zinc and TDS because estimations of these concentrations can be based on the available data. The Indonesian government is recommended to start cleaning up the Bandung Basin by reducing emissions from industry clusters and by improving the sanitation infrastructure of Bandung City. Reduction of these emissions will take away the principal part of the pollution of the basin.

1 INTRODUCTION

The Citarum River in West Java, Indonesia, is notorious for its bad water quality and is often ranked among the most polluted rivers of the world (Cavelle, 2013). The river is of great strategic importance, both for the 9 million people living in its watershed as for the water supply of 25 million people living in the area of Jakarta. In the 270 km long river, three large, multipurpose reservoirs are located (Miyazato & Khan, 2004). The catchment upstream of the first reservoir, ‘Saguling’, is known as the Upper Citarum River Basin, in this thesis referred to as the ‘Bandung Basin’. This catchment is one of the most polluted parts of the whole Citarum River Basin.

Large projects have been financed by the Asian Development Bank in order to solve the problems of the Citarum, which include multiple aspects of integrated water resources management: institutional problems, surface- and groundwater management, erosion and sedimentation, flooding and water pollution (ADB, 2007). Many of these projects have been done by foreign consultants like Deltares, the host organization for this BSc-thesis. In addition, some research on water quality has been done by local and foreign universities. This research is part of the ‘Alliance of Water, Health and Development’, a collaboration of two universities in Bandung (ITB and Padjadjaran), Deltares and the Radboud University Nijmegen (Netherlands). One of the goals of the Alliance is to develop a water quality model for the Bandung Basin, which calculates the water quality based on land-use and policy scenarios. By this, the policy making stakeholders gain an understanding of the impact of their behaviour on water quality in the basin and can take more balanced decisions.

1.1 Study area

The Bandung Basin is located on West Java, Indonesia (Figure 1). The basin measures about 45 x 45 km and has a total area of 1,830 km^2 (Deltares, 2011). The basin is surrounded by volcanic mountains, which are the lowest at the north-west side (Figure 2). On this side, the Saguling reservoir is located. In the centre of the basin, a large floodplain is located. The main river, the Citarum, springs at Situ Cisanti, 78 km upstream of the reservoir. In the basin, about 20 major tributaries with corresponding sub basins can be distinguished.

The climate of the basin is relatively cool compared to the rest of Indonesia, with temperatures mostly between 20 and 30 ºC. The annual rainfall varies from 1200 to 3000 mm, with an average of 2215 mm. The monthly rainfall during the wet season (November-April) is about 250 mm, varying from 100 to 500 mm. During the dry season (June-September), monthly rainfall usually is less than 50 mm (Deltares, 2010a).

Large population growth and urbanization is taking place in the Bandung Basin. In 1995, the population was about 2.5 million and in 2010 the population grew to 7.8 million. It is commonly believed that this urbanization will continue, but it is very uncertain to what extent. The population growth led to an enormous increase in settlements in the basin (Deltares, 2012). This was accompanied by a rapid growth of mainly textile industry in the area.

FIGURE 1 LOCATION OF THE UPPER CITARUM RIVER BASIN (SOURCES: LEFT: LIB.UTEXAS.EDU, RIGHT: PETERLOUD.CO.UK)

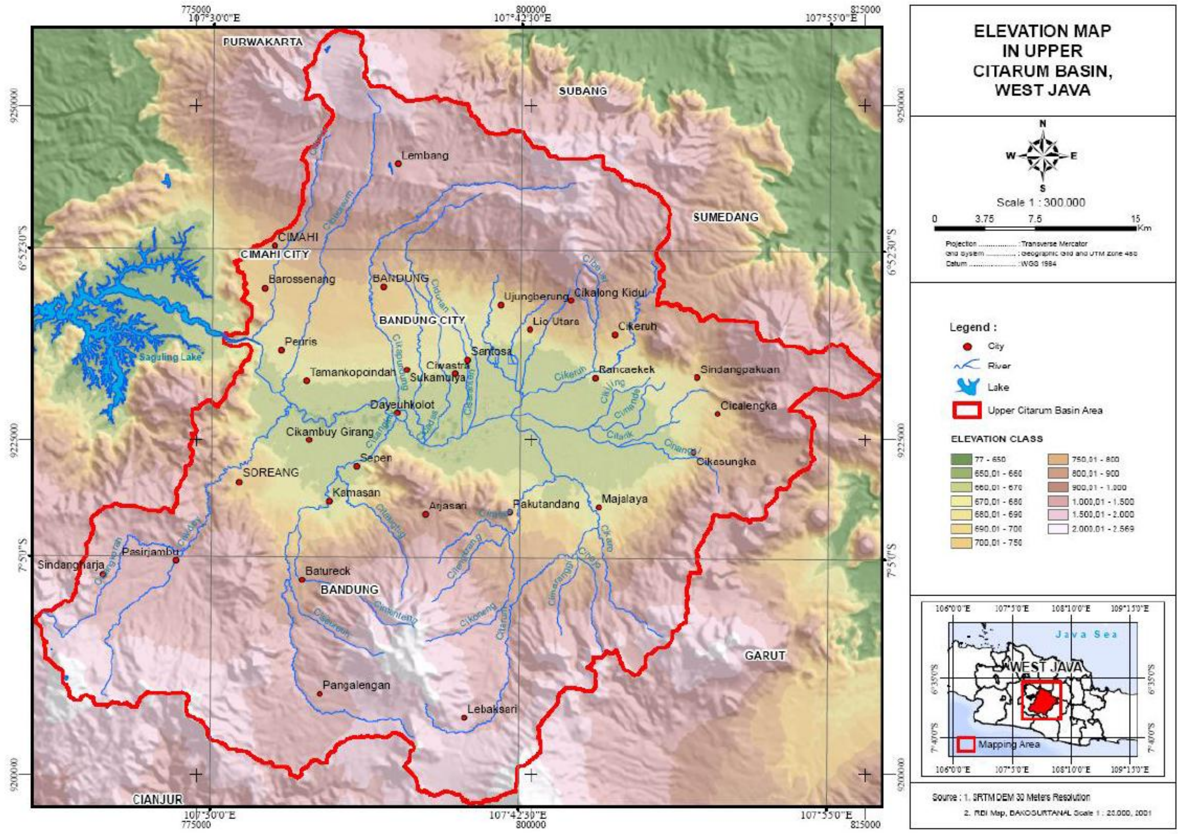

FIGURE 2 ELEVATION MAP OF THE BASIN AND TRIBUTARIES OF THE CITARUM (DELTARES 2011)

1.2 Problem statement

The Alliance wants to develop a model that can be used to manage the water quality and to support land use planning in the Bandung Basin. The input for the model is a number of scenario's, in which the land use of the basin and other factors that influence the water quality are represented. For each scenario, the model will calculate the water quality in the Citarum and its tributaries. However, at the moment it is very difficult to start the modelling, for the following reasons:

- There is lack of clarity about the drivers of the water quality and the way they influence the water quality.
- There is a lack of water quality, hydrological and emission data and little insight in what data is available at what organizations in the basin.
- It is unclear in which way the data from other organizations can be used to model and assess the current condition of the basin.
- There are some specific questions with regard to the reliability of the data, differences between the dry and wet season and the relation between water quality and land use.

1.3 Objective and research questions

The objective of the research is: increasing the understanding of the water quality problem of the Bandung Basin and the available data, in order to support the development of a water quality model.
To achieve the objective, four successive research questions will be answered:

1. What are the drivers of the water quality problem, and how do they influence the water quality in the river?
2. What data can be obtained from organizations to support the water quality modelling?
3. How can additional sensors be used to complement the obtained data?
4. What does the retrieved data reveal about the water quality of the Citarum?

1.4 Methodology and thesis structure

Each research question is answered in a separate chapter. As there is a succeeding order in the questions, the overall methodology and thesis structure is best explained by following the sequence of questions. This also gives a rough indication of the order in which the questions were answered.

Ch 2) To answer the first research question, a system diagram was created, based on field observations, interviews, literature review and some data. The diagram creates insight in the drivers of the water quality, which was directional for the search for data of the second research question.

Ch 3) Data was collected from different organizations, which had to be visited in order to obtain the data. Spatial data was converted to formats suitable for GIS-software. A significant part of the water quality data was converted to a format suitable for import in a water quality database, using Python scripts. The second research question was answered by describing this data in a systematic way. Both the water quality and the discharge data was validated using some intuitive methods, descriptive statistics and statistical tests.

Ch 4) Answering the third research question about data collection by the Levelogger sensors involved a lot of field work and visits to the local community. First, the manual supplied with the purchased devices was carefully studied. Then, the search for appropriate sensor locations was started in collaboration with the local community. After some time a clear image of the field situation was formed, so that a sensor frame could be designed and constructed. The sensors were calibrated and tested in the laboratory and the sensors were positioned in the field. They had to be visited regularly in order to collect the data and to be cleaned. The data was analysed and compared with the data obtained from other organizations. Two presentations were given to share information about the collection procedure: one at the West Java EPA and another at the NGO that represented the local community.

Ch 5) The fourth research question was answered by analyzing the obtained water quality data. First of all, this was done by schematizing the Citarum River and showing the upstream-downstream development of different parameters. Descriptive statistics were used to analyze the water quality at certain points in the river and its tributaries. The test of Wilcoxon-Mann-Whitney was used to test the differences between the water quality in the dry and the wet season. The relation between water quality and land use was investigated using a combination of PC-raster, Python and GIS-tools.

Ch 6) In the last chapter the conclusion was formulated by answering the research questions. Practical recommendations for the model development were given and the Indonesian government was advised where to start in solving the pollution problem of the Bandung Basin.

A detailed explanation of the methods is given in the chapters and appendices in which the corresponding methods are used.

2 SYSTEM ANALYSIS WATER QUALITY PROBLEM

In this chapter, a system analysis is done in order to answer the first research question: *"What are the drivers of the water quality problem, and how do they influence the water quality in the river?"* After describing the methodology, first the drivers determining the water quality will be addressed. The different sources of pollution are described in detail. Secondly, other processes influencing the water quality are described. In the concluding section the research question is answered.
The used methodology can be summarized as follows: the technical processes taking place in the basin were described based on an extensive literature review. The social factors contributing to the water quality problem are mainly based on interviews with stakeholders, conversations with experts and field observations. A so-called 'conceptual diagram' was used to show the relations between different concepts and factors in a visual way (Hawkins, 2003). This diagram was later validated by the interviewed stakeholders. An overview of all interviews is given in the references section of this report.

2.1 Water quality drivers

In this section, six drivers of the water quality in the Bandung Basin will be described. With the term 'driver' is meant: a factor influencing the water quality or a source contributing to the water pollution. The first driver is the natural system of the basin: geo-hydrological conditions and rainfall-discharge patterns influencing the water quality. The other drivers are five different sources of pollution: industrial effluents, domestic waste, domestic sewage, crop growing and stockbreeding activities (Figure 3).

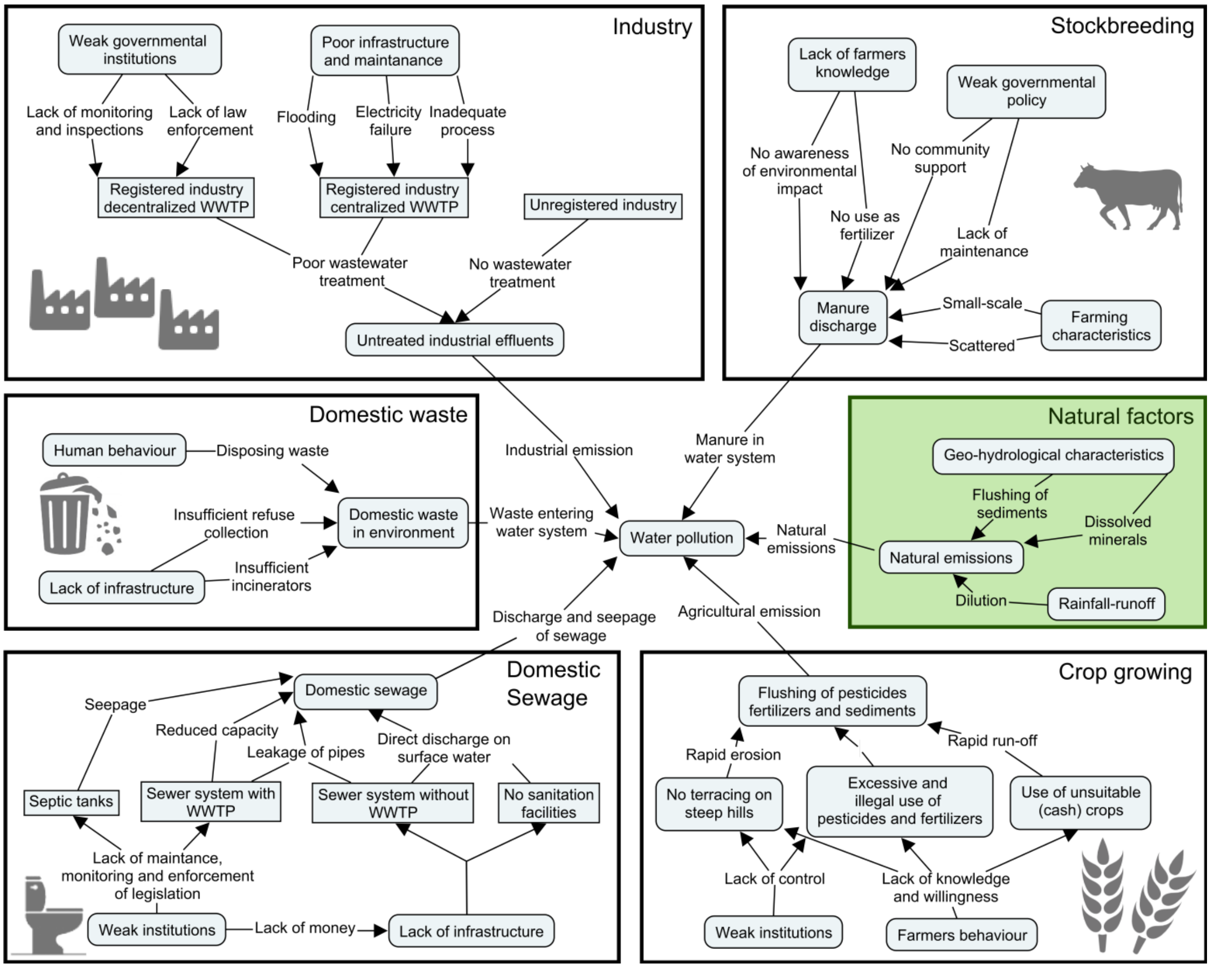

FIGURE 3 CONCEPTUAL DIAGRAM OF DRIVERS FOR WATER QUALITY PROBLEM BANDUNG BASIN

2.1.1 Natural factors

The most important natural factors influencing the water quality are the geo-hydrological characteristics of the basin and the rainfall-runoff pattern.

GEO-HYDROLOGICAL CHARACTERISTICS

Estimated 50,000 years ago, the Bandung Basin used to be a lake, surrounded by late Tertiary and Quartinary volcanic mountains. Nowadays, the former lake bottom forms a large floodplain (Figure 2), about 665 m above sea level, consisting of lake sediments. The volcanic slopes, up to 2400 m high, are eroded, and the eroded particles, volcaniclastic alluvial fan, can be found in the transition zone between the former lake bottom and the mountain slopes (Dam *et al.*, 1996, Deltares, 2011). The deposits in the basin consist mainly of coarse volcaniclastics, fluvial sediments and a thick layer of lacustrine deposits (Deltares, 2012).

The Bandung plain is a very flood-prone area. The river slope in the plain is very small, while the slopes of the tributaries, originating on the slopes of the surrounding mountains, are very high. Moreover, before entering the Saguling reservoir there is a large bottle-neck: the waterfall of Curug Jompong. The erosion of the hard rock of this waterfall close to Nanjung can be neglected, and the ‘obstacle’ is the main cause for the very small gradient (0.00034) of the Citarum in the plain (Syariman, 2005). The rapid urbanization in the basin is leading to land use changes. Deforestation is leading to faster run-off and increased sediment loads.

The sedimentation is not only leading to flooding, but also has a big impact on the ‘natural’ quality of the water in the Bandung Basin, leading to a very high turbidity due to high concentrations of suspended solids (SS). Worldwide, a large number of studies showed that SS have a large impact on the environment: “It is now accepted that SS are an extremely important cause for water quality detoriation, leading to aesthetic issues, higher costs of water treatment, a decline in the fisheries resource, and serious ecologic degradation of aquatic environment.” (Bilotta & Brazier, 2008, p. 42)[1].

RAINFALL AND DISCHARGE

Describing the rainfall and discharge patterns in the basin is difficult, because a lot of the data that can be obtained from the government should be considered unreliable. Especially the automatic sensor systems are very unreliable, due to the use of low-quality sensors and a lack of maintenance, calibration and validation of sensors and data. In Figure 4 an overview of the annual and monthly rainfall pattern can be seen, based on an in-depth survey by Deltares in which the available data was validated and selected on reliability, in order to develop the rainfall-runoff module of a Sobek model of the basin. For a comprehensive discussion of the available rainfall data see section 3.1.

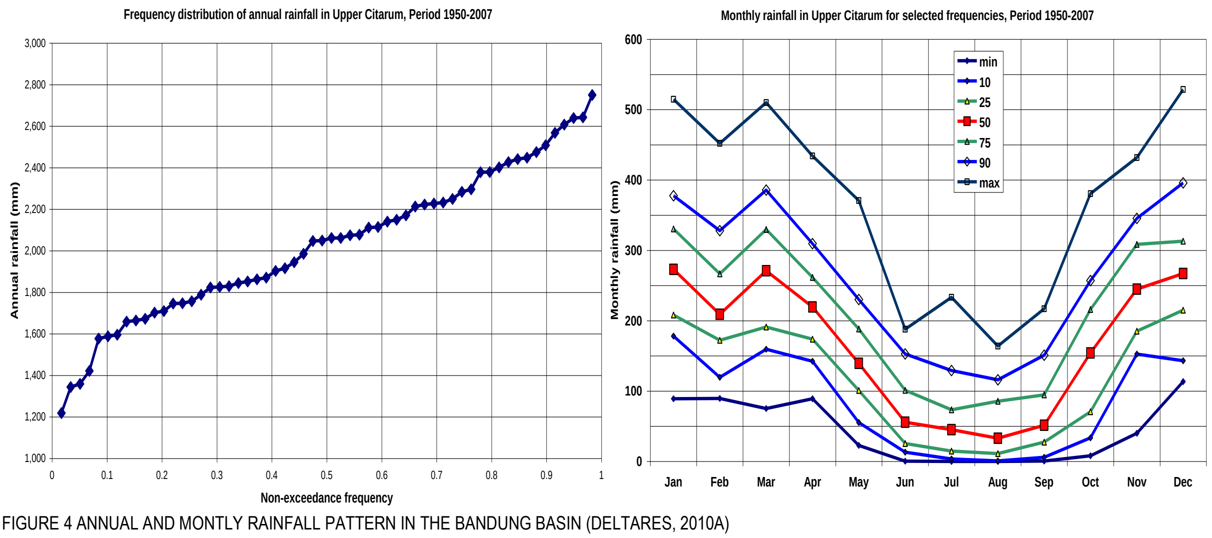

FIGURE 4 ANNUAL AND MONTLY RAINFALL PATTERN IN THE BANDUNG BASIN (DELTARES, 2010A)

[1] Bilotta and Brazier also show that one should be very careful by interpreting turbidity and SS data, for turbidity is also influenced by other factors than just SS, and SS should be characterized in terms of particle-size and chemical composition to understand their impact on the environment.

The river basin organization (BBWSC) of the Citarum provides the most reliable discharge data, including the rating curves used to derive discharge values from water levels. Daily measurements from 2007-2013 were provided for three locations: Nanjung (entrance of reservoir), Dayeuh-Kolot (centre of the floodplain) and Majalayah (upstream of floodplain). However, a small validation check (Annex II) showed that the data at Majalayah and Dayeuh-Kolot should be considered unreliable, for the discharges exceeded the discharges at Nanjung significantly, which cannot be explained. Moreover, it was observed that at some point in time something happened to the sensor or the rating curve, for the discharge pattern changed significantly. Upon inquiry with BBWSC it appeared that indeed Nanjung should be considered as the only reliable discharge data, although one should still be very cautious while using it. This data was also used by Deltares to calibrate the Sobek model.
The BBWSC also published a water balance report of the Citarum, which gives some insight in the discharges at Majalaya, Dayeuh Kolot and Nanjung (Pt Transka Dharma Konsultan, 2013, Figure 5). Note that this figure is constructed in a complex way. First, for every month in the years 2002-2012 the average discharge in m^3/s was calculated. Then, the exceeding frequency of this monthly average discharge within the 2002-2012 period was determined.

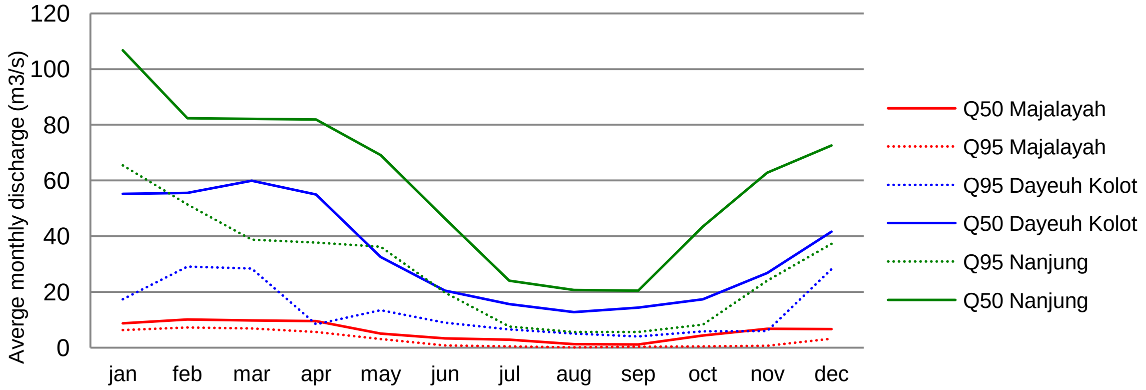

FIGURE 5 EXCEEDING FREQUENCIES FOR THE OBSERVED AVERAGE MONTLY DISCHARGES IN 2002-2012 (PT TRANSKA DHARMA KONSULTAN, 2013)

2.1.2 Industrial effluents

There are large amounts of industries in the Bandung Basin, most of them are textile industries (Figure 6). Although clean technologies are available and affordable (e.g. dying with CO_2 instead of water), these technologies are not used (Smits, 2015). Only medium and large[2] industries have to be registered to get a license, and are obliged to install a wastewater treatment plant (WWTP). The West Java Environmental Protection Agency (West Java EPA) estimates there are 1500 industries in the Basin, of which 300 are registered (p.c. Mayaningtias, 3/3/2015). Therefore, industries can be divided in three categories: (1) registered with centralized WWTP, (2) registered with decentralized WWTP and (3) unregistered industries.
There is one centralized WWTP: Cisirung, located in the Dayeuh-Kolot industry cluster, used by 26 industries, of which 24 textile industries. This plant is facing big problems due to its situation in a flood-prone area: floods and electricity failure stop the treatment process almost every year, while the industrial processes often continue at the same time. At 21/1/2015 the plant was visited and tracks of floods up to 1.80 m were visible. Moreover, large parts of the plant were not operational at the moment of visiting. According to employees this was due to ‘changes in the treatment process’, but obviously part of the equipment was broken. De Vries (2012) reports similar issues during her field visit of the plant on 7/3/2012. This is suggesting the plant is in a continuous state of insufficient operation, which was confirmed by employees of the West Java EPA. It was suggested that the problem is caused by lack of budget provided by the industries, and lack of well-educated human resources.

[2] Stakeholders use various definitions to designate ‘micro’, ‘small’, ‘medium’ and ‘large’ industries. The official classification is prescribed by ministry decree based on number of employees per industry: micro 1-4, small 5-19, medium 20-99 and big > 100 employees (SK Menteri Perindustrian No. 19/M/I/1986).

According to De Vries (2012), the effluent quality of decentralized WWTPs is very variable, depending on the social responsibility of the management teams, the used production process and the investments done on the treatment process. Factories have to take and analyse samples themselves and report their results to the local, provincial or national EPA. It is generally known, and confirmed by De Vries, that this kind of self-monitoring almost always meets the standards, while samples taken by independent institutions provide conclusive evidence to the contrary: standards are rarely met. A large number of factors contribute to this problem, which is a result of social institutions. Registered industries have a WWTP, but the quality is often insufficient due to lack of knowledge of the WWTP manager and cheating by the consultants providing the technology. The industries try to minimize their production costs by cutting back on operation of WWTPs, which costs are a significant part of the whole production process. As a result, many industries only operate their WWTP's during governmental inspections (p.c. Anggara, 6/3/2015). The government is facing big difficulties while trying to monitor the industrial emissions. There is a team of police, West Java EPA and the public prosecutor, trying to stop violating industries. However, it is very hard to prove violations, due to a lack of human resources, budget and sufficient legislation. Moreover, violating industries are often supported by local communities, laboratories and even the police (p.c. Mayaningtias, 3/3/2015). In practice, only 10 industries are fined every year, and the fines are so low that it is more attractive to risk the punishment and continue discharging the polluted water. Moreover, the industries blame the government for selective law enforcement, thus disadvantaging the competitiveness of some industries (p.c. Anggara, 6/3/2015).

Although they are very small in size, the large amount of small companies and home industries may contribute significant to the pollution. A representative of an NGO in the Majalaya area states that there are a lot of small industries that provide semi-manufactures for the textile industry, not using any kind of wastewater treatment, producing small, but heavy polluted discharges (p.c. Riswandani, 4/2/2015). This is confirmed by several stakeholders (De Vries, 2012).

Finally, it should be noted that the problem of unregistered industries is beyond the boundaries of the industry clusters; it was observed that countless small companies in the city of Bandung are discharging oil products and detergents in the sewer and surface water system (cf. Section 5.4.4).

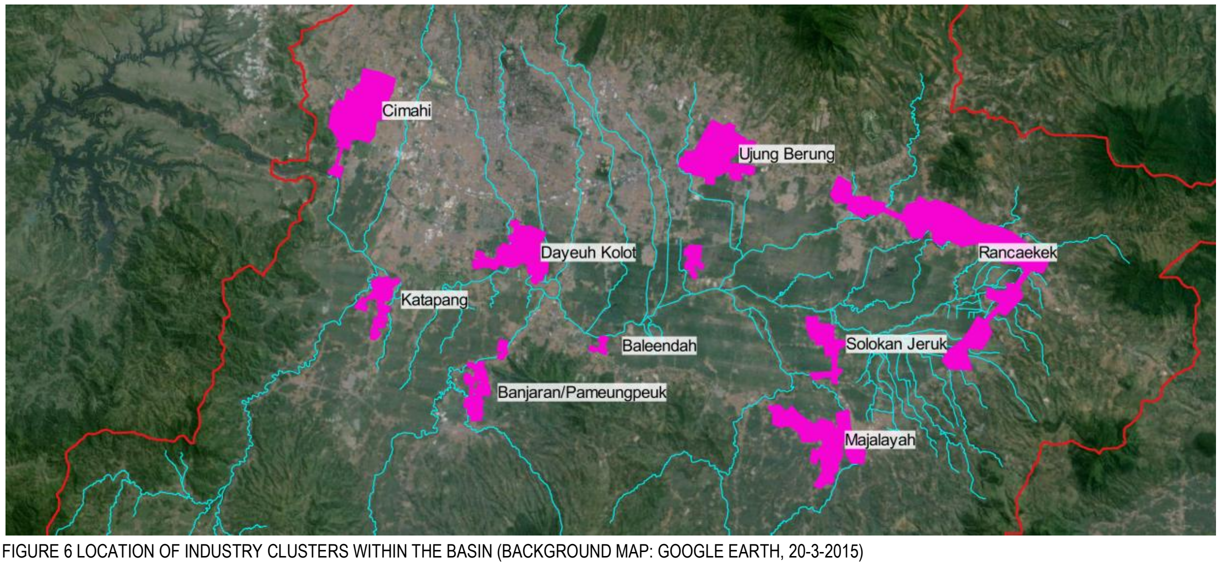

FIGURE 6 LOCATION OF INDUSTRY CLUSTERS WITHIN THE BASIN (BACKGROUND MAP: GOOGLE EARTH, 20-3-2015)

2.1.3 Domestic waste

The domestic waste is the most eye-catching factor contributing to the pollution. Piles of domestic waste, especially plastics, can be found everywhere in the basin. Refuse collection within the city of Bandung seems to be organised somewhat better than in the villages and rural areas. It was often observed that garbage was burned on piles in the open air, sometimes primitive incinerators are used (e.g. 'ecovillage project', visited on 24-1-2015). Almost everywhere garbage is dumped on the river banks, entering the river water at high water levels. Further, waste bins are infrequently found within the city, and a lot of street litter ends up in the drainage system.

The solid waste problem is typical for developing countries. As solid waste disposal often goes together with other types of water pollution, it is hard to assess the precise impact of the waste on the water quality parameters, but at least three different aspects can be distinguished. First of all, the garbage strongly influences the aesthetics of a river. Secondly, the presence of garbage is influencing a variety of other water quality parameters, because contaminants from the solid waste dissolve in the water (Dinesh *et al.* 2006, Karija, 2013, Subin *et al.* 2013). Thirdly, the solid waste provides a breeding ground for bacteria; for example Nkowacha *et al.* (2011) show a very strong correlation between solid waste and the amount of fecal coliform in a tropical river. The domestic waste problem is widely acknowledged in literature about the Citarum (e.g. ADB 2007; Fullazaky 2010) and countless photos of it can be found on the internet. Factors leading to the problem are citizen behaviour and a lack of infrastructure, related to poor city planning, weak governmental institutions and rapid population growth.

2.1.4 Domestic sewage

35% of the city of Bandung, mainly the east side, is connected to a centralized wastewater treatment plant, the IPAL (WWTP) Bojongsoang. According to Prihandrijanti & Firdayati (2011), the operation of this plant is not effective, reducing its capacity by more than 50%. Although a sewer system was constructed for the west side of the city as well, a WWTP has never been built. Therefore, the sewer system is directly discharging on the river water of the Cikapunding tributary. The Bojongsoang plant is serving about 400,000 people (Hendrawan *et al.*, 2013). The efficiency of the plant in 2006 was a COD reduction of 58% and a BOD reduction of 57% (Mangunwardoyo *et al.*, 2013).

Households that are not connected to a sewer system are directly discharging on the surface water, or they are using septic tanks. These septic tanks are also very common in the rural areas, although it is still quite common that villagers directly defecate in the environment. According to the West Java EPA, there is regulation that prescribes how these septic tanks should be constructed, but it is feared that a lot of the tanks are poorly constructed, leading to seepage or even direct discharge to the water system (Calderon *et al.*, 2011). Moreover, the infrastructure required to maintain the septic tanks is lacking. As a result of this, companies responsible for taking the sludge from the tanks sometimes dump it in the river water (p.c. Yusuf, 20/2/2015).

Both the domestic waste and the domestic sewage problem are linked up with a spatial planning dilemma of the government. Many poor people, with low education and no income live in illegal housing, especially on the river banks. These slums do not have any infrastructure and are thus contributing significantly to the waste and sewage disposal. However, if the government would provide this infrastructure, it would indirectly approve the illegal habitation of the river banks, which is an undesirable policy (p.c. Lina, 6/3/2015, Widiani, 6/3/2015).

2.1.5 Crop growing

When characterizing pollution originating from crop growing activities, it is important to distinguish between paddy fields, plantations with perrenial trees and dry crops.

As can be seen from the land use maps (Section 5.4, Annex XIV), paddy fields are mainly found in the plain and on the hills with a relatively small slope in the centre of the basin. Paddy fields are often terraced, and according to Yusuf (p.c. 20/2/2015) the pesticides will mostly be added in the uppermost terrace. The flushed pesticides will be absorbed by more downstream terraces. Yusuf claims that research of PusAir showed that only a small amount of the pesticides finally reach the river water. In fact, it is really hard to estimate the amount of pesticides and nutrients that will enter the river water. The decisive factor in this is the design and operation of the water flow from one terrace to another (Yoshinaga *et al.*, 2007), which might be very different for every farm.

Plantations with perennial trees like coffee and tea, are mostly located on the slopes in the basin. Most of the plantations are very old; they have been established during the colonial period. Exploitation of a plantation is a complex job and a long-term investment, therefore, most of the plantations are exploited by large companies. In general, it can be said that a well-maintained plantation will lead to less soil erosion (van Dijk *et al.*, 2007), although the pesticides used can still pollute the water.

The rest of the agriculture activities can be characterized as 'dry crops', which contrasts with the inundated paddy fields, although also for dry crops irrigation methods can be used. Examples of dry crops are carrots, potatoes, unions, chilli, lettuce and beans. Dry crops are often cultivated on steep hill slopes, without using terrace techniques (Calderon *et al.*, 2011, DHV *et al.*, 2010, Firdaus, 2014). This is leading to fast run-off, flushing of fertilizers and sediments, and erosion of fertile soil. However, after careful observation of the used farming technologies, it became clear that the fast run-off is an intentional strategy used by the farmers to get rid of the water which harms water-vulnerable crops like potatoes. So it is more appropriate to conclude that the used types of crops are unsuitable. However, farmers will continue to use these kinds of crops because these so called 'cash crops' are more profitable (p.c. Widiani, 6/3/2015).
The water from agricultural run-off contains large amounts of pesticides, caused by several factors. Farmers are often low-educated and use their own, intuitive mix of pesticides. Research of the West Java EPA shows that this mix on average exceeds the required amount of pesticides by 76%. Moreover, farmers 'believe' mainly in the use of the often harmful pesticides and strongly prefer it over the use of more environmental friendly pesticides. (p.c. Mayaningtias, 3/3/2015). Although harmful pesticides are officially banned by the government, they are widely available and an NGO claims that they are even provided by state-owned enterprises (p.c. Riswandani, 4/2/2015).
The issue is made more complicated by issues concerning property rights. Especially the paddy fields are often owned by powerful big enterprises (like Indofood and other multinationals) which prescribe and provide the pesticides and fertilizers to be used by the farmers. For the dry crops, farmers have contracts with similar organizations (p.c. Mayaningtias, 3/3/2015). After extensive discussions about property rights of illegal farms in the forests, which had been tolerated by the government for a long time, the government had to give up large areas that were officially designated as protected. Hence, the government contributed to deforestation due to weak law enforcement (p.c. Widiani, 6/3/2015).

2.1.6 Stockbreeding

Pollution from stockbreeding activities already starts in the first kilometer downstream of the Situ Cisanti: the spring of the Citarum. The farming usually is on a very small scale, farmers often own two to five cows for milk production. The milk cows will always be inside the cowsheds, the only 'cows' that were found outside during the fieldwork where Asian buffalos, used for working in the paddy fields. Stakeholders indicated that the manure is never used as a fertilizer, and even the governmental policy does not aim on this use of the manure. A local NGO estimates that 90% of all the manure produced is directly discharged in the river, about 10% might be used in biogas installations built by the government (p.c. Riswandani, 2/3/2015). Governmental stakeholders (PusAir, Bappeda, West Java EPA) all consider biogas installations as the solution to the problem, although they acknowledge that it has been very unsuccessful up till now. The NGO representative explains that of the 37 existing biogas installations, only 16 are still operational, and only during governmental inspections. The farming activities are on a too small scale and too much scattered in space; the community knowledge and support is too small and the governmental policy too top-down to solve the problem using these installations. In general, the farmers are not aware of the impact the manure has on the water quality and it is not attractive for them to use it for any purpose. Moreover, some of the farming takes place illegally, making it very unattractive for the government to provide any facilities (p.c. Riswandani, 2/3/2015).
Besides the countless small scale stockbreeding activities, some larger milk industry farms are located in the area of Lembang, a small town north of Bandung. It is believed that also these farms directly dump the manure in the river water (p.c. Yusuf, 22/1/2015).

2.2 Processes affecting water quality

The pollution of the surface water in the Bandung Basin is interacting with a lot of other processes. It is important to have some understanding of these processes in order to estimate the impact of the impaired water quality.
First of all, there is interaction with the sediments. Pollution is adsorbed and accumulating in the sediments and it might be released again in the water when the water quality of the Citarum improves.

Large quantities of the sediment end up in the Saguling reservoir. Second, the pollution in the river is degraded, transformed, diluted and dispersed as a result of several chemical and physical processes (Figure 7).

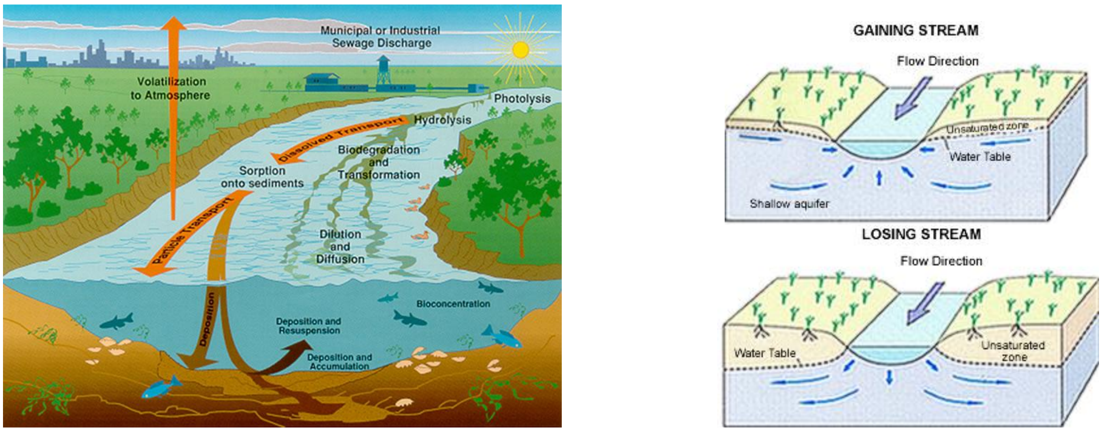

FIGURE 7 CHEMICAL AND PHYSICAL PROCESSES IN THE WATER INFLUECING THE POLLUTION IN THE RIVER (LEFT), AND INTERACTIONS WITH GROUND WATER (RIGHT) (SOURCE LEFT: MEADE, 1995; RIGHT: WWW.USBR.GOV, VISITED AT 1/6/2015)

Thirdly, the quality of the water from the Bandung Basin is determining the quality of the Saguling reservoir. The problems in this reservoir have been big for decades (cf. Koeman *et al.*, 1972 as cited in Djuangsih, 1993). Djuansih describes explosive growth of aquatic weeds, a result of eutrophication, due to an enormous surplus of nutrients in the reservoir. These nutrients originate from the Citarum river water, but also from excessive fish farming which takes place in the reservoir (Figure 8). The high nutrient concentrations, in combination with toxic cyanobacteria blooms, low dissolved oxygen and high ammonia and toxics concentration is leading to regular, massive fish-kills in the reservoir (Hart *et al.*, 2002). However, for the downstream parts of the Citarum river, the reservoir has a purifying and diluting function; the observed water quality at the outlet of the reservoir is significantly better than at the inlet. Therefore, some stakeholders refer to the Saguling reservoir as the 'big septic tank' of the Bandung Basin (van Lier, 2015).

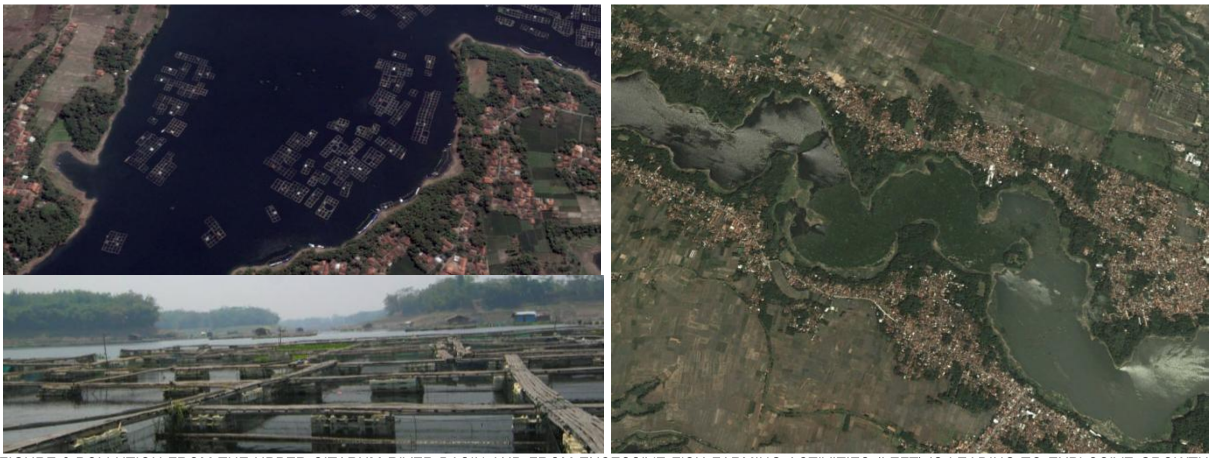

FIGURE 8 POLLUTION FROM THE UPPER CITARUM RIVER BASIN AND FROM EXCESSIVE FISH FARMING ACTIVITIES (LEFT) IS LEADING TO EXPLOSIVE GROWTH OF AQUATIC WEEDS THAT CAN BE SEEN ON SATELLITE IMAGES (RIGHT). (SOURCE: SATELLITE PHOTOS FROM GOOGLE EARTH, 2/1/2014; PHOTO FROM PANORAMIO USER 'DEVITAPRA', OBTAINED AT 1/6/2015)

The fourth process which takes place in the Citarum river water is bioaccumulation. Djuangsih (1993) already reports high concentrations of organochlorine pesticides and more recent research shows very high concentrations of heavy metals in fish (Roosmini, *et al.*, 2006a, Roosmini, *et al.*, 2006b).
Fifth, there are interactions between surface- and groundwater in the basin. Especially the unconfined, shallow aquifers (a few meters to around 40 m below the surface) are intensively exploited by wells

and are very vulnerable to pollution (Soetrisno, 1996 as cited in Deltares, 2012). Especially in the industry clusters, the ground water abstractions are enormous, leading to decreasing ground water levels of over 50 m and land subsidence up till 20 cm per year in the Cimahi area (Abidin *et al.*, 2009). In the dry season, the industries sometimes have to use the very dirty Citarum river water, because there is no water in their wells (p.c. Angara, 6/3/2015). Moreover, it is feared by Yusuf (p.c. 22/1/2015) that near the inlet of the reservoir, near the Cimahi area, a lot of polluted river water is infiltrating in the ground water. In the last decades the Citarum changed from a gaining stream into a losing stream (Figure 7). Combining this with the fact that discharges of the Citarum during the dry season sometimes are lower than 10 m^3/s, then completely consisting of brine water, Yusuf fears that the Citarum might be almost completely dry during extreme drought events in the future. But even if this will not be the case, the infiltration of polluted water in the groundwater will lead to big problems in the city of Bandung, where the wells are the only water supply for those who have no access to piped water. In Ciwalengke, a part of the Majalaya industry cluster, already a lot of skin diseases are reported as a result of highly polluted wells by industrial wastewater (Candra *et al.*, 2010).
Finally, the bad water quality becomes a 'problem' due to the large exposure of the poor people to the water. As also observed by Wichern (2013), people are exposed to the river water by sand, sediment and gravel mining; washing clothes, animals, tools, dishes in the water; fishing and irrigation activities; recreational swimming (especially children); bathing and many other activities. Via infiltration in shallow wells, people even drink the polluted water, with boiling being the only treatment that is commonly used. In combination with the flood problems in the basin, all these aspects are leading to a large number of water related diseases, like dengue, skin diseases, diarrhoea and many others (Wichern, 2013).

2.3 Conclusion

The natural conditions of the Bandung Basin, a large floodplain surrounded by eroded volcanic mountains, make the basin a very vulnerable area. Deforestation, as a result of population growth, is leading to large erosion and flood problems. This is also affecting the water quality in a negative way.
The five different sources of pollution can all be explained by weak social and governmental institutions. The people in the basin are either not aware of the impact of their behaviour, not able to change it, or even not willing to do so. This is probably due to the low living standard, and low education of the poor, who form the 'base of the pyramid' of the Indonesian society. Due to a lack of community support in combination with the continuing population growth, the government is not able to execute their policy effectively. Moreover, the government is facing big problems in law enforcement towards the powerful industry and agricultural businesses.
The bad water quality in the Citarum River leads to: deterioration of the Saguling reservoir; pollution of sediments, pollution of the wells via groundwater and to bioaccumulation of contaminants in fish. The combination with large exposure of people to the water results in a big impact on the health of citizens in the basin.

3 WATER QUALITY MONITORING

This chapter addresses the second research question: "*What data can be obtained from organizations to support the water quality modelling?*" Answering this question will be done in two different ways: 1) by creating an overview of existing water quality, quantity and emission data and identification of gaps within available data; and 2) by describing and assessing the stakeholders concerned with water quality monitoring. The second approach is part of the minor Sustainable Development, and will therefore only be shortly addressed in this B-thesis. The results of this stakeholder approach will be presented in the conference paper (Van Ginkel, 2015), to be presented at the 5th Environmental Technology and Management Conference in November 2015 at Institut Teknologi Bandung.
The overview of data in this chapter was created using the following methodology. First, the existing collection of data of the Alliance was ransacked to get an impression of the available types of data. It was found that much of this data was out-dated. To get a good impression of the current state of the basin, it was desirable to base the research on recent data (2010-2014). Therefore, all organizations owning data were visited, sometimes multiple times, in order to obtain the data. This was often combined with an interview to collect data for the conference paper. The next step was to create some insight in the obtained data. Geographical data describing the sampling locations were converted into formats suitable for GIS-software and maps of the tributary structure and sampling locations were created. The Indonesian parameter descriptions were translated and mutually compared to give insight in the measured parameters. The time indications of the measurements were organized and plotted to obtain insight in the timing of the measurements. Subsequently, a selection of the data was converted to a uniform csv-format, so that it could be systematically analyzed in Excel. This was a very time consuming process, because there were big differences in formatting of the data, even within datasets obtained from the same organization. The conversion process has been automated to a large extent, using Python scripts. However, there were countless faults and errors in the datasets that had to be corrected manually. The used csv-format was made suitable for import in the FEWS-database system developed by Deltares and some time was spent to initiate the set-up of this database for the Bandung Basin. Finally, the data was imported in Excel and spreadsheets were set-up to create descriptive statistics and plots of the data based on array formulas.

3.1 Water quantity data

The water quantity data required for water quality modelling, can be derived from two different sources: rainfall data (to be converted to discharge via rainfall-runoff relations) and water level measurements (to be converted to discharge using Q,h-relations). It is also possible to simulate rainfall and runoff using the Deltares Sobek model developed for the Bandung Basin.
Rainfall data can be obtained from the meteorological institute BMKG. However, one should be careful in using this data, for it needs validation due to inconsistencies and errors (Deltares, 2010a). A free alternative is the use of the information derived from the Tropical Rainfall Measuring Mission (TRMM) satellite, which was specifically designed for monitoring rainfall in tropical areas. The 3-hourly and daily rainfall data derived from the satellite's images is stored in the operational FEWS database at the office of Deltares in Bandung, and the TRMM can easily be added to a FEWS system for the Bandung Basin. The main disadvantage of TRMM is that the the used grid is very rough: the whole Bandung basin is covered by only 6 grid cells. A rainfall study done by Deltares (2010a) shows that the rainfall patterns within the basin can hardly be modelled using such a rough grid, for rainfall intensities are strongly variable within the basin during a storm.

As already explained in section 2.1.1, the recent discharge data which the river basin organization BBWS Citarum obtains via the automatic recorders is sometimes unreliable (p.c. Muchni, 12/5/2015). Some (anonymous) users of the BBWSC data suggest that the automatic level recorders are damaged or shifted as a result of flooding and pollution (Figure 9). The measurements that are considered the best are done in Nanjung, Dayeuh-Kolot and Majalaya. However, the validation in Annex II shows that the data of Dayeuh-Kolot is inconsistent, and that one should also be very careful using data from Nanjung or Majalaya because the used rating curves are erratic. Daily discharge data at Nanjung was retrieved for the period 1990 until 2013. Discharge data at Dayeuh-Kolot and Majalaya was retrieved for the period 2007 until 2013.
Another option to obtain water quantity data is using the Sobek model developed by Deltares. In this model the discharge of the tributaries is calculated based on rainfall input and a basin schematisation with assumptions about the rainfall-runoff relation. However, this model has only been calibrated for the discharge at Nanjung, and therefore the contribution of the different tributaries to the total discharge might be unrealistic. Moreover, the model was developed for flood prediction, and has therefore not been calibrated for low-flow periods (Deltares, 2010b).

FIGURE 9 CONDITION OF THE STAFF GAUGE AT NANJUNG (7/3/2015)

3.2 River quality monitoring

On the river basin level, three organizations are doing regular water quality measurements: R&D-centre PusAir, West Java EPA and reservoir operator PJT-II[3]. Occasionally, some measurements are done by local universities and the river basin organization BBWS, but the amount of this data is very limited. Further, measurements are done on the regencies/city (Kabupaten/Kota) level by the five regency level EPAs, see Annex I for an overview of the administrative regions in which these EPAs are operating. Within the context of this research, only the data from Kabupaten Bandung EPA and Kota Bandung EPA were considered, as these EPAs are covering the largest part of the basin (Annex I).
In Table 1, an overview of the most relevant obtained data is given. The data displayed in this chapter is restricted to the period 2010-2014, but more data has been obtained (see Annex V). In Figure 10, the sampling sites of PusAir, West Java EPA, Kabupaten Bandung EPA and PJT-II can be seen. PusAir, West Java EPA are doing measurements in the main Citarum river. PJT-II is also doing measurements in the main tributaries. The Kabupaten Bandung EPA is sampling in very small tributaries.

TABLE 1 SUMMARY OF AVAILABLE DATA (2010-2014)

Organization	**PJT-II**	**West Java EPA**	**PusAir**	**Kab. Bdg. EPA**	**Kota Bdg. EPA**
Time and date	time-date-month-year	date-month-year	time-date-month-year	month-year	month-year
# locations in basin	19	4[4]	4	72 – 75	32
# meas. per year	12	3 - 5	1 - 2	3	3
Available data	2010-2014	2010-2014	2010-2013	2010-2013	2012-2013

[3] The tasks that are executed by PJT-II make the organization, practically spoken a River Basin Organization, competing with the tasks that are assigned to the RBO BBWS (van Lier, 2015). See the conference paper for an elaborate discussion about the monitoring activities of the stakeholders.
[4] Before 2011, the West Java EPA used to have 7 monitoring stations. In 2011 three of the sites where removed, due renewed task division after establishment of BBWSC, and two other sites were moved to a different location.

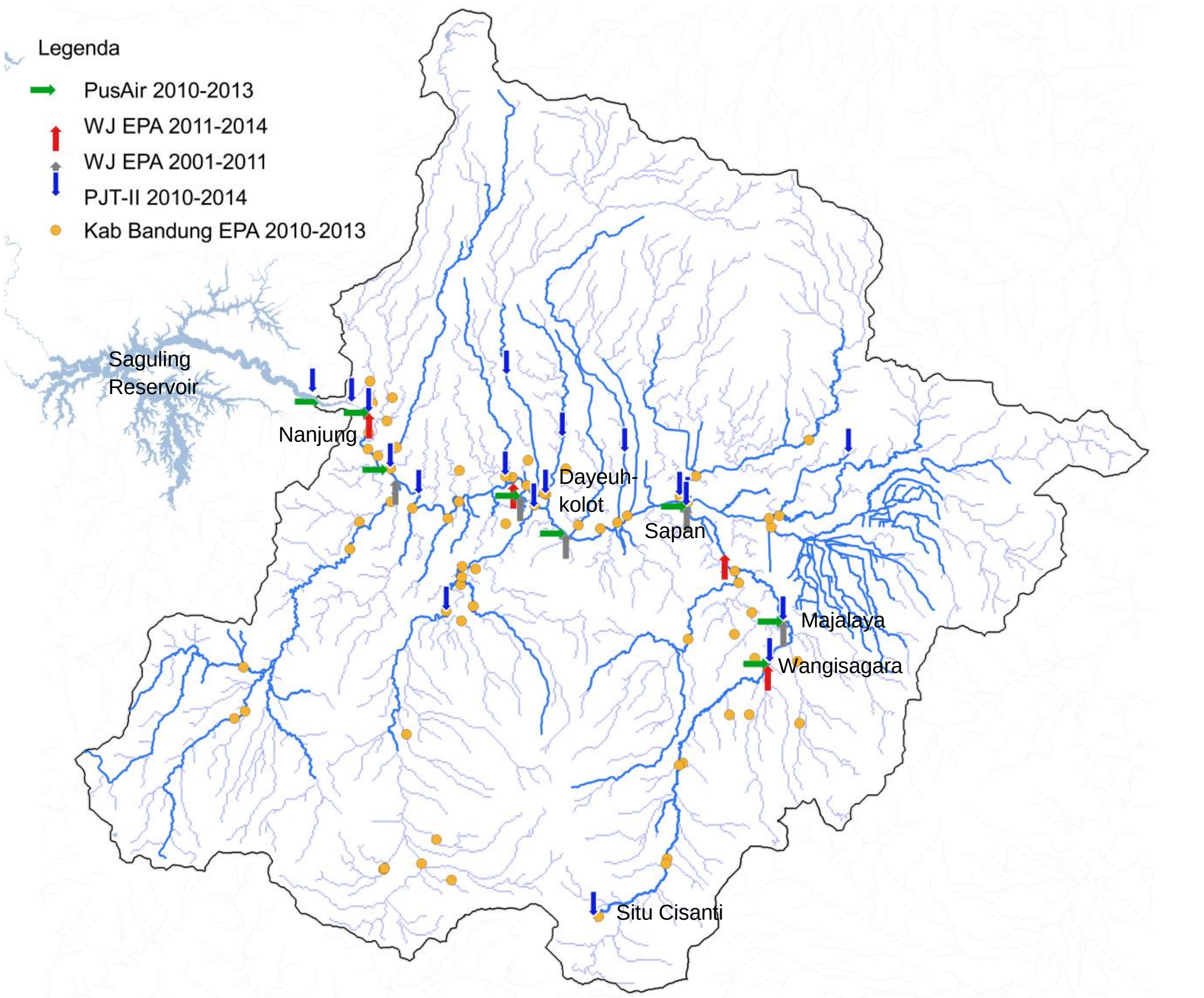

FIGURE 10 SAMPLING LOCATIONS OF DIFFERENT ORGANIZATIONS[5]

In Figure 11, the timing of the water quality measurements is displayed. PJT-II is the only organization which does regular, monthly measurements. The others are mainly doing measurements during the dry season, in which the water quality is considered the worst.

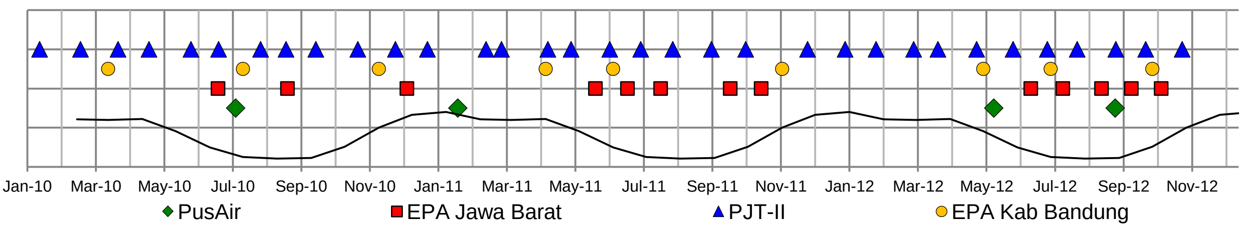

FIGURE 11 TIMING OF WQ MEASUREMENTS IN 2010, 2011 AND 2012, LINE IS INDICATING ROUGH YEARLY RAINFALL PATTERN (MEDIAN RAINFALL, SEE FIGURE 4), DOTS ARE INDICATING WQ MEASUREMENTS[6]

In Table 2, an overview of the parameters measured by the different organizations is given. Sometimes it was very hard to interpret the Indonesian description of the parameters provided by the laboratory and due to the inconsistencies in formatting of the source data, there can be some minor mistakes in this overview.

[5] The locations of the Kota Bandung EPA are missing in this overview, as no location set was provided.

[6] The locations of the Kota Bandung EPA are missing in this overview, because the data was obtained just before the thesis had to be finished.

TABLE 2 PARAMETERS MEASURED BY DIFFERENT ORGANIZATIONS (2010-2014)

			EPA's		
	PJT -II	**Pus Air**	**West Java**	**Kab Bdg**	**Kota Bdg**
Physical parameters					
Discharge	⓪	❷	⓪	❶	⓪
Electrical Conductivity *	⓪	❷	❷	⓪	⓪
Turbidity	❷	❷	⓪	❶	❷
Temperature	❷	❷	❷	❷	⓪
TDS	❷	❷	❷	❷	❷
TSS *	⓪	❷	❷	❷	⓪
Chemical parameters					
pH	❷	❷	❷	❷	❷
Dissolved Oxygen	❷	❷	❷	❷	❷
BOD *	❷	❷	❷	❷	❷
COD *	❷	❷	❷	❷	❷
Detergent	⓪	❷	❷	❶	❷
Free ammonia	❷	❷	❷	⓪	❷
Total ammonia	⓪	❷	⓪	⓪	⓪
Fenol	⓪	❶	❷	❷	❷
Nitrite	❷	❷	❷	❷	❷
Nitrate *	❷	❷	❷	❷	❷
Organic Nitrogen	⓪	❷	⓪	⓪	⓪
Chloride (Cl_2) *	❷	❷	⓪	❷	❷
Cyanide	⓪	⓪	❷	❷	⓪
Sulphate (SO_4) *	❷	❷	❶	❶	❷
Ortho Phosphate	⓪	❷	⓪	⓪	⓪
Total Phosphate	⓪	❷	❷	❶	⓪
Hydrogen Sulfide (H_2S)	❷	⓪	❷	❶	⓪

			EPA's		
	PJT -II	**Pus Air**	**West Java**	**Kab Bdg**	**Kota Bdg**
Chemical parameters (continued)					
Alcalinity	⓪	❷	⓪	⓪	⓪
Acidity	⓪	❷	⓪	⓪	⓪
Boron (B)	⓪	❶	⓪	⓪	❷
Fluor (F)	⓪	❶	⓪	❶	❷
Iron (Fe) *	❷	❶	❶	⓪	❷
Potassium (K)	⓪	❷	⓪	⓪	⓪
Calcium (Ca)	⓪	⓪	❷	⓪	⓪
Hardness ($CaCO_3$)	⓪	❷	⓪	⓪	⓪
Chromium	⓪	❶	⓪	⓪	❷
Manganese (Mn) *	❷	❶	⓪	⓪	❷
Magnesium (Mg)	⓪	❷	⓪	⓪	⓪
Oil-grease	⓪	❷	❶	⓪	❷
Sodium (Na)	⓪	❷	⓪	⓪	⓪
Sodium %	⓪	❷	⓪	⓪	⓪
Nickel (Ni)	⓪	❶	⓪	⓪	❷
SAR (?)	⓪	⓪	⓪	⓪	⓪
Zinc (Zn) *	❷	❶	⓪	❷	❷
Lead (Pb)	⓪	❶	⓪	❶	❷
Cadmium (Cd)	⓪	⓪	⓪	❶	❷
Copper (Cu)	⓪	❷	⓪	❶	❷
Chrom. (Cr^{6+})	⓪	⓪	⓪	❶	⓪
Biological parameters					
Fecal Coliform*	⓪	❷	❷	❷	⓪
Total Coliform	⓪	⓪	❷	❷	⓪

Frequency: ⓪ = not frequently measured ❶ = sometimes measured ❷ = most of the time measured
Parameters marked with a * are chosen for further analysis, see chapter 5.

WATER QUALITY ASSESSMENT METHODS

The results of the water quality monitoring are often presented using the Water Pollution Index (WPI) and STORET method, see Annex IV. These methods give an indication of the extent of the water pollution relative to the norms. Use of these methods is prescribed by Indonesian law. It is common practice at the EPAs only to share the raw data with governmental organizations, and the STORET output with other parties (Van Ginkel, 2015). However, it was observed that the way the STORET method is used is not according to the Indonesian law. The STORET score requires a series of measurements, so that the minimum, average and maximum value for each parameter can be calculated. However, most of the time there is no series of data available and some kind of STORET score is simply assigned to a single sample. Another problem with STORET is that it does not distinguish between a small or a large exceedance of a norm. For application of the WPI-method, no series of data is required and the extent to which a norm is exceeded is taken into account. Therefore, the WPI-method is preferred over the STORET-method. However, in reality the STORET method is always used.

3.3 Validation different water quality data sources

In Annex VI, the obtained water quality data is validated. Several organizations are doing measurements at the same locations with the same parameters. The concentrations observed by the different organizations are mutually compared, to investigate if there are systematic deviations between the different organizations. The findings in Annex VI are complemented by data comparison in Section 5.2, where data from the Kabupaten Bandung EPA is compared with measurements by the author of the thesis, and by the graphs in Section 5.4 and Annex XI, where all measurements in the Citarum River are plotted in surveyable graphs.

The first observation is that there are large differences between datasets. The graphs in Section 5.4 clearly show that for certain parameters, the concentrations observed by one organization systematically differ from concentrations observed by another organization. It is clear that this cannot only be ascribed to natural scattering of the data, because the same differences are found on all

locations. The differences between the datasets are that large, that there is a need for further clarification before one can give a final judgement about the water pollution in the Bandung Basin. This section aims to give an initial impetus to this clarification, but can only indicate some global trends and lines of reasoning, that need to be further researched in the future.
The second observation is derived from comparison of the PJT-II data with data from the other organizations. PJT-II is doing measurements during the whole year, while other organizations take their samples mainly during the dry season (Section 3.2). Further, the PJT-II dataset is bigger than the other datasets, because the measuring frequency is higher. As a result, one would expect that the few observations from the other organizations are mainly within the range of PJT-II. Assumed that the water quality during the dry season is worse compared with the wet season for most parameters (Section 5.3 shows that this assumption is true), one would expect that the average concentrations of PJT-II are lower than the concentrations observed by the other organizations. For some parameters, this pattern is indeed observed: the measurements of PJT-II (almost) span the range of the West Java EPA and PusAir, and the average of the latter two is relatively high (cf. pH at Wangisagara Figure 38, Annex VI; TDS, Nitrite and Nitrate at Nanjung, Figure 39 Annex VIAnnex XI). The same pattern is observed for most parameters by comparing PJT-II with Kabupaten Bandung EPA (Figure 40 and Figure 41, Annex XI VI). However, often the measurements of the other organizations are not within the range observed by PJT-II (see other graphs in Figure 38 and Figure 39 Annex VI).
The third observation is that especially the West Java EPA data is strongly deviating from the other organizations. For example, the COD measured by the West Java EPA is almost two times higher than the COD measured by PJT-II and PusAir (Figure 27, Section 5.3). This cannot only be due to the differences between dry and wet season, because the West Java EPA measurements also exceed the third quartile of the observations of PJT-II that roughly indicate the concentration during the dry season. A similar difference is found for the BOD concentrations observed by the West Java EPA, (Annex XI). For some parameters, the West Java EPA data is deviating even more: the fecal coliform, nitrate, H_2S and free ammonia concentrations (section 5.3 and Annex XI) are so high that it is hard to plot the data in one graph. In contrast, the iron concentrations measured by the West Java EPA are much lower than observed by PJT-II (Annex XI).
The fourth observation is the most observations of PJT-II, Kabupaten Bandung EPA and PusAir are within the same range, although there are exemptions for some parameters. Comparison of the Kabupaten Bandung EPA data with measurements done by the author of this thesis, also gives no reason to question the reliability of the Kabupaten Bandung EPA's data. Therefore, it is tentatively concluded that the measurements of PJT-II, Kabupaten Bandung EPA and PusAir are more reliable than the measurement of the West Java EPA. The West Java EPA seems to overestimate the concentrations in the river. However, it is also possible that the other organizations underestimate the concentrations. More research has to be done to explain the differences between the different datasets. Maybe, the differences can be explained from different field of lab procedures. Those procedures need to be standardized in order to get reliable data that can be mutually compared.

3.4 Emission data

The amount of available emission data at governmental institutions is limited. The amount of pesticides and fertilizers used for agricultural purposes is very hard to estimate, but some research on it has been done by West Java EPA. However, all the available reports are written in Indonesian. There is no direct data on domestic emissions either, but there is information about population density on which emission estimates can be based. Further, there is some data and literature on the sewage system of Bandung and the operation of the WWTP (Mangunwardoyo *et al.*, 2013, Prihandrijanti & Firdayati, 2011). The garbage disposal of Bandung has been roughly estimated by the Asian Development Bank (2007) at 500,000 m^3/year, of which 250,000 m^3/year ends up in the Saguling reservoir. When estimating the emissions from stockbreeding activities, the biggest difficulty is the lack of reliable data about the amount of cows, and the locations where they are held. According to mr. Riswandani of the NGO in Majalaya, the government underestimates the amount of cows in his area with a factor 3 in their official publications (p.c. Riswandani, 2/3/2015). When the amount of cows in

the basin is known, further emission estimates can be done, for it can be assumed that practically all manure will end up in the water system in the current situation.
Some water quality modelling in the Bandung Basin has been done by mr. Yusuf, from the national R&D centre for water resources (PusAir). The elaborate emission estimates done by this researcher have been obtained (Yusuf, 2015). However, the report is in Indonesian, and it is not always clear on what data the calculations are based. Further, the amount of nutrients entering the Saguling reservoir are quantified in a study of Hart *et al.* (2002).
Estimating the industrial emissions requires a special approach. Due to the decentralization policy, large industries have to register at provincial and medium industries at regency/city level. Some special types of hazardous industries have to register at national level. Small industries and home industries are not registered at all. According to the NGO in Majalaya, these industries contribute significantly to the pollution (p.c. Riswandani, 2/3/2015). In some cases, even the larger industries are not registered (p.c. Anggara, 6/3/2015).
Part of the registration procedure of the industries is the issuance of a license from the national, provincial or regency/city level EPA. In practice, the factories always start before the license is issued (p.c. Anggara, 6/3/2015). One of the data sheets, containing licensing information per industry was obtained. It shows the allowed discharge the factory can discharge, and the amount of Chromium the water can contain. The datasheet also contains columns about the Copper, Zinc, Nickel and Cadmium concentrations the water may consist of, but those columns were not filled in. However, such a datasheet can also be made based on the legislation per type of industry, in which the allowed concentrations are stated. The problem of using this approach is that industries in fact will not meet the standards as stated in the license, for reasons explained in section 2.1.2.
Similar problems arise when industrial emission estimates are based on the monitoring datasheets of the provincial and local EPAs. This data is based on self-monitoring of the industries, which is biased and will always meet the license standards. A third approach could be based on the sporadic inspections that are done by the West Java EPA or private companies like the one De Vries (2012) attended during her research. However, also this approach will underestimate the real amount of discharges, for as explained in paragraph 2.1.2 some industries will only operate their WWTP during these inspections. Further it is feared that illegal discharge of chemicals takes place during night (p.c. Riswandani, 2/3/2015).

3.5 Set-up of water quality database

Because of the big differences in the formats used to store the water quality data among different organizations, one standard format was developed in order to do further analysis of the data. It was decided to use the open source, relational database system developed by Deltares, named FEWS. Originally, FEWS was meant to support a Flood Early Warning System, but the powerful interface in which all available data series are displayed on a map makes it also suitable for water quality data. Data was converted to a suitable FEWS import format, using Python scripts. For a detailed overview of the data currently ready for import in FEWS, see Annex V. Using this data, a FEWS system can directly be created by employees of Deltares.
The importance of a sound database, containing water quality and quantity data, has also been recognized by the Asian Development Bank (ADB) and the government of Indonesia. As a part of the technical assistance provided by the ADB, a Decision Support System (DSS) for the whole Citarum river basin has been developed and implemented by an international consultant K-water (2012). The interface of this DSS looks very similar to the interface of FEWS. The database underlying the DSS was also meant to contain the water quality data of the Bandung Basin. However, despite all the efforts and money invested in the project, the database has never been really operational (Van Ginkel, 2015).

3.6 Conclusion

The state-of-the-art of water quality monitoring in the Bandung Basin is very poor. The water quantity data required for water quality analysis is unreliable, and should be carefully validated before use. Water quality monitoring is limited to taking samples of the river water. This sampling is done by three different organizations in the main river, and by different regency/city level EPAs. There are big differences in frequencies, timing and measured parameters among these stakeholders. Moreover, the data is not easily shared and attempts to set-up a database system for organising and sharing the data failed. Further, the used water quality assessment methods are not executed in the right way and hence disguise the true condition of the river water. Emission data is scattered among different governmental institutes, and is very incomplete. Industrial emission data in particular is very biased, rather displaying the desired state of the discharge as formulated in the issued licenses than the actual state.

Therefore, one has to derive most of the relations between water quality and polluting sources from literature, when doing water quality modelling in the Bandung Basin. The land use maps derived from satellite images are an important data source in this. Subsequently, the model can be calibrated and validated using the water quality measurements described in this chapter. While doing this, it is important to have a good understanding of the physical and social processes that take place in the basin, as described in the first chapter of this thesis. Further there is a need of more knowledge about the water quality pattern in time. The next chapter of this thesis provides some of this information.

4 DATA COLLECTION

In this chapter, the process of data collection using Levelogger devices will be described, in order to answer the third research question: "*How can additional sensors be used to complement the obtained data?*" This question will be answered by explaining the used methodology, by drawing conclusions from the acquired data and by giving practical recommendations for data collection by similar devices in the future.

In the previous chapter, it was found that the available water quality data is limited to periodic sampling at a number of locations and some unreliable license emission data. For several reasons, the Alliance of Water and Health is interested in collecting more continuous water quality and water quantity data. First of all, the water quality in rivers can be very variable and the used sampling methods only give limited insight in this variability. Moreover, there was immediate cause to assume that the water quality at sampling times did not represent the real condition of the river, as sampling only takes place at daytime during working hours of the governmental stakeholders. Local NGOs claim that industries tend to discharge the heaviest polluted wastewater during the night (p.c. Riswandani 4/2/2015, Suranto 26/5/2015). The third reason for using the devices is that the Alliance is interested in the relation between river discharge and water quality which is an essential aspect of the modelling. Finally, both the Alliance and the West Java EPA are interested in this 'pilot study' using continuous sensors, as they are both planning to collect additional water quality data using similar devices in the future.

The following procedure was used to collect the data. First, the manual of the Levelogger devices was carefully studied, in order to get an understanding of the operation of the devices. In consultation with the Alliance, it was decided to locate the sensors somewhere in the area around Majalaya. Then, the search for appropriate sensor locations was started in close collaboration with local NGO Elingan. The people of this NGO know the situation in the field very well and maintain strong ties with the community, which is essential for the safety of the devices. After some time a clear image of the field situation was formed and sensor locations were chosen, so that a sensor frame could be designed and constructed. The sensors were calibrated and tested in the laboratory of ITB and the sensors were positioned in the field. They had to be visited regularly in order to collect the data and to be cleaned. The data was analysed and compared with the data obtained from other organizations. Two presentations were given to share information about the collection procedure: one at the West Java EPA and another at the NGO that represented the local community.

Videoblog

4.1 Device specifications

The type of device used is the Solinst® LTC Levelogger Junior model 3001 (F30, M10), see Figure 12. This device should be placed under water and is measuring three parameters: total absolute pressure, temperature and electrical conductivity.

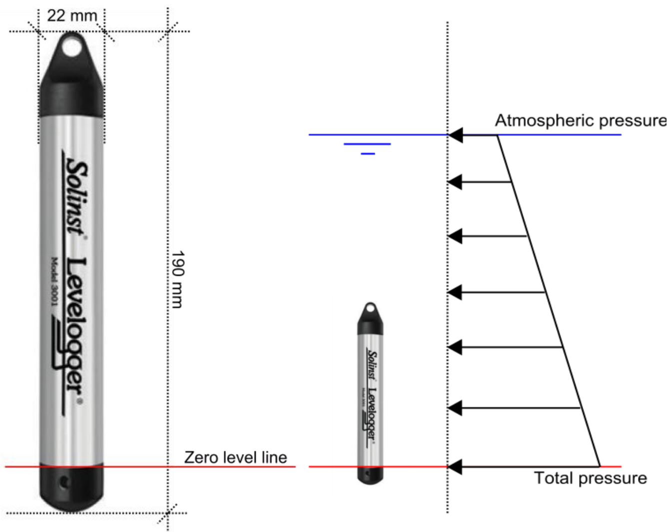

FIGURE 12 LEFT: DIMENSIONS OF LEVELOGGER, RIGHT: MEASURING TOTAL PRESSURE USING THE PRESSURE SENSOR, SENSOR IMAGE TAKEN FROM USER MANUAL (SOLINST, 2012)

An overview of the most relevant specifications of the three sensors within the device is given in Table 3. The data from the Levelogger can be read out using a Windows PC, connected via USB to the supplied optical reader.

TABLE 3 SPECIFICATIONS OF THE THREE SENSORS WITHIN THE LEVELOGGER DEVICE (SOLINST, 2012)

Parameter	**Total absolute pressure**	**Temperature**	**Electrical conductivity**
Type of sensor	Piezoresistive Silicon with Hastelloy Sensor	Platinum Resistance Temperature Detector	4-Electrode Platinum
Calibrated range	0 to 10 m (Total waterpressure)	10 ^{0}C to 40 ^{0}C	500 to 50,000 μS/cm
Typical accuracy	+/- 0.1 cm	+/- 0.1 ^{0}C	+/- 2% of reading
Resolution	3 mm	0.1 ^{0}C	1 μS/cm
Normalization	Automatic Temperature Compensation (from 10 ^{0}C-40 ^{0}C)	No normalization.	Specific Conductance normalized to 25 ^{0}C for full range

TOTAL ABSOLUTE PRESSURE

The Levelogger is measuring the total absolute pressure: the sum of the barometric pressure and the water pressure. The actual water pressure can be calculated by subtracting the barometric pressure from the total absolute pressure (Figure 16). The water level readings are automatically corrected for the temperature dependent density by the device (Solinst, 2012). Because no barometric pressure sensor was provided, and no reliable data was obtained from local weather stations, no correction for barometric fluctuations has been done. The sensor has been calibrated for its full lifetime by the manufacturer.

TEMPERATURE

The Levelogger can measure temperatures between -20 to +80 ^{0}C, but will give accurate data for temperatures between 10 to 40 ^{0}C. The temperature sensor has been calibrated for full lifetime by the manufacturer (Solinst, 2012).

ELECTRICAL CONDUCTIVITY

The Levelogger is measuring the conductivity at the measured temperature. However, conductivity is strongly temperature-dependent. The measured conductivity can be converted to specific conductance (SC), i.e. the electrical conductivity (EC) at 25 ^{0}C, using Equation 1 (Fofonoff & Millard, 1983, as cited in Solinst, 2012):

$$Specific\ Conductance = \frac{Electrical\ Conductivity}{1 + 0.02 * (Temp(°C) - 25)} \qquad \text{Equation 1}$$

Calibration of the conductivity sensor has to be done at minimum twice a year, using a liquid solution with a known conductivity. A detailed overview of the used sensor settings and calibration procedure is given in Annex VII.

4.2 Purpose and relevance of measured parameters

TOTAL ABSOLUTE PRESSURE

The total absolute pressure measurements can be used to estimate the water level in time. Water level data can be converted to discharge, for this a rating curve is required (Shaw *et al.*, 2011). As no rating curve is available for the sensor locations, the water level data can only give a rough indication of relatively high and low discharges in the river. However, this rough indication can provide very useful information about the relation between discharge, temperature and electrical conductivity.

TEMPERATURE

Doing temperature measurements is relevant because it can be used to prove thermal pollution of river water. Unnatural increase of water temperature can lead to an increase of biological activity, which can lead to deficiency of oxygen for organisms in the water (Augustijn & Entrop, 2012). High temperature is one of the characteristics of wastewater from textile industry (Rott *et al.*, 1999, as cited in de Vries, 2012). Fiercely steaming pipes were found numeral times during field work in industry clusters.

ELECTRICAL CONDUCTIVITY

The electrical conductivity (EC) of the river water is affected by the amount of dissolved anions (e.g. chloride, nitrate, sulphate and phosphate) and cations (e.g. sodium, magnesium, calcium, iron and aluminium). Both the negative and positive charged solutes contribute to the EC positively. Uncharged (neutral) organic substances do not contribute to the EC. As stated above, the EC is temperature dependent, therefore, specific conductance (equal to EC at 25 ^{0}C) should be used (United States EPA, 2012).

The EC is influenced by the geology of the area. In general it can be said that water flowing through a soil with clay containing a lot of minerals, will have a higher EC than water flowing over inert rock (e.g. granite). The EC of pure water is approximately 0.05 µS/cm (McCutcheon *et al*., 1993 as cited in Wang *et al.*, 1997). Conductivity of rivers in the USA is ranging from 50 to 1500 µS/cm, with values from 150 to 500 µS/cm for streams with good mixed fisheries. Industrial waters in the USA can have EC values up to 10,000 µS/cm (United States EPA, 2012). Concentrated brines can have values up to 225,000 µS/cm (McCutcheon *et al*., 1993 as cited in Wang *et al.*, 1997). Since the soil of the Bandung Basin contains a lot of clay, it is expected that natural EC values are relatively high. Unfortunately, only PusAir and the West Java EPA are doing EC measurements, and those organizations do not monitor the spring waters of the Citarum and its tributaries, see section 3.2.

In general, significant changes in conductivity are considered as indicators for discharges of polluted substances (United States EPA, 2012). Within this research, it is assumed that there is a correlation between the conductivity and other water quality parameters, this assumption is confirmed by Wang & Yin (1997). To verify this assumption for the Citarum river, a correlation test was done for some parameters at measuring point Sapan[7]. In Figure 13 it can be seen that there indeed is a positive relation between EC values and all the five tested variables. The correlation with TDS is very strong (R^2 = 0.98) and the correlation with COD is also very clear (0.75), compare with R^2 value found in literature: 0.95 for TDS (Wang & Yin, 1997). The correlation with metals[8] is noticeable for iron (R^2 = 0.30) and negligible for manganese (0.03) and zinc (0.01).

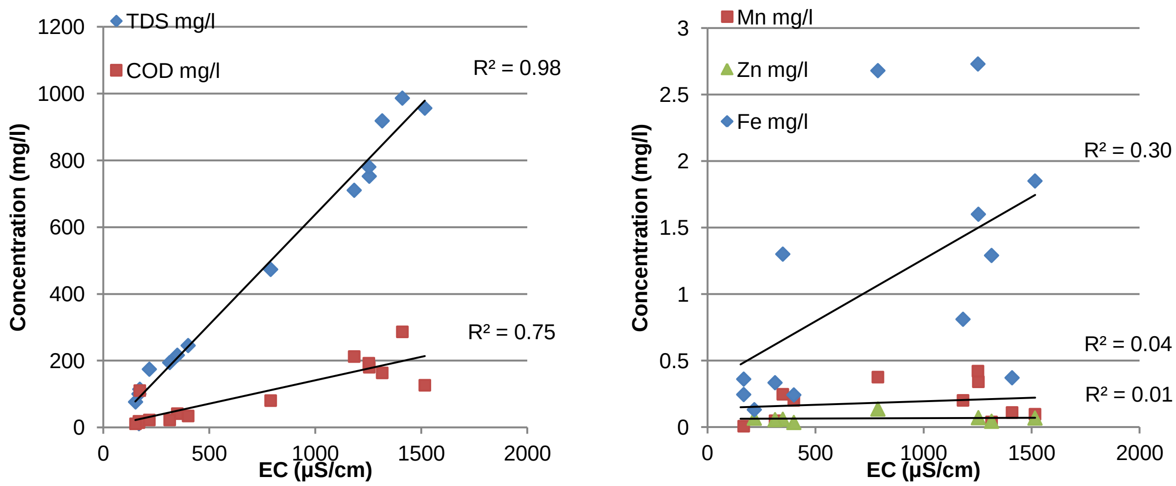

FIGURE 13 CORRELATION BETWEEN EC VS. TDS, COD, [MN], [ZN] AND [FE] – DATA PUSAIR 2006-2013 LOCATION SAPAN

From Figure 13, the following relation between TDS and EC can be derived:

$$TDS\left(\frac{mg}{l}\right) = 0.661 * EC\left(\frac{\mu S}{cm}\right) - 22.65 \qquad \text{Equation 2}$$

[7] Sapan is a sample location of PusAir in the Citarum, 10 km downstream of the Levelogger sensor locations (Figure 25, page 35)

[8] Some of the data points for metals were missing in the data. This can mean two things: 1) these parameters were not measured at this time or 2) the actual values are too low to be measured in the lab. Missing points were neglected in the analysis, not taken as "0".

The relation found in Equation 2 is very similar to other empiric formulas describing the relation between TDS and EC: “You can estimate the total dissolved salt concentration of a water sample by multiplying its temperature normalized electrical conductivity by a factor of between 0.5 and 1.0 for natural waters. The value of this factor depends upon the type of dissolved solids. A widely accepted value to use for a ballpark guestimate is 0.67.” (Lake Superior Streams, n.d.).

4.3 Selection of locations

The search for locations for the Levelogger device was restricted to the area around Majalaya. Majalaya is one of the six industry clusters, located in the south-east of the Bandung Basin, approximately 50 km upstream of the Saguling reservoir. The reason for this restriction is that other parts of the research of the Alliance will also be focused on this area, which is notorious for the huge impact of bad water quality on health of the citizens (Candra *et al.*, 2010). Moreover, upstream of the industry, the land-use is dominated by agriculture. Therefore, the impact of industry and agriculture on water quality can be easily isolated in the Majalaya. Further, some water quality monitoring data is already available in Majalaya, which can be compared with the newly obtained data. Finally, the West Java EPA has good relations with a local NGO, Elingan. These relations are essential for community-based supervision of the devices, to avoid theft.

Videoblog

Two major tributaries flow through the Majalaya area: the Cirasea at the west side, and the main Citarum at the east side. During field visits it was observed that the Citarum upstream of Majalaya was unsuitable for placing the sensors for three reasons: 1) The flow velocities in the river are very high, resulting in a considerable risk of a hydraulic jump around the sensors in the devices, which will spoil the results of the sensor according to the user guide (Solinst, 2012); 2) Careful observation of the tributary structure revealed that only a small amount of the industries was discharging directly in the Citarum, this was confirmed by the local NGO; 3) The high flow velocities cause stones to move which makes it hard to install the devices.

Finally it was decided to locate the first sensor in an industry dominated stream: the Cipadaulun, the second sensor in the Cirasea before it mixes with the industry dominated streams, and the third sensor in the Cirasea downstream the mixing with the industrial effluents, see Figure 14, 15 and 16. The exact locations of the sensors were based on the availability of communities that are willing and able to supervise the sensors. This last reason led to the less optimal position of sensor 1, which is not covering all the industrial effluents of the industries.

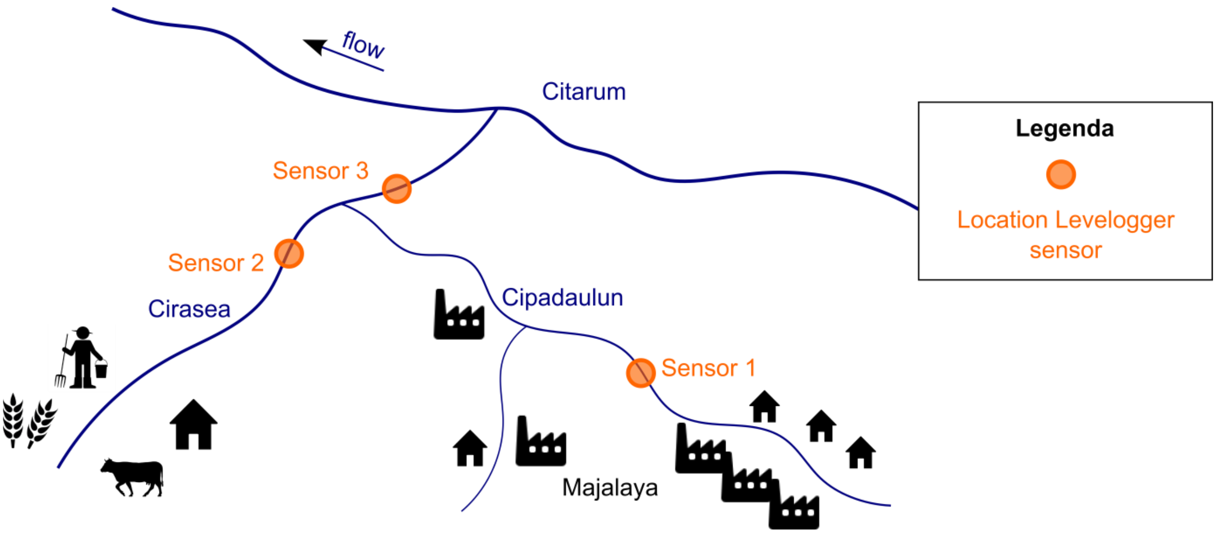

FIGURE 14 SCHEMATIC OVERVIEW OF SENSOR LOCATIONS

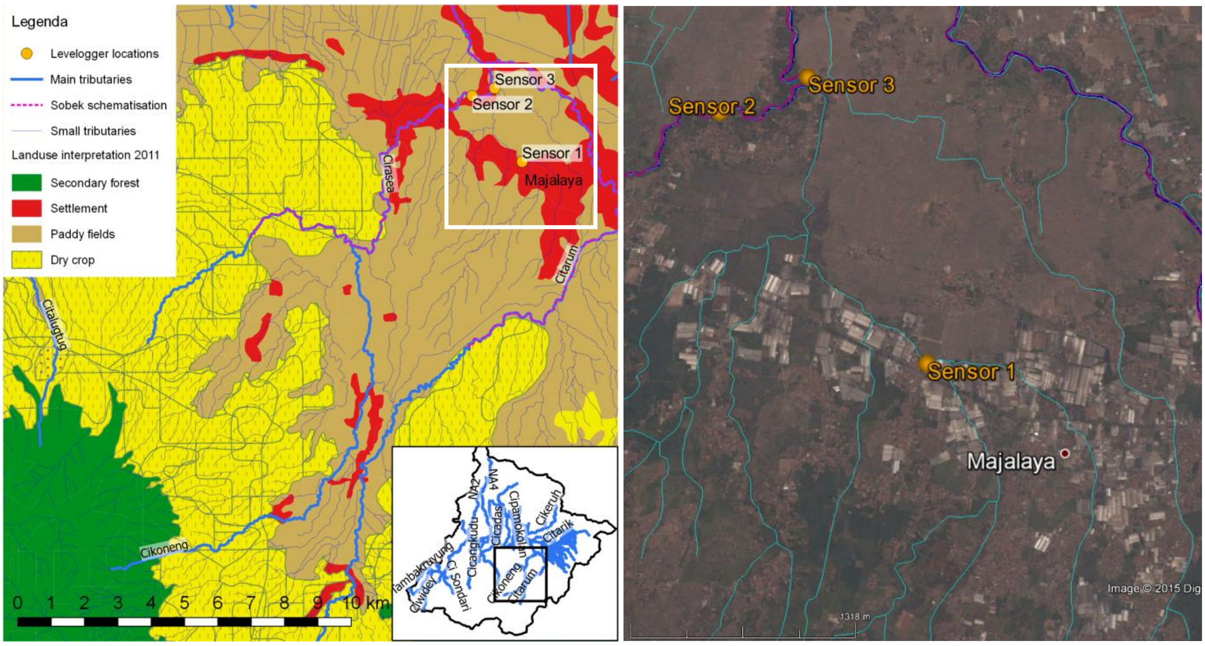

FIGURE 15 LEFT: LANDUSE MAP (LANDSAT-2010, INTERPRETATION 2011) OF AREA UPSTREAM OF SENSOR LOCATIONS RIGHT: SATELLITE IMAGE OF MAJALAYA AREA, WITH RIVER TRIBUTARIES (GOOGLE EARTH, SATELLITE PHOTO TAKEN 12-10-2014)

FIGURE 16 FROM LEFT TO RIGHT THE LOCATIONS OF SENSOR 1, 2 AND 3. SEE ANNEX VIII FOR MORE PHOTOS

Videoblog

In Figure 14 the locations of the three sensors can be seen. During fieldwork it was observed that the turbidity of location 1 was very high. Moreover, the water was often very smelly and the colour changed from black to brown to red. At a distance of about 5 meter, a pipe was discharging water with a colour different from the main water. Because it was feared that the water from this pipe would influence the measurements of the sensor, the sensor was moved upstream of the pipe during the second inspection. At the second location, the large amount of waste was remarkable. The river banks were very clayey. However, the turbidity of the water was much lower than at the first location, giving the water a better appearance. At the third location, the river was much wider, and sediments and waste led to a small ‘island’ in the river. The velocity distribution over the cross-section was relatively unequal compared with the first two locations. For more information about the sensor locations, see Annex VIII.

4.4 Design

Several designs for constructions to connect the sensor were discussed. The most serious options were: 1) connecting the sensor to an existing structure in the water, 2) connecting the sensor to a bamboo tripod drilled in the mud and 3) connecting the sensor to a steel-concrete constructing, anchored in the mud. Bridges spanned the small tributaries usually without any pillars and to construct the tripods the river had to be entered for a long time to drill the stick in the muds; therefore the third option was chosen. The construction was made by local people. The zero-point of the sensor was located 10 cm above the top of the concrete, see Figure 17.

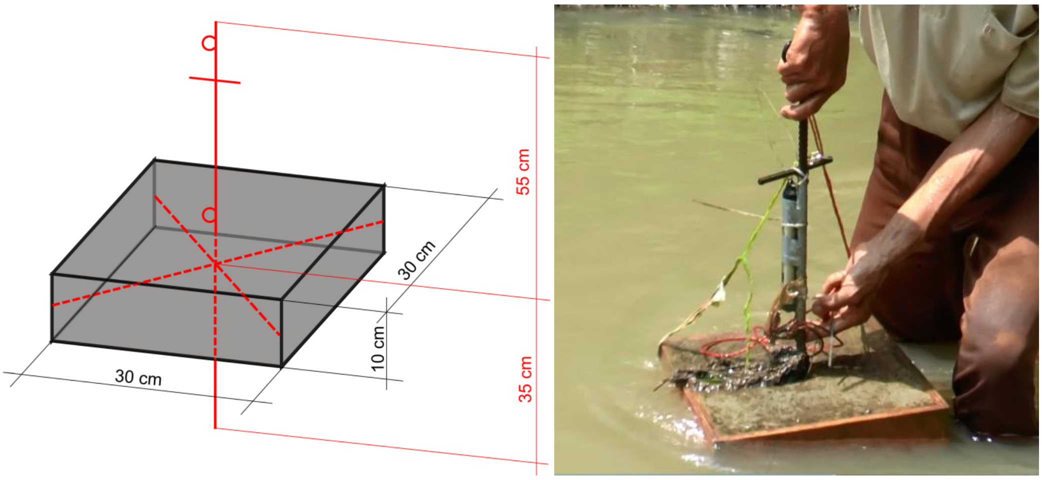

FIGURE 17 CONSTRUCTION TO CONNECT THE LEVELOGGER

4.5 Obtained data

The Leveloggers were put in the water at 2/3/2015 for the first time. They were cleaned and placed back at 13/3/2015, 7/4/2015. At the 22/5/2015 they were definitively removed from the water. During the inspection at 7/4/2015, the first sensor location was moved to another location, 10 m more upstream of the Cipadaulun, because it was feared that a pipe was influencing the results at the old location. See Annex IX for an overview of all the obtained data, completed with rainfall data from the TRMM-satellite.

During the first and the last field visit, the river discharge was estimated. The cross-sections, calculations and underlying assumptions are presented in Annex VIII, the results are shown in Table 4.

TABLE 4 ESTIMATED DISCHARGE AT SENSOR LOCATIONS DURING A DAY IN THE DRY AND THE WET SEASON

Site	**1: Cipadaulun**	**2: Cirasea before mixing**	**3: Cirasea after mixing**
Wet day: 2/3/2015	1.0 m^3/s	1.3 m^3/s	2.6 m^3/s
Dry day: 22/5/2015	0.8 m^3/s	0.2 m^3/s	1.3 m^3/s

It is noticeable that the discharge of the Cipadaulun is relatively constant (Table 4); the discharge during the dry day was only 20% less compared with the wet day. In contrast, the discharge of the Cirasea was substantial smaller at the dry day: a decrease of 85% compared with the wet day. As a result, the composition of the Cirasea after mixing is mainly determined by the water quality of Cipadaulun in the dry season. During the wet season, the upper catchment of the Cirasea is the main contributor. The difference can be explained by the different characteristics of both tributaries. The Cipadaulun is partly fed from the Citarum, via a channel that regulates the water supply of Majalaya. Moreover, the industries abstract water from wells that will be discharged in the Cipadaulun as wastewater (p.c. Riswandani, 22/5/2015). As a result, the discharge of the Cipadaulun is relatively stable throughout the year. The Cirasea is fed by larger catchment with a lot of agricultural activities. During the dry season, the farmers will use most of the water for irrigation purposes. As a result, the discharge during the dry season will be significantly lower compared to the wet season.

The difference between the contributions of both tributaries in the dry vs. the wet season has large impact on the water quality in the Cirasea after mixing of the tributaries. During the wet season, the water quality after mixing was of reasonable quality. However, during the dry season, the same part of the river was very dark and smelly: comparable with the water in the industry dominated Cipadaulun.

TEMPERATURE

In Figure 18 it can be seen that the water temperature follows a regular day-night rhythm. The temperature at the first location is always significantly higher (often 5 to 10ºC) than the temperature at the second location, and even higher than the general air temperature, which is normally between the 20 and 30 degrees in Majalaya. Assumed that the temperature of the Cirasea before mixing (location 2) is a 'normal' situation, the temperature at location 1 is almost always exceeding the stream standard according to law 82/2001. This law says that the maximum temperature deviation for water class 3 is 3

^{o}C (Annex III). It can also be seen that the temperature of the Cirasea is increasing by 2 to 3 ^{o}C due to the mixing with the industrial wastewater of the Cipadaulun. The temperature pattern at sensor 3 is obviously an average of the sawtoothed sensor 1, and the more flattened pattern of sensor 2.

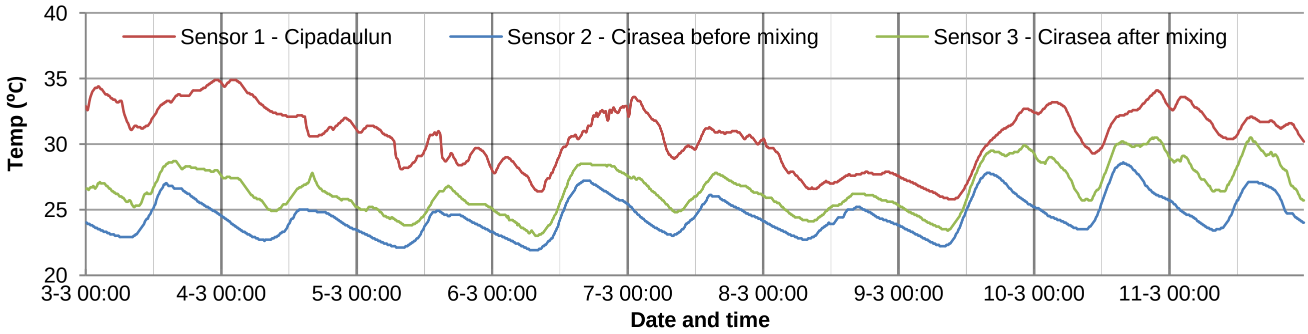

FIGURE 18 OBSERVED WATER TEMPERATURE IN THE FIRST PERIOD (2/3/2015-13/3/2015)

The small fluctuations in the water temperature at sensor 1 seem to indicate variations in discharged wastewater of the industries, that usually is very warm. Larger variations indicate that the temperature and amount of discharged wastewater can be very different from day to day. The temperature at sensor 1 is relatively low from 8/3 12:00 (Sunday) until 9/3 18:00 (Monday). This might be related to the weekend, however, this pattern was not found during other weekends (cf. Annex IX).

WATER LEVEL

Since the river cross-sections and the flow velocities at the different locations are very different, and the flow velocity over the cross-sections far from uniform, one should be careful by comparing the different water levels. In Figure 19, the corrected water levels are displayed. Correction was not done using barometric compensation, but by simply measuring the water level at installation and checking of the devices. Considered that no barometric compensations was used and there was no guarantee that the concrete would stay on the same location, but might be shifted by waste, the strong current or the community, the measured water level was relatively close to the expected water level according to the sensor data (error of 2 cm, 10 cm and 1 cm respectively)[10].

There is an interesting difference in discharge pattern between the Cipadaulun (sensor 1) and the Cirasea before mixing (sensor 2). There are only small differences in the water level of the Cipadaulun, but there are large fluctuations in the level of the Cirasea. There are also evident day-night patterns in the level of the Cirasea, these are absent in the Cipadaulun. The level behaviour in the Cirasea after mixing (sensor 3) is a combination of the different patterns.

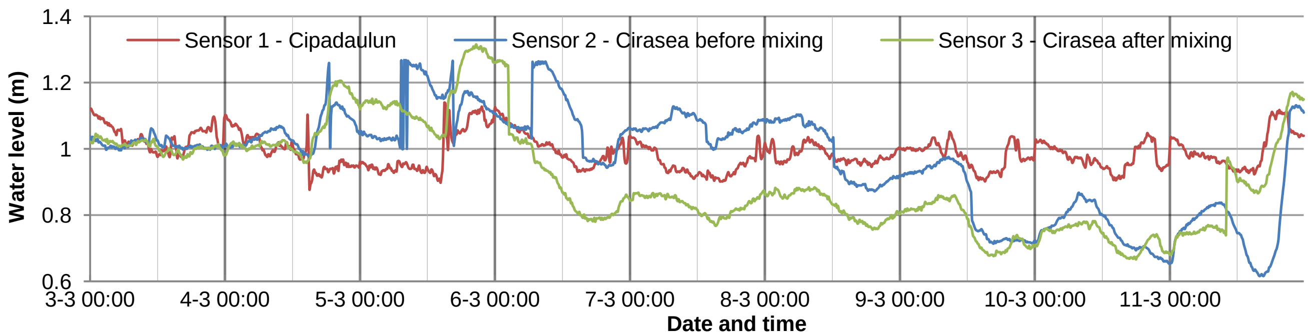

FIGURE 19 OBSERVED WATER DEPTH IN THE FIRST PERIOD (2/3/2015-13/3/2015)

[10] The water level was measured at the end of the first period (13/3/2015) and was compared with the water level measured by the sensor, after correction for the measured water level at the start of the first period (2/3/2015).

CONDUCTIVITY

The specific conductivity (SC) at the first location started with very high values on 3 and 4 March, with values mostly between 1500 and 2300 μS/cm, see Figure 20. On 5 March, the value suddenly dropped to relatively stable lower values between 1200 and 1500 μS/cm as a result of rainfall (Annex IX). Compared with sensor 3, the conductivity pattern of sensor 1 is quite stable. This is probably due to clogging of the device by multiple layers of (mainly plastic) waste, which is causing slow exchange of the passing water into the sensor and may not be representative for the true conductivity of the river water. However, an increase of water level in the afternoon of 11 March, due to rainfall (Annex IX), still leads to a drop in conductivity. In any case, it can be concluded that the specific conductivity of the stream is high (compared for example with the most polluted rivers in the USA, with values up to 1500 μS/cm). However, it is much lower than industrial brine streams in the USA, with values up to 10,000 μS/cm (United States EPA, 2012). Although there is no standard for conductivity according to law 82/2001, using equation 2, the estimated value of TDS (at SC = 2000 μS/cm) is over 1300 mg/l, with a TDS standard of 2000 mg/l for class 3.

The specific conductivity in the Cirasea before mixing with the industrial wastewater (sensor 2) is very low, with values between 100 and 200 μS/cm until 12 March afternoon. Although the water level of the river has large fluctuations at this point, this cannot be seen in the SC At 12 March, the conductivity started to rise up to 370 μS/cm, after a small drop to 150 μS/cm due to a rapid increase in water level. As stated before, values below 500 μS/cm should be considered as very good under normal conditions. However, the very low conductivity in the Cirasea might also be related to high concentrations of fecal coliform observed in this tributary (Section 5.2). Wang en Yin (1997) show that high fecal coliform concentrations strong negatively correlate with EC-values. They also show strong negative correlations with turbidity and suspended solids. Therefore, one cannot conclude that the Cirasea is 'clean' just based on the EC-measurements.

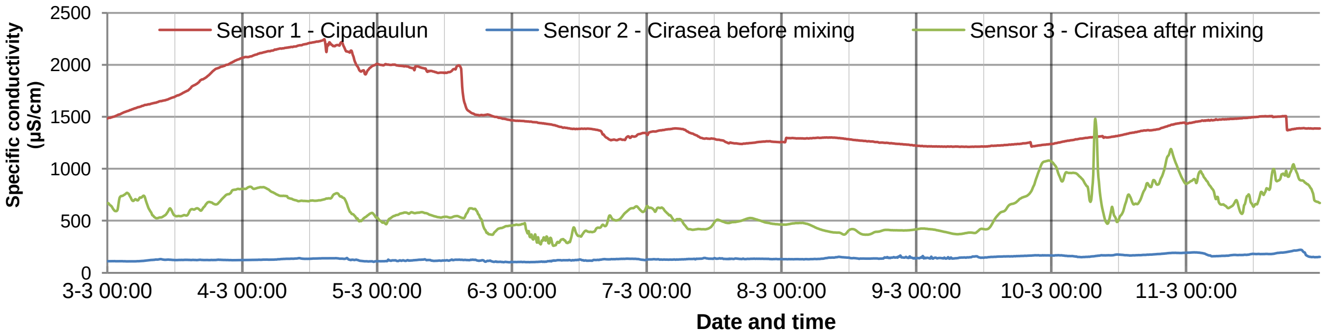

FIGURE 20 OBSERVED SPECIFIC CONDUCTIVITY IN THE FIRST PERIOD (2/3/2015-13/3/2015)

The very flat patterns observed by sensor 1 and 2 are suspicious. How can the pattern of sensor 3 come into being as a mix of the patterns of sensor 1 and 2? An explanation is that the fluctuations of sensor 3 are the most realistic, and the patterns of sensor 1 and 2 are flattened by the clogging of the devices. Especially the flattened pattern of sensor 1 is inconsistent with the large fluctuations in temperature and water level at this location. Moreover, at the start of period 1, sensor 1 shows larger fluctuations then at the end of the period. This is another indication that the increased clogging of the device is influencing the sensor behaviour.

TRENDS AND MUTUAL RELATIONS

In Annex IX an overview of all obtained data is given, and completed with rainfall data from the TRMM-satellite. The time between the four field visits is divided in three periods; each period is preceded and concluded by one field visit. The data collected in each period was carefully studied in order to detect trends in and relations between the different parameters. In this section, the results of this analysis will be presented in the form of statements about the data. The proof of each statement is confined to a number of examples from the data, to be found in Annex IX.

1. There is a strong relation between the rainfall data from the TRMM-satellite and the observed peaks in water level data. This seems to state the obvious, but it should be seen as a strong indication that the data from the TRMM-satellite can be used to investigate the relation between water quality and water quantity in the future. This is a promising observation, for one could argue that the data from the TRMM-satellite is rather useless for this type of analysis, because it is only based on cloud detection, not corrected for observed rainfall and based on a very course grid: only 6 cells for the whole Bandung basin.

2. A dry period according to TRMM-rainfall data correlates with a gradual decrease in water level of the Cirasea before mixing (location 2). This pattern is not evident in the in the Cipadaulun (sensor 1). This difference confirms the hypothesis derived from Table 4, namely: the discharge of the Cipadaulun is dominated by supply of water from the Citarum via an irrigation channel and by industrial effluents originating from well abstractions. In contrast, the water supply of the Cirasea is dominated by rainfall.

3. A dry period according to TRMM-rainfall data correlates with a gradual increase in temperature of the Cirasea before mixing and after mixing. Again, this pattern cannot be clearly found in the Cipadaulun. It can be concluded that the temperature of the Cirasea is mainly dominated by natural factors like rainfall and day-night patterns. In contrast, the temperature of the Cipadaulun is dominated by the volume and temperature of industrial effluents.

4. Intensive rainfall is leading to a decrease in conductivity and temperature of the Cipadaulun, but does not influence the conductivity of the Cirasea. This trend can be explained by noticing that the industrial effluents in the Cipadaulun get diluted by the rainfall, but that the flushing of agricultural pollutants will remain the same: both the amount of flushed pollutants (load) and the amount of water increase, so concentrations remain the same. Moreover, the catchment of the Cirasea is very big, so any possible change in emissions will scatter over a long period before being observed at location 2.

It is also interesting to see which patterns are not observed in the obtained data, but that were expected based on the system analysis.

5. The water temperature and EC of the Cipadaulun is not noticeable lower during the weekends, compared with working days. One would expect that at least some part of the industries would not be operational during the weekend, although it is also known that some industries produce 24 hours a day, 7 days a week. For example, the NGO of mr. Riswandani is only organizing rafting activities in the Citarum during the weekends, because they assume that the water quality during the weekends is better than during workdays (p.c. 2/3/2015).

6. At night, there is no observable difference in conductivity of the Cipadaulun compared to daytime. On one hand, many stakeholders fear that the industries discharge the most polluted wastewater at night. On the other hand, one can expect that some industries are closed at night. One can do much speculation why such patterns are not found in the data: maybe both aspects cancel each other out, maybe the water is too diluted to see the discharge or maybe the discharge of dangerous chemicals just does not correlate with high EC-values. Also, the measurements were not very reliable due to the clogging of waste to the devices. More research is required to make well-founded statements about these issues.

4.6 Discussion

For several reasons, one should be careful by interpreting the obtained data. The two most important reasons are: 1) the use of EC as in indicator for water quality has its limitations. Many harmful and toxic substances do not influence the EC. Moreover, some substances contribute positively to the EC and others negatively. Although most relevant substances will lead to an increase in EC, sometimes an extra emission (and thus a further deterioration of water quality) will lead to a decrease in EC (Wang & Yin, 1997). 2) During fieldwork it was observed that large amounts of solid waste and sediments clog the devices. The clogging might especially influence the conductivity measurements, for it hinders the exchange of the river water and the water in the sensor. It is assumed that the thermal conductivity of the water and plastic is that high that the temperature measurements are not

Videoblog

affected by the clogging. Also the pressure measurement is probably not significantly affected by the waste. To check the impact of the pollution on the measurements, a small test was done before the devices were removed from the water on 22/5/2015, using the following steps:

1. The time on which the device did its last three measurements in the river was noted.
2. A sample was taken from the river, in a bucket.
3. The device was taken from the water, and was cleaned
4. The devices was put in the bucket containing the river sample, for at least 30 minutes, so that 3 measurements of the sample water were done in the bucket
5. The measurements in the river (before cleaning) are compared with the measurements in the bucket (after cleaning)

The results of this test are presented in Table 5. The differences between the measurements in the bucket and the river were not very big, given the serious clogging of plastic to the devices (Figure 21), and the fact that the sensor hole was partly filled with sediment. However, during the previous inspections the situation was worse, because the NGO had weekly removed the plastics during the last period. In the future would be good practice to use the test described above during every field visit to get an impression of the reliability of the obtained data. Note that the test cannot be used for checking the temperature and water level measurements, because those will not be the same in the bucket.

TABLE 5 DIFFERENCE BETWEEN EC IN THE RIVER (BEFORE CLEANING DEVICE) AND EC OF SAMPLE IN THE BUCKET (AFTER CLEANING DEVICE)

Sensor location	**1: Cipadaulun**	**2: Cirasea before mixing**	**3: Cirasea after mixing**
EC in the bucket*	1652	313	1109
EC in the river*	1707	338	1077
Absolute deviation	-54	-25	+32
Deviation in %**	-3 %	- 8%	+ 3%

* Average of three succeeding measurements
** Deviation divided by EC in the bucket

FIGURE 21 CLOGGING OF WASTE TO THE SENSOR AND ITS FRAME (LEFT) AND THE SENSOR HOLE (RIGHT) AT LOCATION 3 (22/5/2015)

4.7 Conclusion and recommendations

Discharge measurements combined with TRMM-satellite rainfall data are a strong combination in order to study the relation between rainfall-runoff and water quality. The temperature measurements are helpful to identify industrial discharge from textile industry, because its wastewater is characterized by high temperature.

Electrical conductivity measurements as individual indicator for water quality are insufficient to assess the state of the river water. Even the measurements in the most polluted tributary, the Cipadaulun, suggest that the river water quality is within acceptable range. In contrast, field observations, common sense and analysis of other parameters in the next chapter show that the state of this tributary is very undesirable. On the other hand, the EC-measurements are a cheap and easy way to get at rough impression of the changes of the water quality in time. They can provide useful information when combined with other sampling methods. The author's suggestion to the Alliance is to combine the use of the Levelogger devices not only with the passive sampling method[11], but also with normal water samples that can be analyzed in one of the accredited laboratories in Bandung[12]. Preferably, during every sensor inspection a water sample is taken. The obtained additional data about a number of water quality parameters at certain points in time will help to interpret the Levelogger data.

Communal protection of the devices was sufficient to ensure the devices were not stolen during the research. The developed sensor construction was reliable, safe and prevented displacement of the device. However, it did not provide enough protection against the solid waste in the river. It is questionable if one can design a construction that can fully prevent the device from clogging. Therefore, it is recommended to clean the devices once a week, perhaps in collaboration with the local community.

[11] The Alliance is planning to extend the experiment with the Leveloggers with a passive sampling method, developed by Deltares. Using passive sampling, the average concentrations of a very large number of complicated parameters can be determined. However, some basic water quality parameters like BOD and COD are missing in the results. For more information see Vrana *et al.* (2005) or contact Jasperien de Weert, Deltares Netherlands.

[12] One should take into consideration that the Kabupaten Bandung EPA is already doing some sampling activities in this area. This EPA has its own accreditated laboratory, and can also benefit from the sampling results.

5 ANALYSIS OF WATER QUALITY DATA

In this chapter, the water quality data obtained in chapter 3 and 4 will be used to analyze the water quality of the Citarum River and its tributaries. The underlying research question is: "*What does the obtained data reveal about the water quality of the Citarum?".*
The chapter consists of seven sections. In the first section, background information is given about six parameters selected by the Alliance for further analysis. In the second section, the data obtained with the Levelogger device (Chapter 4) is compared with the measurements done by the Kabupaten Bandung EPA. The third section describes the differences in observed concentrations between the dry and the wet season. In section four, the upstream-downstream development of the water quality in the Citarum River is described. A qualitative approach will be used to explain the changes in observed concentrations, where possible related to land use in the corresponding catchments. In the fifth section, a quantitative approach is used to assess the relation between land use and water quality. In the sixth section, the limitations of all methods are discussed. The concluding section reflects on the obtained knowledge, in order to reveal some general trends in the water quality of the Bandung Basin.

5.1 Interpretation of selected parameters

The Alliance decided to start the modelling with the parameters BOD, COD, Nitrate, Sulphate, Fecal Coliform and Zinc. In Table 6 it is shown how these parameters are indicators for certain types of land use based on literature. Other parameters of interest are TDS, because it strongly correlates with the EC-values measured by the Levelogger devices, and the temperature, which is directly measured by the Levelogger devices.

TABLE 6 EXPECTED REPRESENTATION OF LANDUSE TYPES FOR SELECTED PARAMETERS

	Domestic	Industry	Stockbreeding	Crop growing	Natural
BOD	❷	❷	➊	⓪	⓪
COD	❷	❷	➊	⓪	⓪
Nitrate	❷	❷	➊	❷	⓪
Sulphate	⓪	❷	⓪	⓪	➊
Fecal Coliform	❷	⓪	❷	⓪	⓪
Zinc	⓪	❷	⓪	⓪	➊

⓪ = not relevant source of pollution; ➊ = small contribution to pollution; ❷ = large contribution to pollution

BIOLOGICAL AND CHEMICAL OXYGEN DEMAND

The Biological and Chemical Oxygen Demand (BOD and COD) are representing the amount of oxygen that is required to break down the organic material present in the river water. The BOD is indicating the amount of material that micro-organisms can break down, normally within five days. To determine the COD, a strong oxidizer is used. COD values are normally higher than BOD values, for the used oxidizer is able to break down all organic material, which is more than organisms can break down in five days (Augustijn & Entrop, 2012). Futher, the ratio between BOD and COD gives some information about the source of the pollution. A large BOD/COD-ratio indicates a small amount of non-biodegradable organic material, corresponding with 'natural' land use, like a forest. A low BOD/COD can indicate large amounts of non-biodegradable substances, for example originating from industry. However, also some types of organic materials originating from natural sources are not easily degradable.

NITRATE

Nitrate is an important type of nutrients, used for agricultural purposes. Nitrate is only one of the forms in which nitrogen can occur in the water, other forms are nitrite, organic nitrogen or total ammonia (Augustijn & Entrop, 2012). Nitrate is an important indicator for agricultural, mainly crop growing, activities. However, industrial and residential areas can also strongly contribute to high nitrate concentrations (Poor & McDonnell, 2007).

SULPHATE

Sulphate is an important by-product of textile industry, often found in industrial wastewater (Seif & Malak, 2001). In the Bandung Basin, the acidic volcanic lake Kawah Putih is an important natural source of sulphate. In the area around the lake, man-made sulphur mud deposits can be found (Sriwana & Bergen, 2000).

FECAL COLIFORM

Fecal coliform is a group of bacteria originating from human or animal excrements, and is a good indicator for the presence of domestic sewage or stockbreeding activities (United States Environmental Protection Agency, 2012).

ZINC

Various heavy metals are originating from the textile industry, mainly from the painting process, when appropriate wastewater treatment is lacking. Among many others, the presence of zinc has been reported as an indicator (Bisschops & Spanjers, 2003, Correia *et al.*, 1994, De Vries, 2012), although the presence of this metal is strongly depending on the type of product and production process of the factory.

5.2 Comparison Levelogger data with existing data

In this section, the data obtained using the Levelogger devices will be compared with data obtained from the Kabupaten Bandung EPA. The chosen sampling locations are 10, 11 and 15, and the samples are taken in the years 2011-2013. Every year, three samples were taken, however, only the month is known, not the exact date. However, it is very likely that the samples at the three locations are taken at the same dates, and can therefore be compared with each other. In Figure 22 can be seen how the sampling locations match with the Levelogger sensor locations: (1) corresponds with the industrial water measured at sensor 1; (10) is measuring the Cirasea before mixing with the Cipadaulun just like sensor 2; and (11) is located in the Cirasea after mixing, similar to sensor 3.

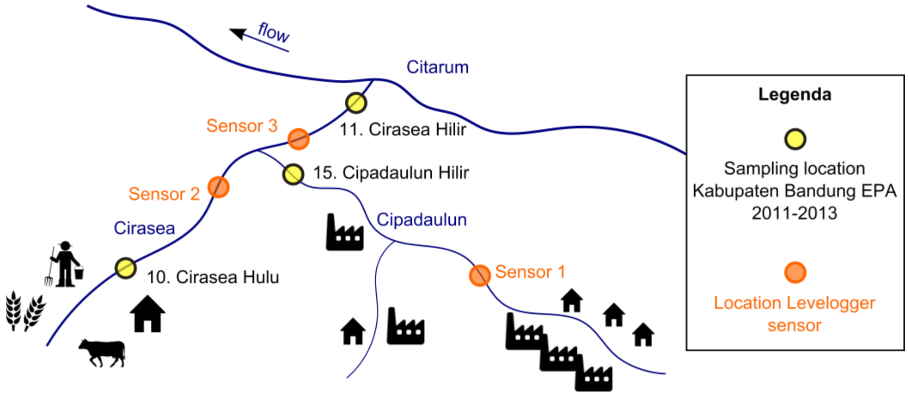

FIGURE 22 SCHEMATIC OVERVIEW OF LANDUSE, LOCATIONS OF LEVELOGGER SENSORS AND SAMPLING

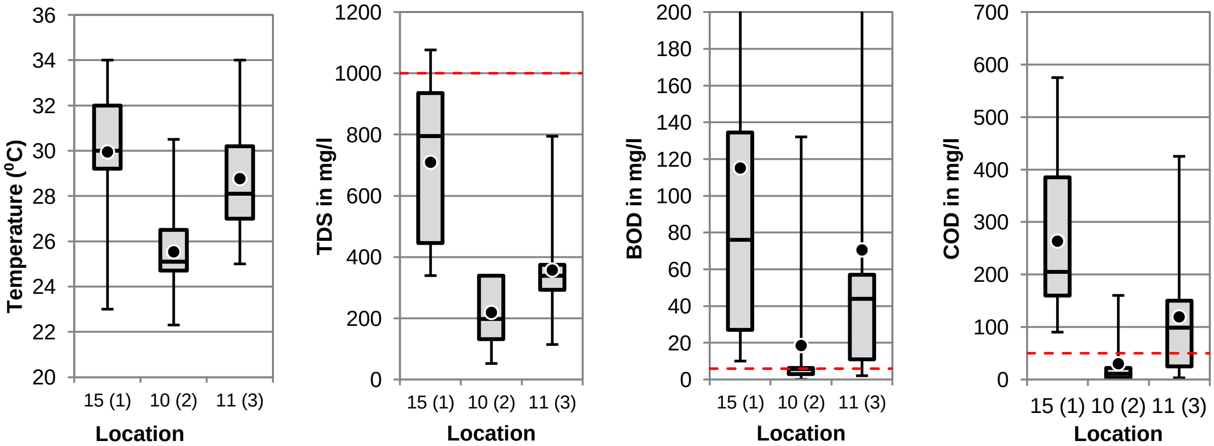

FIGURE 23 BOXPLOTS OF THE TEMPERATURE, TDS, BOD AND COD PER SAMPLING LOCATION KABUPATEN BANDUNG, CORRESPONDING SENSOR LOCATION BETWEEN BRACKETS. EACH BOXPLOT BASED ON NINE OBSERVATIONS DURING THE DRY SEASON (3X 2011, 3X 2012 AND 3X 2013). RED DASHED LINES INDICATE THE NORM ACCORDING TO LAW 82/2001, WATER CLASS 3.

In Figure 26, it can be clearly seen that the water at (11) is a mix of (15) and (10). The temperature at (15) ranges from 23 to 34ºC, with an average around 30ºC, this is very consistent with the Levelogger data (cf. Figure 21). The temperature at the other locations is also consistent with the data obtained in the previous chapter. The TDS at (15) is ranging from 445 mg/l to 935 mg/l in 50% of the samples. Using the relation between TDS and EC derived in the previous chapter (equation 2) these TDS values correspond with EC values between 710 and 1450 μS/cm. The minimum (339 mg/l) and maximum (1076 mg/l) observed TDS at (15) correspond with EC values of 550 and 1660 μS/cm. Comparison of these values with the measurements of the Levelogger (Annex IX) shows that all observations of the EPA fit well within the range observed by the Levelogger. Although there are big differences between the TDS concentrations at the different locations, almost all observations are within acceptable levels. In contrast, the BOD and COD of the Cirasea after mixing (11) are far above the standards. This pollution is clearly originating from the industrial area via de Cipadaulun (15) and not from the upstream area of the Cirasea (10).

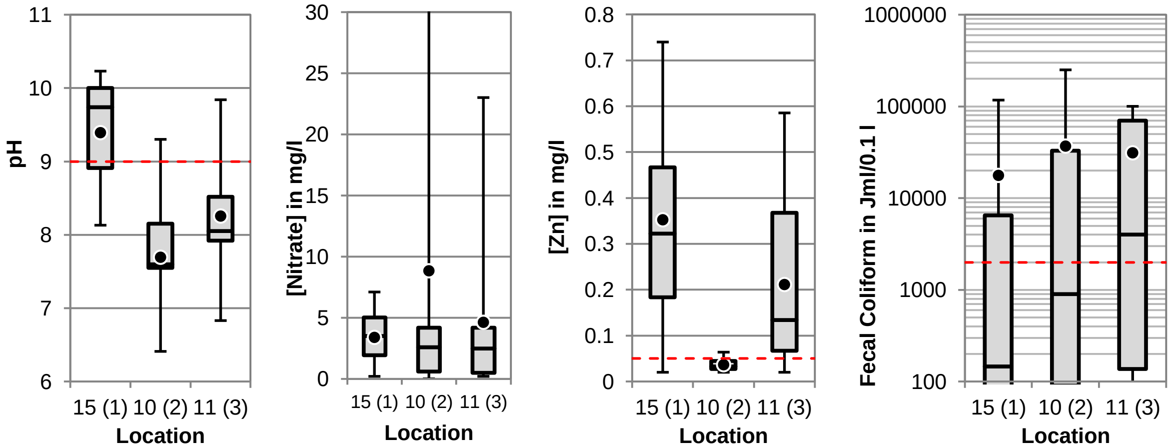

FIGURE 24 BOXPLOTS OF THE PH, [NITRATE], [ZN] AND FECAL COLIFORM PER SAMPLING LOCATION KABUPATEN BANDUNG, CORRESPONDING SENSOR LOCATION BETWEEN BRACKETS. EACH BOXPLOT BASED ON NINE OBSERVATIONS DURING THE DRY SEASONS: 3X 2011, 3X 2012 AND 3X 2013. DASHED LINES INDICATE THE NORM ACCORDING TO LAW 82/2001, WATER CLASS 3.

In the first graph of Figure 24 can be seen that the pH at (15) is above the standard of 9 for almost 75% of the measurements. Thus, the industrial effluents are strongly alkaline. The pH at (10) is mostly within the accepted range of 6-9, and so is the pH at (11). The observed Nitrate concentrations are not very different on each location. In the Cirasea after mixing (11), the [Zn] is almost always above acceptable level. This Zinc is originating from the industrial wastewater, because the concentration at (10) is very low compared with (15). The fecal coliform concentrations in all rivers are often above acceptable limits. The fecal coliform in the Cirasea after mixing (11) is mainly originating from the Cirasea upper catchment (10). Both the median and the average value in the upper catchment of the Cirasea (10) is a multiple of the value in the industrial wastewater in the Cipadaulun (15). The high Fecal Coliform concentration can be explained from the land use in the Cirasea catchment: a large agricultural area (probably with many cows) and many small settlements with sewage systems directly discharging in the river. However, in the Cipadaulun also a lot of settlements (Majalaya city) can be found. Apparently, the Fecal Coliform originating from Majalaya city is very small compared with the Coliform originating from the (much larger) Cirasea catchment.
From what has been stated before, three things can be concluded: 1) the Kabupaten Bandung EPA data fits within the range observed by the Levelogger devices; 2) industry is the primary source of high TDS, BOD, COD and [Zn] in the Cirasea; 3) the agricultural area of the Cirasea is the major contributor to high fecal coliform values in the Cirasea.

For additional parameters on these locations, see Annex X.

5.3 Differences between dry and wet season

As mentioned in section 3.2, it is commonly believed among monitoring stakeholders that the water quality during the dry season is worse compared with the wet season (e.g. p.c. Resmiani, 3/3/2015). As a result, monitoring activities are focused on the dry season when the budget is not sufficient for monitoring during the entire year. In this section, the following hypothesis will be tested: ‘The water quality during the dry season is significantly worse than during the wet season’. A detailed explanation of the used methodology and results is presented in Annex XIII. The methodology can be summarized as follows:

- The used data is restricted to the dataset of PJT-II, 2010-2014, the only set that covers both the dry and wet season.
- For the period 2010-2014, a number of typical dry and wet months are selected, based on a rainfall study by Deltares (2010) and discharge data presented in Annex II.
- The test of Wilcoxon-Mann-Whitney is used to test if there is a significant difference between the parameter values in the populations ‘dry season’ and ‘wet season’.
- This test was executed for the locations Nanjung (8 parameters) and Sapan (4 parameters).

The hypothesis ‘The water quality during the dry season is significantly worse than during the wet season’ can only be accepted for some parameters.

- The TDS, BOD- and COD are on average more than two times higher during the dry season, compared with the wet season. The test of Wilcoxon-Mann-Whitney shows that these concentrations are significantly higher during the dry season, compared with the wet season.
- The sulphate and free ammonia concentrations seem to be much higher during the dry season as well, but this is not significant according to Wilcoxon-Mann-Whitney.
- The iron and nitrite concentration are even lower during the dry season compared with the wet season, but this is not significant according to Wilcoxon-Mann-Whitney.
- The temperature at Sapan during the wet season is not significantly different during the wet season, compared with the dry season.
- The turbidity at Nanjung seems to be much higher during the wet season, where the turbidity at Sapan seems to be much higher during the dry season. However, both differences are not significant according to Wilcoxon-Mann-Whitney.

5.4 Upstream-downstream development

In this section, the Citarum will be followed from the spring at Situ Cisanti until the entrance of the Saguling reservoir, 77 km downstream. The development of the water quality will be described, and is as much as possible linked to the land use and the sources of pollution described in chapter 2.

The following method was used to get insight in the water quality development of the Citarum. First, the data obtained in the previous chapters was converted to a usable format for plotting in excel. Second, the main Citarum river was schematized as a line and the tributaries flowing into the Citarum as arrows on this line, see Figure 25. In the same figure, the monitoring locations in the Citarum are indicated with symbols. Thirdly, the water quality data along the river was plotted in graphs that match with the river schematization; see Figure 26,27 and Annex XI. In these figures, for each parameter the following descriptive statistics of each set of samples are displayed: 1) the average - central line, 2) the first quartile of the data, i.e. the 25th percentile - down dashed line and 3) the third quartile of the data, i.e. the 75th percentile – upper dashed line. Those indicators will give the reader an impression of the distribution of the data, while ignoring the extreme values. By reading the graphs, the following characteristics of the different data should be kept in mind:

- PJT-II: around 55 measurements[13] for each sampling location, taken in the period 2010-2014. The data is spread all over the year, so it includes both the dry and the wet season.

[13] The exact number of available samples is depending on the parameter, as sometimes a few parameters of a sample where not analyzed in the lab.

- PusAir: only 6 measurements per sampling location, taken in the period 2010-2013. Most of the samples are taken during the dry season, see Figure 11. As a result, one would expect that most parameters of PusAir would be a bit higher than from PJT-II.[14]
- West Java EPA: approximately 20 measurements for each sampling location, taken in the period 2011-2014. The timing of the measurements is mostly during the dry season.
- Kabupaten Bandung EPA: mostly 9 measurements, mostly in the dry season. Only at Situ Cisanti.

The fourth step was to create land use maps in QGIS, based on SPOT-satellite images of 2014. For a discussion on the quality and interpretation of these images, see Annex XIV. On these images, also the sampling locations in the tributaries are displayed, see Figure 28, 31 and 32. The final step was to analyse the water quality in some tributaries of the Citarum. These parameters are analysed using descriptive statistics, and the results are shown in boxplots. As the selection of outliers is a time-consuming procedure, the whiskers of the boxplots indicate the minimum and maximum observed values (see Annex XII for the boxplots).

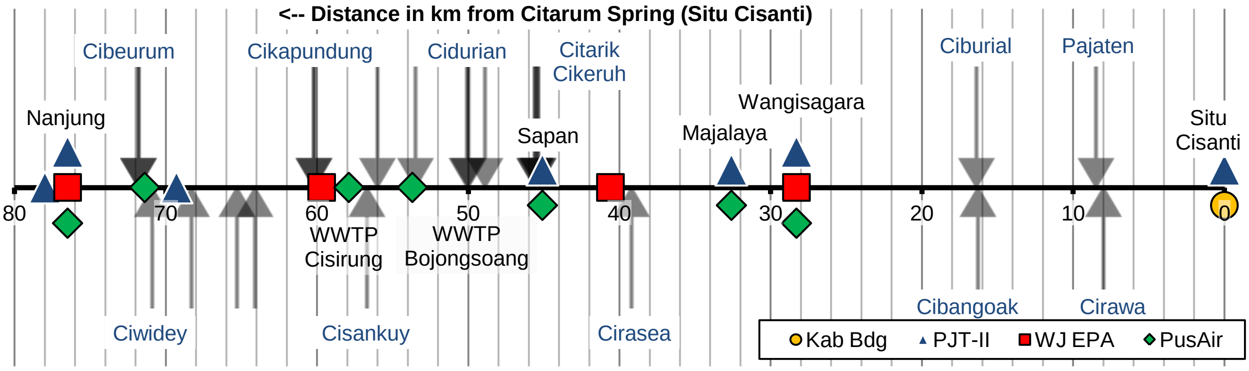

FIGURE 25 MEASURING LOCATIONS AND TRIBUTARIES OF THE MAIN CITARUM RIVER

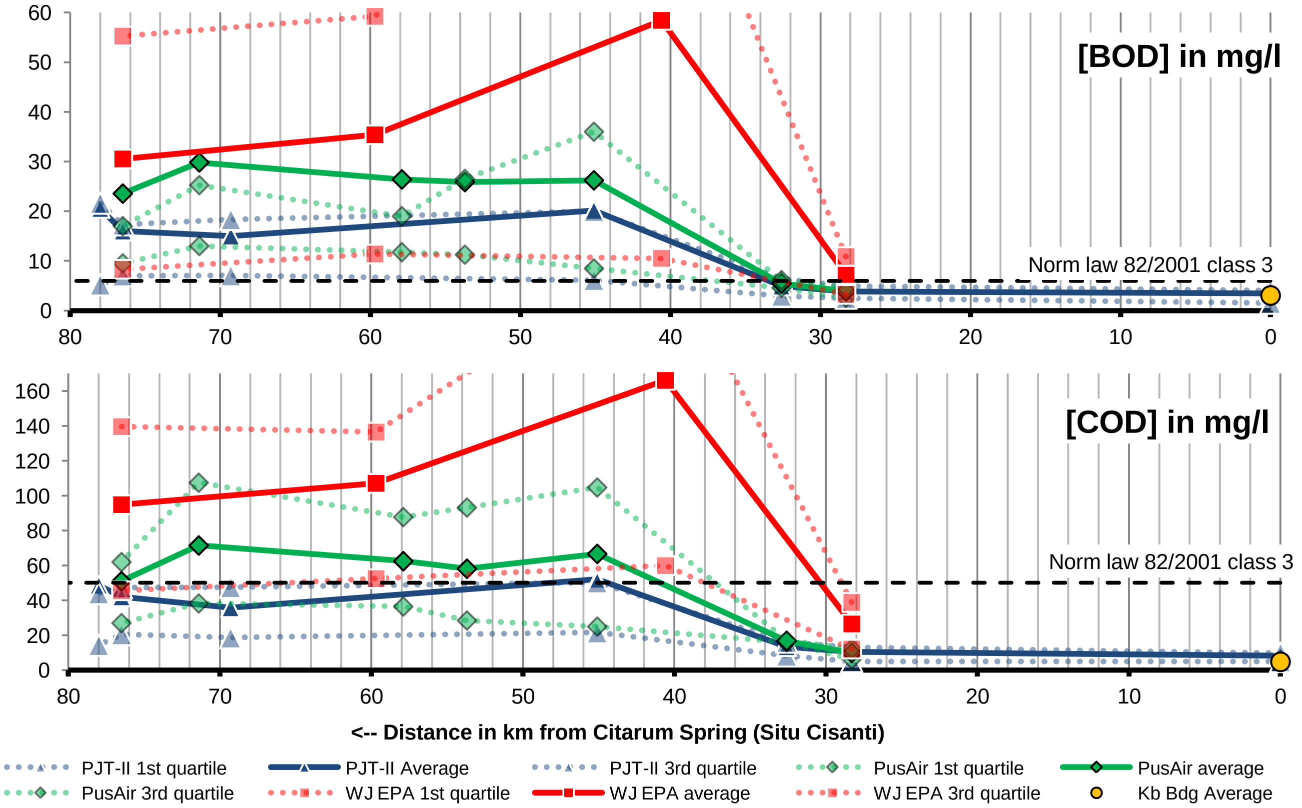

FIGURE 26 BOD AND COD IN THE CITARUM RIVER – MORE GRAPHS CAN BE FOUND IN ANNEX XI

[14] This is valid for most parameters, see section 5.3 for an extensive discussion on this topic.

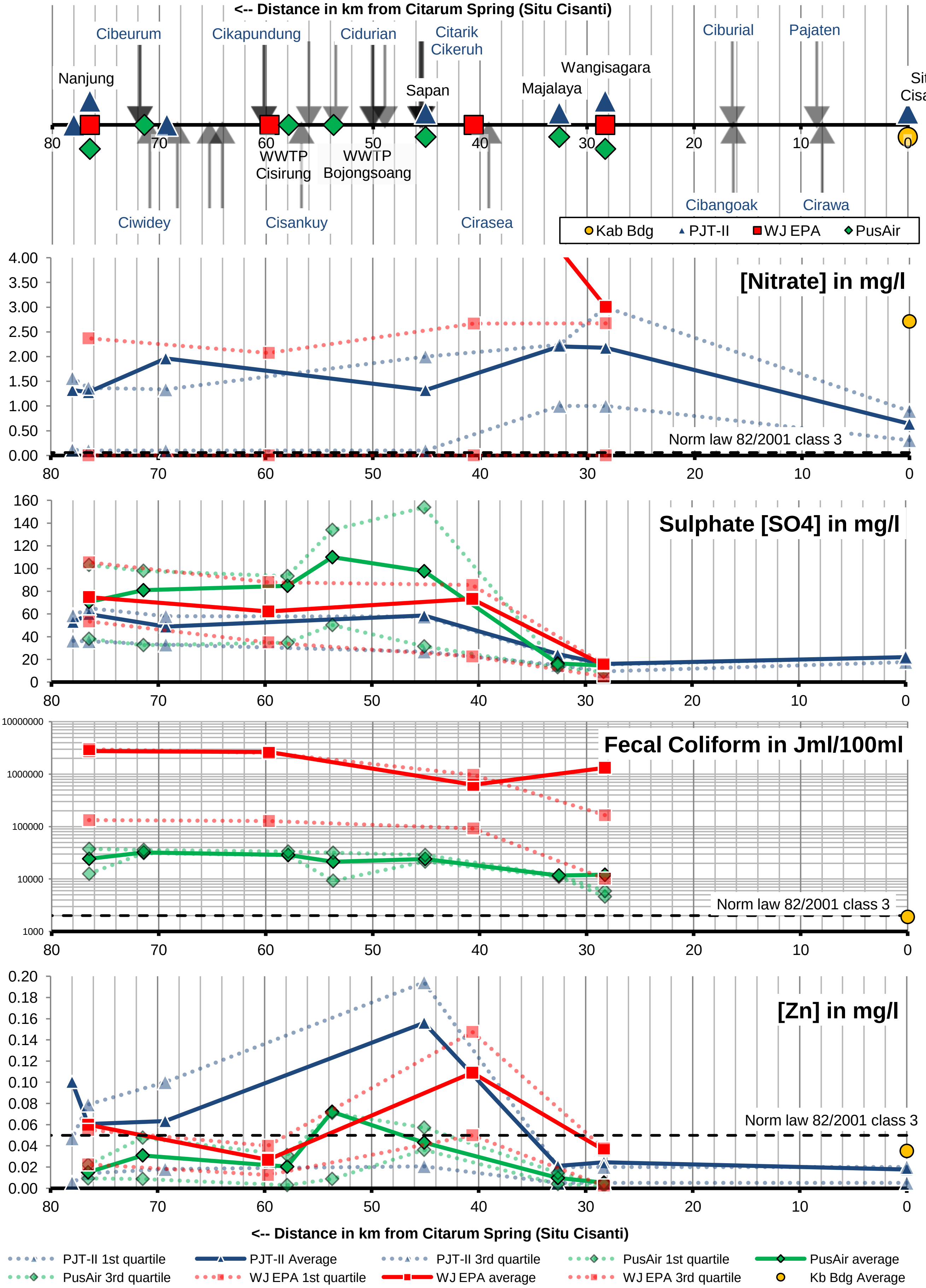

FIGURE 27 COD, SULPHATE, FECAL COLIFORM AND ZINC CONCENTRATIONS IN THE CITARUM RIVER – MORE GRAPHS CAN BE FOUND IN ANNEX XI

5.4.1 From Situ Cisanti (spring) to Wangisagara (28.3 km): stockbreeding and agriculture

Between Situ Cisanti (0 km) and Wangisagara (28.3 km), the Citarum is a fast-running river with an average monthly discharge between 10.2 m^3/s during the wet season and 1.2 m^3/s in the dry season (Pt Transka Dharma Konsultan, 2013)[15]. The catchment area is dominated by natural vegetation: forest and bush; agricultural activities: mainly not irrigated rainfed (dry) crops[16] and small settlements, (Figure 28). In the settlements, many small barns with 2 to 10 cows can be found (Fieldwork, 7/3/2015). Sporadic, some larger farms with around 50 cows are found (Fieldwork, 22/5/2015).

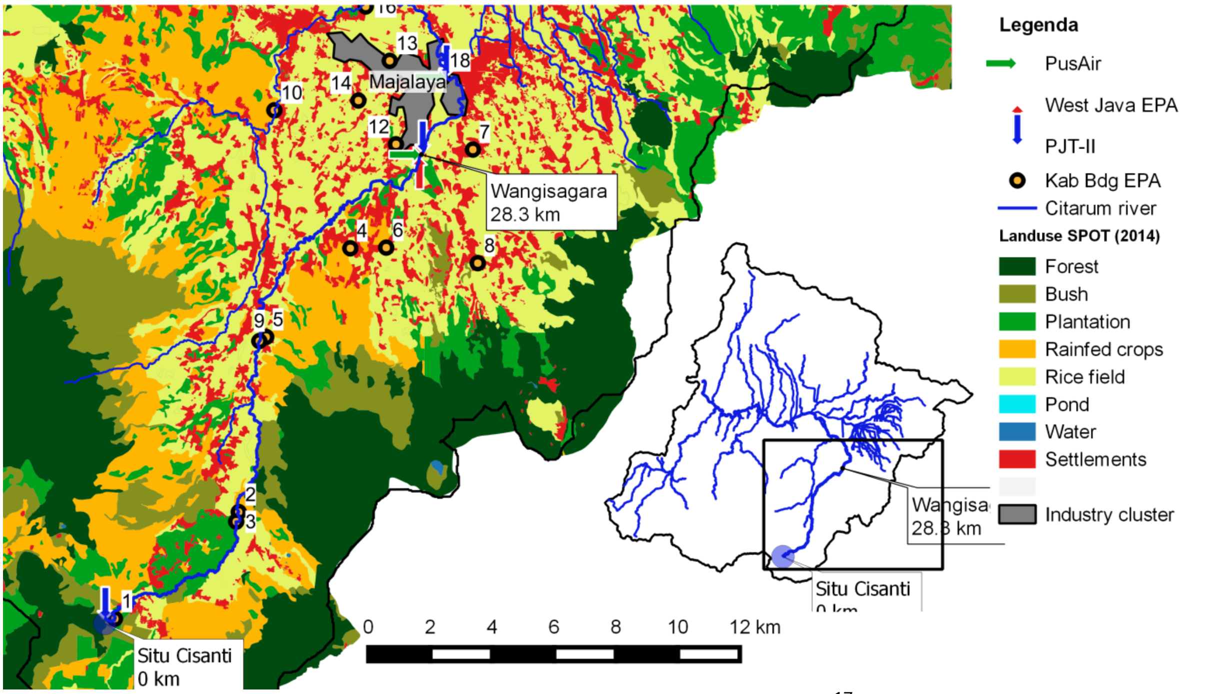

FIGURE 28 LAND USE AND MONITORING LOCATIONS IN THE AREA BETWEEN SITU CISANTI AND WANGISAGARA[17]

In the area, most water quality parameters do not show a considerable rise. Figure 26, 27 and Annex XI show that the temperature and the DO are very stable. The BOD and COD show a small increase, but the levels observed at Wangisagara are still far below the standard. The pH and sulphate concentrations remain the same. However: there are a few exemptions: there is a considerable rise in concentrations of nitrite, nitrate and fecal coliform.

Figure 29 shows that the average nitrite concentrations increase from 0.023 mg/l to 0.065 mg/l (PJT-II). The median at Wangisagara equals the governmental standard (0.060 mg/l), which means that the standard is exceeded 50% of time. The average nitrate concentration is increasing from 0.64 mg/l to 2.18 mg/l (PJT-II), the governmental standard is 0.06 mg/l. The nitrate concentration is practically always at an unacceptable level.

The nitrite, nitrate and fecal coliform emissions in this area can be related to the stockbreeding activities observed during the field work, Figure 29. This assumed link is confirmed by high concentrations of nitrate, nitrite and fecal coliform observed by Kaputen Bandung EPA in the

[15] Compare with calculation of the author, based on BBWS data 2010-2013, measuring station Majalaya: yearly average value 9.3 m^3/s, Q25= 4.3 m^3/s and Q75 = 12.4 m^3/s. These years are relatively wet compared to the years analyzed by the Pt Transka Dharma Consultant which uses BBWS data 2002-2012.

[16] The SPOT satellite interpretation is wrongly interpreting rainfed (dry) crops in this area as ‘bush’, ‘plantations’. During Fieldwork it was observed that these types of vegetation are rarely found in this part of the basin, and that most of the area is planted with dry crops such as beans, carrots and potatoes. See Annex XIV.

[17] Mind that the locations of Kabupaten Bandung EPA sometimes seem to be located in the main Citarum, while they in fact are taken from small tributaries, just before entering the Citarum river. Those tributaries are not displayed on the map.

tributaries of the main river. The main sources of stockbreeding emissions are the tributaries 2, 3, 5 and 9 in Figure 30. The observed concentrations in these rivers can be found in Annex XII.
Surprisingly, the stockbreeding activities cannot be identified from the free ammonia concentrations[18]: the observed values are on average 0.011 mg/l at Situ Cisanti and 0.012 mg/l at Wangisagara (PJT-II), see Annex XII. In general, stockbreeding activities are related to ammonia emissions (Bittman & Mikkelsen, 2009).

FIGURE 29 STOCKBREEDING ACTIVITIES AND FARMING ON STEEP HILLS (AUTHOR, 7/3/2015)

5.4.2 From Wangisagara (28.3 km) to Sapan (45.6 km): Majalaya industry cluster

Between Wangisagara (28.3 km) and Sapan (45.6 km) the flow velocity of the Citarum is significantly lower than upstream of Wangisagara, as the river starts to enter the Bandung floodplain. As a result, a lot of sedimentation takes place in this area. At 39.2 km, the Cirasea merges with the main Citarum river. Between the Cirasea and Citarum, the big Majalaya industry cluster can be found. According to license data of the West Java EPA, at least 56 textile industries (20 - 200 employees per industry) are located in the area. Moreover, a local NGO states that many home industries are located here (p.c. Riswandani, 4/2/2015). By studying the Digital Elevation Map (DEM) and the structure of the small tributaries in the industry cluster it was found that most of the industrial wastewater is first discharged into the Cirasea, before entering the Citarum. The rest of the Cirasea catchment is an agricultural area, with small settlements (Figure 31). The city and industry cluster of Majalaya is surrounded by rice fields (Figure 30).

FIGURE 30 THE RICE FIELDS IN MAJALAYA ALTERNATE WITH TEXTILE INDUSTRIES DISCHARGING HEAVILY POLLUTED WASTEWATER (PHOTO'S BY AUTHOR)

Because the Majalaya industry cluster is the first industrial-urban area in the Citarum River, and the area upstream is not densely populated, a big increase in almost all water quality parameters can be observed.

[18] As can be seen in Annex XI, there are very big differences in observed free ammonia concentrations. According to PJT-II and PusAir, the concentrations are at acceptable level for drinking water (water class 1) in the whole river (below 0.5 mg/l). However, the West Java EPA reports values of a completely different order of magnitude (median values of 0.1, 1.1, 2.8 and 3.3 mg/l in the whole river respectively, with outliers up till 56 mg/l).

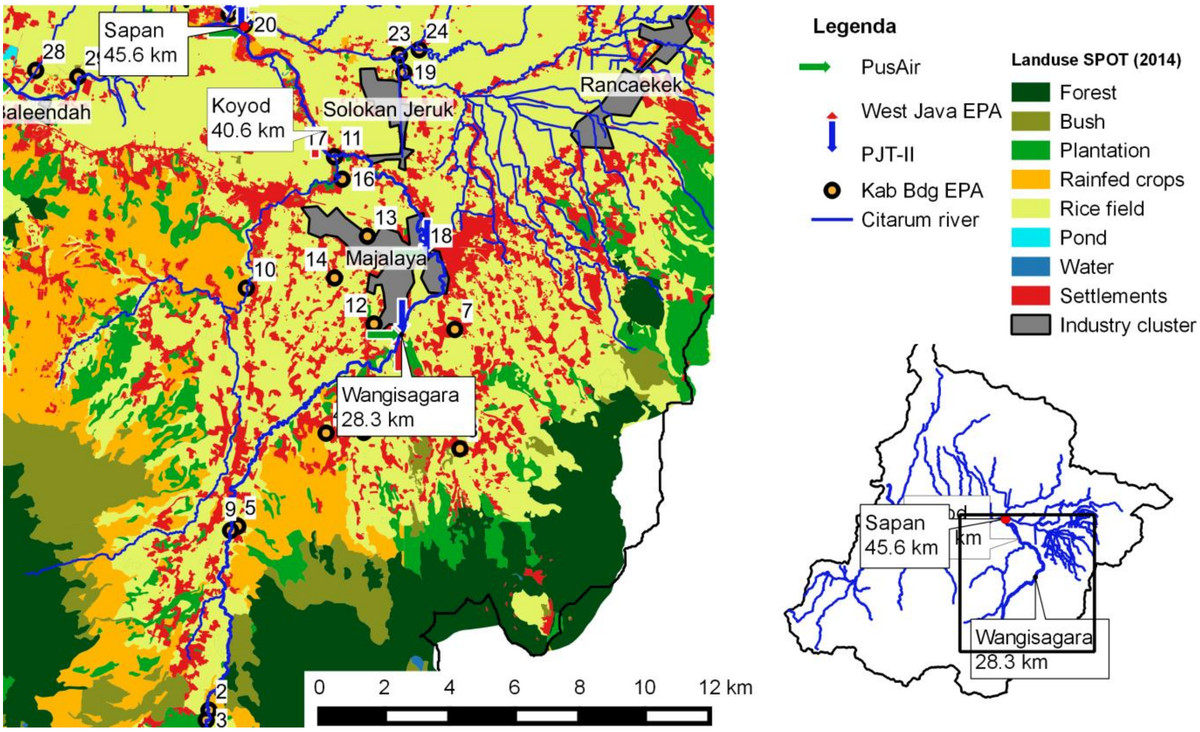

FIGURE 31 LAND USE AND MONITORING LOCATIONS IN THE AREA BETWEEN WANGISAGARA AND SAPAN

The Majalaya industry cluster causes a significant increase in water temperature. PJT-II and PusAir data shows an increase of about 2 ºC (from 23.4 to 25.1 ºC and from 24.6 to 26.8 ºC respectively), the West Java EPA data an even bigger increase between Wangisagara and Koyod: from 22.7 to to 26.6 ºC. The research with the Levelogger devices shows that this increase can be clearly attributed to the textile factories, who use large boilers (Factory inspection 22/4/2015) in their production process. There also is a strong increase in BOD and COD. According to PJT-II, average BOD increases from 4.9 mg/l at Wangisagara to 20 mg/l at Sapan. PusAir reports a comparable increase from average 5.5 mg/l to 26 mg/l. In Koyod (40.6 km), the West Java EPA even measures an average value of 58 mg/l. The norm is 6 mg/l. So before entering the Majalaya industry cluster, the BOD is almost always according to the standards, except for some time in the dry season (WJ EPA). After the Majalaya industry cluster, the BOD is according to the standards only 25% of the time. In the worst 25% percent of measurements, the BOD exceeds 20.0 mg/l (PJT-II), 36 mg/l (PusAir) or even 103 mg/l (WJ EPA).
The pattern of COD is similar: an average increase from 11 mg/l to 52 mg/l (PJT), 10 mg/l to 67 mg/l (PusAir) and 27 mg/l to 166 mg/l (WJ EPA). The standard is 50 mg/l. Before entering the industry cluster, the COD is almost always according the norm. After the industry cluster, the norm is exceeded 25% percent of the time (PJT), and in the dry season between the 25% and 50% of time according to PusAir, and almost always according to the WJ EPA.
The BOD:COD-ratio can be used as an indicator for the proportion of biochemically degradable organic material to the total amount of organic material (Lee & Nikraz, 2014). One would expect that the BOD:COD at Wangisagara would be higher than at Sapan, because the organic material at Wangisagara is mainly originating from agricultural and domestic areas, and at Sapan from industrial areas. However, in fact the BOD:COD in Wangisagara and Sapan is very similar: 0.38 resp. 0.38 (PJT); 0.41 resp. 0.38 (PusAir) and 0.30 resp. 0.31 (WJ EPA).
Also, a very large increase in [Sulphate] can be seen in Figure 29, the yearly average value changes from 25 to 59 mg/l (PJT-II) and during the dry season from 16 to 98 mg/l (PusAir) or from 15 to 73 mg/l (WJ EPA). There is no Sulphate standard for water class 3, but the water still meets the strictest standard, class 1 for drinking water: 400 mg/l.
The [Zn] reaches the highest value in the whole river just after the Majalaya industry cluster (Figure 29). According to the West Java EPA and PJT-II, the Zn-standard of 0.05 mg/l is exceeded approximately 75% of the year at Sapan. The median value of PJT-II increases from 0.020 at

Wangisagara to 0.058 mg/l at Sapan and the 3rd quartile (exceeded 25% of the year) even from 0.020[19] to 0.194.

5.4.3 Sapan area (45.6 km to 50 km)

Sapan (45.6 km – 50 km) is an important point in the Citarum, because here four tributaries mix with the main river: Citarik, Cikeruh, Cipamokolan and Cidurian, see Figure 32 and 33. The Citarik is fed from a large number of small tributaries, many of those come from the Rancaekek industry cluster, where 15 large industry factories are located (license data West Java EPA) and the from the Solokan Jeruk industry cluster, consisting of 2 large textile factories (license data West Java EPA). The Cikeruh is fed by different sources: partly coming from the city of Bandung, but also from the Ujung Berung industry cluster. A bit more downstream (48.9 and 50 km) two tributaries coming from Bandung City can be found: the Cipamokolan and the Cidurian. A summary of the discharge and water quality of the tributaries is given in Table 7. A simplified scheme of the area is presented in Figure 33. A full overview of the water quality data in the tributaries can be found in Annex XII.

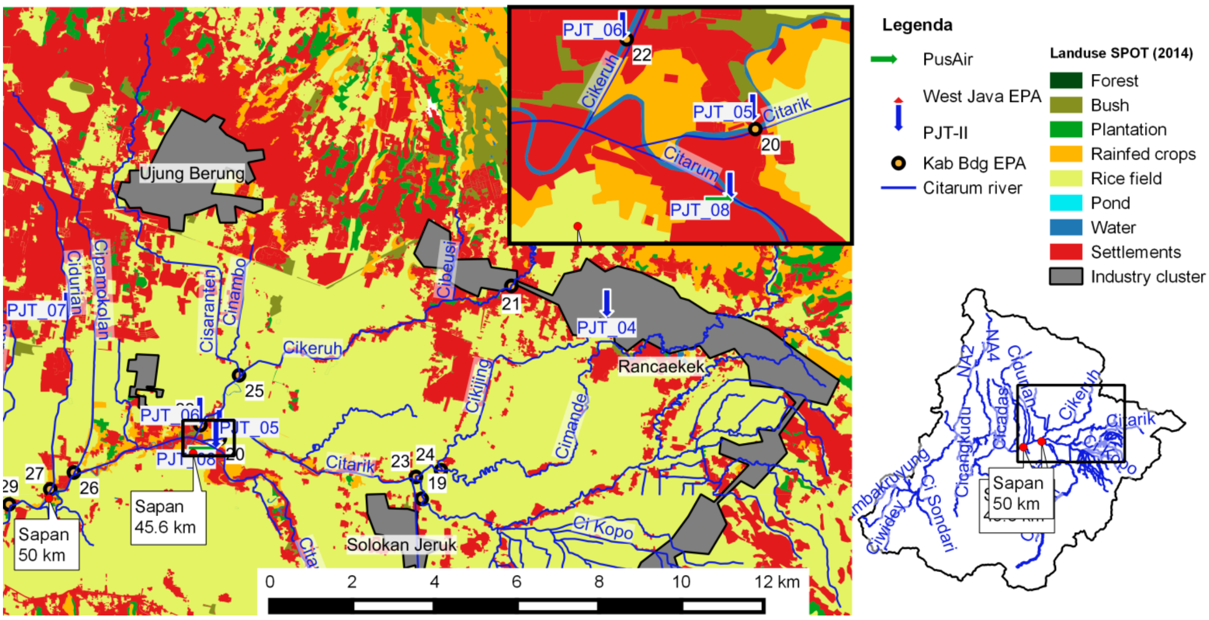

FIGURE 32 LAND USE AND MONITORING LOCATIONS IN AREA UPSTREAM OF SAPAN

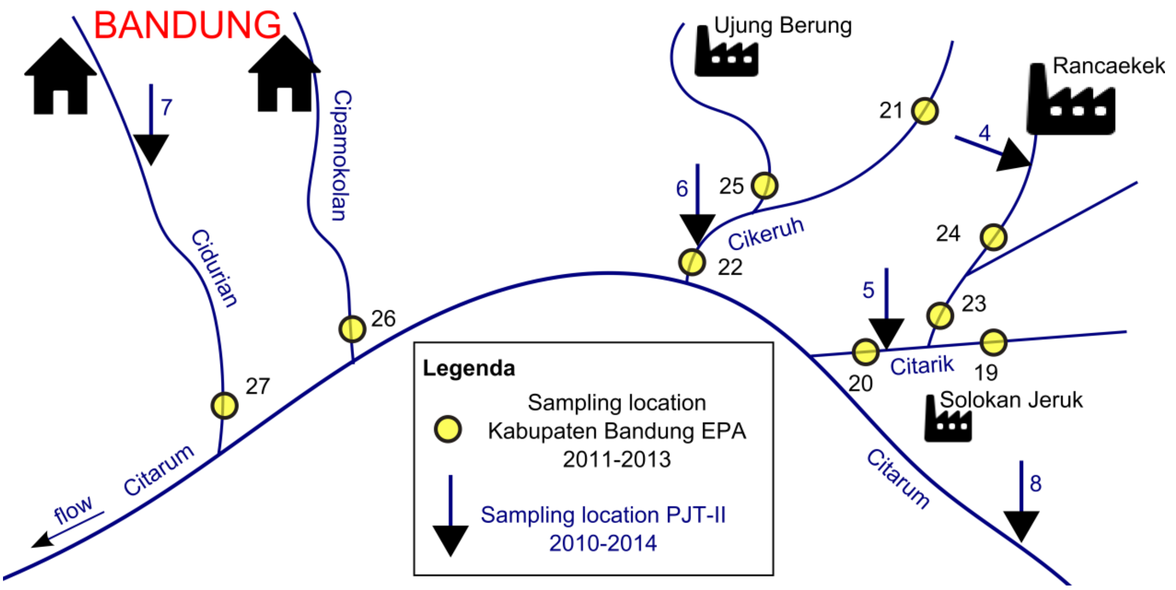

FIGURE 33 SCHEMATISATION OF THE FOUR TRIBUTARIES AND CORRESPONDING MONITORING LOCATIONS IN THE SAPAN AREA

[19] The coinciding of the median and 3rd quartile data show that the value 0.020 mg/l is observed very often.

TABLE 7 AVERAGE VALUES OF OBSERVED WATER QUALITY PARAMETERS IN 4 TRIBUTARIES IN THE SAPAN AREA

	Discharge (m^3/s)*		BOD (mg/l)		COD (mg/l)		Nitrate (mg/l)		Sulphate (mg/l)	Fecal Coli. * 1000 Jml/0.1l	Zn (mg/l)
	Dry	*Wet*	*Kab Bdg*	*PJT-II*	*Kab Bdg*	*PJT-II*	*Kab Bdg*	*PJT-II*	*PJT-II*	*Kab Bdg*	*PJT-II*
Citarum**	-	-	-	20.8	-	52.2	-	1.3	59	-	20.2
Citarik	1.3	2.1	41.9	15.5	62.9	43.8	8.6	1.8	133	31.8	15.5
Cikeruh	1.2	2.0	15.7	15.3	37.3	39.2	2.6	2.8	61	5.6	15.3
Cipamokolan	0.3	0.9	19.2	-	41.3	-	4.7	-	-	6.9	-
Cidurian	2.2	4.9	17.4	11.5	37.4	32.0	5.2	1.8	33	33.9	11.5
Standard (law 81/2003, class 3)			6		50		20		-	2	0.05

* (Pt Transka Dharma Konsultan, 2013)
** Concentration in the main Citarum river, before mixing with the tributaries: Sapan 45.6 km (PJT-II location 8)

In Table 7, the water quality in the Citarum (PJT-II location 8) is compared with the water quality in the four tributaries schematized in Figure 35. Based on PJT-II, it can be concluded that the BOD, COD and [Zn] in the tributaries is lower than in the main Citarum, but still far above the standard. In contrast, the [nitrate] is much higher. The Kabupaten Bandung EPA observes higher values for most parameters because their measurements are taken during the dry season.
There are interesting differences between the locations shown in Figure 32, which can be related to differences in land use. The BOD and COD in the small stream coming from the Rancaekek industry cluster are extremely high. According to PJT (location 4), the average [BOD] is 65 mg/l and the average COD is 195 mg/l (Annex XII). Kabupaten Bandung EPA reports similar values at location 24. While going downstream, the brine stream gets strongly diluted (cf. Kab Bdg locations 23 and 19, Annex XII). However, before entering the Citarum, the Citarik finally passes by the Solokan Jeruk industry cluster. As a result, the average BOD and COD of the Citarik are far above the standard (Table 7). Similar patterns are found for Sulphate, Nitrate and Zinc (Annex XII). It can be concluded that the largest part of the BOD, COD, Sulphate, Nitrate and Zinc load in the Citarik can be attributed to the Solokan Jeruk and Rancaekek industry cluster.
The pollution of the Cikeruh is comparable with the Citarik. But the differences between the two branches of the Cikeruh are not very big. The BOD, COD, [Zn] and [nitrate] at location 25 (west branch Cikeruh) are somewhat higher than at location 21 (east branch Cikeruh). In contrast, the fecal coliform at 21 is much higher than at 25. The west branch of the Cikeruh (with the higher, BOD etc.) is originating from the Ujung Berung industry cluster, in the east branch some industries from the Rancaekek cluster can be found.
From the data of the Cipamokolan and the Ciduarian, originating from Bandung city, the following can be derived: the urban tributary water also is characterized by high COD and BOD. The COD and BOD in the urban tributary water is somewhat smaller compared with industrial wastewater. In contrast, the [Zn] is very high compared with the water from the industry clusters. According to the Kabupaten Bandung EPA data, the acceptable [Zn] is exceeded in more than 75% of time in the urban tributaries. Average values are 2.5 times the standard of 0.05 mg/l. Fecal coliform in urban tributaries exceeds the standards 50% of the time, but is not so bad as in many other tributaries.

5.4.4 From Sapan (50 km) to Nanjung (76.5 km)

Between Sapan (50 km) and Nanjung (76.5 km), the Citarum is flowing from east to west through the very flat floodplain before entering the Saguling reservoir. Very high sedimentation rates can be observed and the area is very flood-prone (Deltares, 2012). North of the Citarum the city of Bandung can be found, criss-crossed by four rivers, from east to west: the Cicadas (or Cijawura), the Cikapundung, the Citepus and the Cibeurum, see Figure 34. At the confluence of the Cikapundung and the Citarum, the Dayeuh-Kolot industry cluster is located. This cluster consists of 38 industries, almost all producing textile, and is equipped with a communal wastewater treatment plant: IPAL Cisirung. Upstream of the industry cluster, the Cikapundung splits in two tributaries.

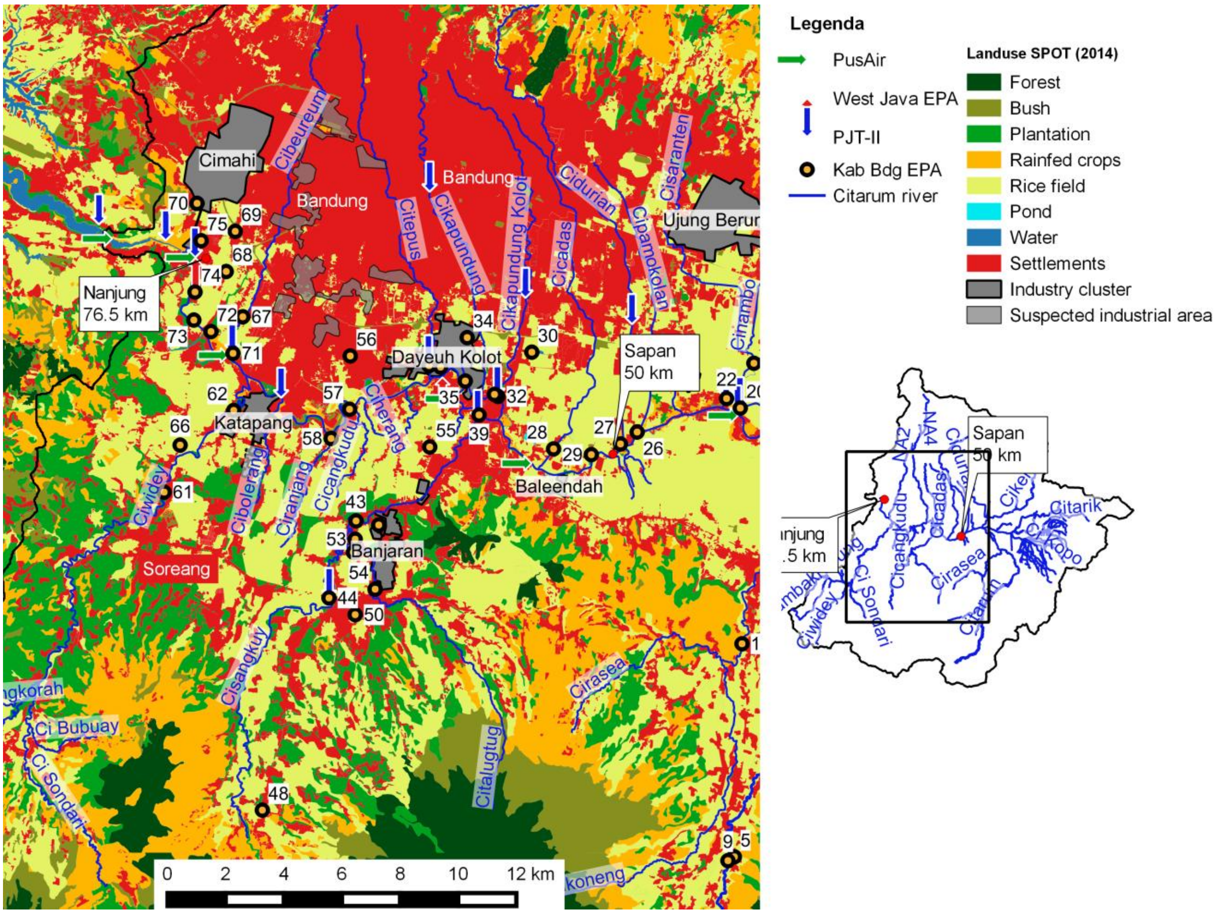

FIGURE 34 LAND USE AND MONITORING LOCATIONS IN THE AREA BETWEEN SAPAN AND NANJUNG

Almost all observed BOD values in the four northern tributaries are far above the standard. The BOD in the Cibeurum is relatively high, this can especially be seen in the PJT-II data: averages of the Cikapundung, Citepus and Cibeurum are respectively: 14, 31 and 74 mg/l, the standard is 6 mg/l. For COD the pattern is similar: 33, 79, 181 mg/l, the standard is 50 mg/l. It is very remarkable that the Cibeurum is much more polluted than the Cikapundung, for in the Cikapundung area the big Dayeuh-Kolot industry cluster is located and around the Cibeurum, initially only settlements were found. It is not logical to attribute the pollution of the Cibeurum to domestic wastewater, for one would then also expect high values in the other three northern rivers. A careful study of satellite images and photo's on Google Earth shows that in fact many industries are located in the city of Bandung, around the Cibeurum river, see Figure 35 for an example of a very big one. Those industries are added to the Land use map in Figure 36 as 'suspected industrial areas'. Those industries are not located in the usual clusters used for water quality modelling (cf. Yusuf, 2015). Consultation with West Java EPA employees suggested that some of these textile industries are considered as part of the Cimahi industry cluster (p.c. 4/5/2015).

FIGURE 35 A VERY BIG TEXTILE FACTORY OF PT. KAHATEX (600 * 350 M) IS LOCATED AROUND THE CIBEURUM, NORTH OF THE TOLROAD IN THE WEST OF BANDUNG CITY (SATELLITE IMAGE OF 2/1/2014, RETRIEVED FROM GOOGLE EARTH)

The fecal coliform concentrations in the four northern rivers are all very high, and far above the norms. The most striking is the fecal coliform concentration in the Cikapundung, which is a multiple of the concentrations in the other tributaries. The average value of 285,000 Jml/0.1l is 143 times above the norm of 2,000 Jml/0.1l. Two different sources of this high coliform concentration can be indicated. First, Hendrawan *et al.* (2013) claim that the west part of the Bandung sewage system is not connected to the Bojongsoang WWTP, and is directly discharged to the Cikapundung. During field observations, it was observed that indeed many pipes directly discharge domestic wastewater to the Cikapundung. Second, the Lembang area north of Bandung, is well-known for its intensive, large-scale stockbreeding activities. Several stakeholders claim that most of the manure of this area is directly discharged to the Cikapundung (e.g. p.c. Yusuf, 20/2/2015). The contribution of both factors has been a subject for debate between the West Bandung Regency EPA (responsible for Lembang area) and Bandung City EPA (responsible for Bandung city) for a long time (p.c. Wardhani, 19/5/2015). Additional research on the available data might reveal the main source of the pollution, but it is not inconceivable that both factors significantly contribute.

South of the Citarum, two very large tributaries can be found: the Cisangkuy and the Ciwidey, both branching off into many streams. Those rivers mainly flow through agricultural areas, but also some cities and industry clusters can be found. The Ciskankuy starts at a reservoir west of Situ Cisanti (spring of the Citarum), and flows through the cities Penglengan and Banjaran. In Banjaran, an industry cluster with 16 factories of which 9 producing textile is located (license data West Java EPA). The Ciwidey starts in Ciwidey city, and subsequently flows through Soreang. Between the Cisankuy and the Ciwidey, many small tributaries can be found. Between the Ciwidey and the Cibolerang (or Cikambuy) the Katapang industry cluster with 8 factories, half textile, is located (license data West Java EPA).
There are remarkable differences between the water quality of the Cisankuy and the Ciwidey. According to the Kabupaten Bandung EPA data, the Ciwidey is very clean. All observed BOD and COD values are far below the norms. The norms for [Zn] and fecal coliform are only exceeded 25% of the time. In contrast, the COD, BOD and Zn of the Ciwidey are comparable with the Cikapundung.
Between Sapan and Nanjung, the BOD and COD remain rather stable according to PusAir and PJT-II, see Figure 26 and Annex XI. It can be concluded that the average BOD and COD in the tributaries between Sapan and Nanjung are similar with the concentrations in the Citarum before Sapan.

Finally, a large industry cluster can be found in Cimahi, west of the city of Bandung. Although Cimahi is located in the Bandung Basin, the Cimahi river directly discharges into the Saguling reservoir, and is therefore not influencing the water quality of the Citarum River.

5.5 Relation between water quality and land use

In this section, the relation between water quality and land use will be researched in a more quantitative way. The methodology was inspired by the work of Firdaus (2013, 2014), who also researched the relation between water quality and land use of some catchments in Indonesia. The methodology used in this thesis can be described as follows: 1) selection of suitable sampling locations, from the Kabupaten Bandung 2011-2013 dataset; 2) calculation of catchments corresponding with each sampling location, based on a Local Drain Direction (LDD) map derived from a Digital Elevation Map (DEM); 3) calculation of the land use in each catchment, using the SPOT-2014 land use interpretation; 4) regression analysis between the land use and observed water quality samples in each catchment; 5) synthesis of the obtained regression data. For an extensive explanation and all results, see Annex XV. In Annex XIV the choice for the SPOT-2014 land use map is motivated. It was decided to use the Kabupaten Bandung dataset, because this dataset contains the largest number of locations, and the sampling locations are in relatively small tributaries so that the different types of land use could be easily isolated.
First, all the regressions were researched including the catchments containing industry clusters. The factories cannot be distinguished from other buildings on the SPOT-2014 land use interpretation, and are therefore categorised under ‘settlements’. As it was feared that the industry clusters

misrepresented the land use in some catchments, the analysis was repeated without the catchments containing the industry clusters. Sometimes, the results of both approaches were very different, because there was a relation between the occurrence of certain land use types (like rice fields) and the presence of a very polluting industry cluster.
For several reasons stated in Annex XV, one should be careful by interpreting the R^2-values resulting from the analysis. The most appropriate way of interpretating them is to consider each R^2-value as a percentage indicating which part of the observed scattering of a certain water quality parameter can be explained from the land use in the catchment where the samples were taken. However, even a very high R^2-value does not necessarily mean that the contribution of this land use to the pollution is very large. It only indicates that this land use type can be very well used to explain the observed values in the Bandung Basin; there is a strong correlation between the land use and the concentrations. As a result, in many cases a high R^2 value is an indicator that a certain type of land use is an important determinant of a water quality parameter.

TABLE 8 R^2 –VALUES (IN %) INDICATING THE REGRESSION BETWEEN PERCENTAGE OF LAND USE AND WATER QUALITY PARAMETERS

Land use / parameter	Settlements*	Forest*	Rice fields*	Dry agriculture**	Industry***
BOD	23	-47****	0	-1	49
COD	28	-47	-1	2	58
Nitrate	0	-21	0	1	0
Sulphite	17	-8	-4	-9	25
Fecal Coliform	39	-2	3	-2	15
Zn	94	-31	0	-36	20

* Catchments containing industry are neglected, values are corresponding with "... without industry" in Table 21 of the annex
** The sum of the land uses 'bush', 'dry crops' and 'plantations'
*** Industrial density graded in two classes: x=0 for no industry and x=1 for any kind of industry, values are corresponding with "industry yes/no" in Table 21 of the annex
**** Negative values are indicating a negative correlation between parameter and land use

In Table 8, R^2-values of the selected parameters are given, indicating the correlation with five classes of land use. As expected from the findings in the rest of the report and from water quality literature, there is a strong correlation between BOD, COD and the presence of an industry cluster in a certain catchment. Those parameters also positively correlate with the percentage of settlements in a catchment, even when the mixed catchments containing both settlements and industry clusters were removed from the analysis. BOD and COD do not correlate with rice fields or other agricultural activities. Because the forests are the complementing land use in the basin, it is logically to observe very negative correlations with this type of land use.
The nitrate concentration does not positively correlate with any particular type of land use. It can only be concluded that nitrate is not originating from the forest areas. It might be that all the other types of land use contribute to the concentrations to the same extent.
Sulphite positively correlates with settlements and industrial areas. This might only be due to faeces coming from the settlements, because industrial catchments also always contain settlements. However, it is also possible that the industries themselves are a direct source of sulphite.
Surprisingly, fecal coliform only strongly correlates with settlements and industry. However, one should be careful by drawing conclusions from this, because the correlation is strongly dominated by the average parameter value observed in one tributary (Annex XV). However, as this average based on nine observations, it at least shows that some settlement areas contribute strongly to coliform concentrations. One can only speculate about the reasons why coliform does not correlate with agricultural areas: maybe the selected areas do not contain a lot of stockbreeding activities or these activities are found all over the basin: not only in agricultural areas. In section 5.4.1 a clear relation between the presence of cows and observed coliform concentrations was found.
When industry clusters were excluded from the analysis, a very strong relation between [Zn] and settlements was found. Although the [Zn] in industrial areas does not correlate very strong, some of the observed values in industry clusters exceed the concentrations in settlement areas to such an extent that one cannot conclude that settlements are a more important source of zinc than industrial areas based on the R^2-values. It is interesting to see that forest and dry agricultural area's negatively correlate with the [Zn], while there is no correlation with rice fields. This might signify that some zinc is originating from the rice fields.

Some other interesting findings are that both the pH and the temperature are positively correlating with settlements and industry but negatively with forest and dry agriculture (Annex XV). For pH, this means that the water coming from households and industry is mainly alkaline and the water from forest and dry agriculture acid. The high water temperatures of built-on areas can be related to multiple types of water use, but also to different catchment characteristics.

5.6 Discussion

In the preceding sections, different methods were used to get insight in the obtained data. Here, the limitations of each method will be discussed, to show the reader what can be concluded from the different results.

First of all, the analysis has been based on a selection of the available data, in terms of time span, measuring locations, measuring organizations and chosen parameters. In addition, data has only been compared with norms according to the Indonesian law, this law is incomplete on several aspects (see Annex III). Comparison with other norms might have led to different results.

The comparison of Levelogger data with Kabupaten Bandung EPA data in the second section was not completely fair, because the measuring locations and time were not the same. Moreover, the correlations of equation 2 is not necessarily valid at all the locations where it was used, although it is likely that the conditions are approximately the same. It would be better to use continuous sensors that measure the exactly the same parameters as measured by the EPA, so that no correlations have to be used to estimate the parameter values. Next time, it would be interesting to take samples during inspections of the Levelogger devices, and compare the lab results of these samples with the Levelogger data. That would help by the interpretation of the data obtained with the Levelogger devices.

In the third section, the comparison of the dry and the wet season showed significant differences for some parameters. However, for other parameters, the data also seemed to be very different during the dry and wet season, but according to the test of Wilcoxon-Mann-Whitney this difference was insignificant. If the test would be based on a longer time period, probably these differences also would turn out to be significant. If the T-test (assuming normal distribution) would have been used instead of Wilcoxon-Mann-Whitney, the results also might have been different. For some parameters, like COD, the shape of the distribution might justify the assumption of a normal distribution. However, for many other parameters the distribution shape shows that it is improper to assume a normal distribution.

The large obstacle for investigating the upstream-downstream water quality development in the fourth section is the large difference in observed parameters between different organizations. More research on these differences has to be done before one can judge the real state of the Citarum River. Investigating differences in sampling and lab procedures should clarify the differences between the datasets.

The most difficult aspect of researching the relation between water quality and land use in the fifth section, is that certain types of land use practically always coincide in a catchment: for example rice fields and industry clusters. It is hard to distinguish between settlements and industries because in most industry clusters both types of buildings are mixed. The SPOT-2014 image also does not automatically distinguish between them. Larger industries can be seen from normal satellite photos, but home industries cannot be recognized by this method. As stockbreeding activities often take place in very small farms, without identifiable pastures, those activities cannot be distinguished from satellite images. Moreover, the SPOT-2014 interpretation especially performed bad on distinguishing between different types of crop growing activities; it often misinterpreted the land use types forest, bush, perennial plantations and dry crops (Annex XIV).

All the issues with the interpretation of land use maps also strongly influenced the reliability of the qualitative research of the influence of land use on water quality in the fifth section. The results are especially influenced by the fact that certain land use types often mutual correlate within catchments. The calculation of a catchment for each sampling point based on a LDD-map normally works well, but is not perfect. For example, it does not take into account the existence of man-made irrigation channels that change the natural drainage patterns. Many of these irrigation channels can be found in the Bandung Basin. The final issue is that the industrial areas were not included in the land use maps, and that therefore another method had to be used to study the relation between water quality and industrial activities.

5.7 Conclusion

Comparison of the obtained Levelogger data with sampling results of the Kabupaten Bandung EPA shows that both data sources give consistent information about the water quality in this area. It reveals that the high pH, temperature, TDS, BOD, COD and [Zn] in the downstream part of the Cirasea are originating from the Majalaya industry cluster and not from the upstream part of the Cirasea. In contrast, this upstream part is the main contributor to high fecal coliform concentrations in the Cirasea. This can easily be linked to the stockbreeding activities that take place in this area.
There are many differences between the water quality in the dry season and in the wet season. For most parameters, the observed concentrations during the dry season are higher than during the wet season. For some parameters it is the other way around. However, the test of Wilcoxon-Mann-Whitney shows that only the differences in TDS, BOD and COD are significantly different: the observed values for these parameters during the dry season are approximately two times the concentrations during the wet season.
The qualitative research gives the following relations between land use and water quality. Stockbreeding activities in the first 28 km of the Citarum lead to very high nitrate concentrations and large quantities of fecal coliform bacteria. Industrial cities like Majalaya contribute strongly to high BOD, COD, zinc; observed concentrations are far above acceptable levels. Industry is also leading to Sulphate emissions, but Sulphate concentrations remain within acceptable levels. In rivers from Bandung City, also very high BOD, COD and zinc concentrations are found. The fecal coliform concentration is especially very high in the Cikapundung tributary, but it is not clear if this pollution is mainly originating from Bandung City or from stockbreeding activities further upstream.
The quantitative approach shows that positive relations between the selected parameters and land uses are only found for domestic and industrial areas. High BOD, COD and sulphite mainly correlate with industrial areas and with domestic areas to a smaller extent. Nitrate does not correlate within any type of land use in particular. Fecal coliform and zinc is mainly originating from domestic areas and to a smaller extent from industry.

TABLE 9 FOUND RELATIONS BETWEEN LAND USE AND SOURCES OF POLLUTION

	Domestic	Industry	Stockbreeding	Crop growing	Natural
BOD	❹❺	❷❹❺		No correlations found	
COD	❹❺	❷❹❺			
Nitrate		④	❹		
Sulphate		④			
Fecal Coliform	❹❺		❷❹		
Zinc	❹❺	❷❹❺			

❷ = correlation found in section 5.2; ❹ correlation found in section 5.4 pollution is exceeding acceptable level; ④ correlation found in section 5.4 pollution remains within acceptable level; ❺ = correlation found in section 5.5, ≥ 0.20

In Table 9, the results of the different methods are summarized. Now, all the results will be compared to draw a final conclusion about the relation between water quality and land use. The industry clusters are responsible for the highest BOD and COD values, this can be seen from both the qualitative and the quantitative approach. However, domestic areas are also an important contributor to BOD and COD. The BOD and COD from other land use types can be neglected. Stockbreeding activities are an important source of nitrate according to the qualitative approach. However, the quantitative approach shows that nitrate cannot directly be related to land use types distinguished on the available land use maps. This can mean that 1) stockbreeding activities can be found within different land use types or 2) nitrate is also originating from industrial and domestic areas. Observed sulphate concentrations are always within the strictest limits for drink water production. Fecal coliform originates from both domestic areas and stockbreeding activities. The qualitative approach shows that stockbreeding is an important contributor, but according to the quantitative approach the contribution of domestic areas is bigger. Zinc is mainly originating from domestic areas, and to a smaller extent from the industry.

6 CONCLUSION

This thesis aimed to increase the understanding of the water quality problem of the Bandung Basin and to give insight in the available data. By answering four successive research questions, the thesis provides several stepping stones towards the development of a water quality model. Moreover, the obtained data has been conveniently arranged and mapped, which helps policy makers to find focus by managing the water quality and spatial planning of the basin.

ANSWERS TO THE RESEARCH QUESTIONS WITH RECOMMENDATIONS FOR MODELLING THE WATER QUALITY

1. What are the drivers of the water quality problem, and how do they influence the water quality?
The six drivers of the water quality problem are: the natural system, industrial effluents, domestic waste, domestic sewage, crop growing and stockbreeding. The agricultural drivers: stockbreeding and crop growing, are mainly determined by farmer behaviour, which can be influenced by combination of policy instruments like promoting the use of sustainable crops and enforcing the ban on hazardous pesticides. The domestic waste and sewage drivers result from interference between a lack of infrastructure and citizen behaviour. The rapid economical growth can have a positive influence on both aspects. The industrial driver is a direct result of weak law enforcement. As profit-oriented businesses, industries will only change their behaviour when discharging polluted wastewater will lead to inevitable and severe sanctions. Because all those drivers can be derived from social-governmental factors, the water quality problem is mainly a non-technical issue. From a technical perspective, the natural driver is important because the basin characteristics make the basin very vulnerable for erosion, mainly during the wet season. As a result, the turbidity and amount of suspended solids is high during the wet season. Because the eroded soil mainly comes from agricultural areas, it is expected that the wet season correlates with high fertilizer and pesticide loads. In contrast, empirical evidence in the last chapter of the thesis shows that the dry season correlates though with high concentrations of indicators related to non-agricultural sources: BOD, COD and TDS.

2. What data can be obtained from organizations to support the water quality modelling?
Currently, there is no reliable emission data of any of the polluting sources so that emissions have to be estimated. Indicators of loads from each type of land use can be derived from literature, and from the observed concentrations in the Basin. For industrial emissions, the available license data and satellite images can be used to map the industries. A complete list with coordinates and surface areas of all textile industries of the basins, combined with a general typology of discharged wastewater from textile industries might be enough to model a principal part of industrial emissions. The SPOT-2014 land use map gives an accurate and up-to-date image of the settlements and agricultural activities in the basin. The available water quantity data is limited, and sometimes unreliable. The available reports can be used to develop a water balance during the dry and the wet season but the raw data needs to be validated. A suggestion for this validation is to compare the runoff with the surface area of each subcatchment, or with the runoff predicted by the hydrological model of the basin developed by Deltares. The collected river water quality data can be used to estimate emissions of certain parts of the basin. Moreover, this data can be used for validation and verification of the model.

3. How can additional sensors be used to complement the obtained data?
The fieldwork shows that the Leveloggers can be used to collect continuous water quality data. Important preconditions for successful data collection are: 1) the use of a reliable sensor frame, for example the one designed by the author; 2) close collaboration with the local community via a trustworthy NGO, for example Elingan in the Majalaya area; 3) weekly cleaning of the devices, to avoid clogging of the sensors by solid waste and sediments, for example by the researcher or an employee of the NGO. The limited amount of parameters gives a good indication of the development of the water level, total dissolved solids, electrical conductivity and temperature in time, but can be

made more sensible by combination with other sampling techniques. If during every sensor inspection a water sample is taken, the data collected by the sensor can be validated and detailed data about a variety of parameters is obtained; a cheap way to collect detailed water quality data and its development in time. The water level data can be combined with rainfall data from the TRMM-satellite to study the rainfall-runoff relation.

4. What does the retrieved data reveal about the water quality of the Citarum?
The data shows that the Citarum is heavily polluted; observed concentrations of almost all parameters are a multiple of the governmental standard. As the Alliance will start the modelling with the parameters BOD, COD, nitrate, sulphate, fecal coliform and zinc, the recommendations focus on these parameters. The most distinct source of BOD and COD are the industries, but settlements also contribute significantly to the observed concentrations. Nitrate can be linked to stockbreeding activities, but there is no clear relation with any type of land use: all land use types except from forest seem to contribute to a similar extent to the nitrate emissions. The observed sulphate concentrations are within acceptable levels, so the Alliance is recommended to exclude this parameter in the modelling. In the upstream area of the Citarum manure emissions from stockbreeding activities are the main source of fecal coliform, in the Bandung area inadequate sanitation seems to be the main source. The main source of zinc are domestic emissions, but the contribution of industry clusters is also significant.

To start the modelling, the Alliance is recommended to estimate indicators for BOD, COD and zinc emissions per surface area for two types of land use: domestic and industry. It is expected that these sources can explain the observed concentrations of these substances to a large extent. Modelling of fecal coliform and nitrate will be more difficult, because no detailed information about stockbreeding activities was obtained. As a first step, it is suggested to assume a certain emission per surface area independent of the land use type and to add an extra emission for domestic areas. Sulphate can be excluded from the modelling, because the observed concentrations are within acceptable limits. The Alliance should be aware of the fact that none of the selected parameters clearly represents crop growing activities, although this land use type is most frequently found in the basin. It should be taken into consideration to include total suspended solids into the modelling, as these particles mainly originate from agricultural areas and therefore might correlate with the presence of pesticides and fertilizers. Moreover, it is an interesting parameter because the observed concentration has an opposite dry-wet pattern compared with the other selected parameters, which are high in concentration during the dry season.

RECOMMENDATIONS FOR THE MONITORING AND POLICY MAKING GOVERNMENT

The West Java EPA should have a coordinating role in organizing the available water quality data, because all stakeholders consider this as the West Java EPA's responsibility. The central government should ensure that the West Java EPA has the authority and resources to carry out this task. It is suggested to standardize the measured parameters and set-up a database in which the collected data can be stored. Further, a simple method should be developed that gives a comprehensive overview of all the available data, the data visualizations in this thesis are a first step towards such an overview. The sampling and lab procedures have to be investigated, to understand the differences in observed concentrations between different organizations. Preferably, the used procedures are standardized.

The reader of this thesis is most likely robbed of the illusion that the water quality problem of the Bandung Basin can be easily solved, and might wonder where to start. In the authors' opinion, the West Java government should focus on law enforcement towards industries, for two reasons. First of all, the empirical data in this study shows that a large part of the pollution can be directly derived from the industry clusters. Secondly, the industries are relatively concentrated in space and are legal bodies that can be held liable for their behaviour. The government itself should start with providing proper sanitation for the Bandung City. Reduction of industrial and domestic emissions will take away the principal part of the pollution of the Citarum.

GLOSSARY

Term	Explanation
ADB	Asian Development Bank
Alliance	Alliance of Water, Health and Development: Radboud University, Deltares, Institute Teknologi Bandung (ITB) and Padjadjaran University (UNPAD)
Bandung Basin	Upper Citarum River Basin, Indonesian: DAS Citarum Hilir
BBWSC	River Basin Organization Citarum, Indonesian: Balai Besar Wilayah Sungai Citarum
BMKG	Indonesian Badan Meteorologi, Klimatologi dan Geofisika. Research institute on Meteorology, Climate and Geophysics.
BOD	Biological Oxygen Demand: the amount of dissolved oxygen biological organisms need to break down the organic material in the water
COD	Chemical Oxygen Demand: the amount of dissolved oxygen required to break down the organic material in the water using chemical oxidizers.
DSS	Decision Support System
EC	Electrical Conductivity
EPA	Environmental Protection Agency
FEWS	Flood Early Warning System. Deltares software that can be used to organize spatial data.
LandSat	Satellite providing images from which land use maps can be derived
NGO	Non-Governmental Organization
PJT-II	State owned enterprise, responsible for management of the third reservoir in the Citarum
PusAir	Indonesian: Pusat Litbang Sumber Daya Air. Research and Development institute on water resources.
Sobek	Hydrological modelling software by Deltares.
TDS	Total Dissolved Solids
TRMM	Tropical Rainfall Measuring Mission, satellite from which rainfall data can be obtained
West Java EPA	Indonesian: Badan Pengelolaan Lingkungan Hidup (BPLHD) Jawa Barat
WWTP	Wastewater Treatment Plant

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2. Personal communication

Organization	Interviewee	Function	Date(s)
PusAir (R&D institute on water resources)	mr. Iskandar Yusuf	Senior water quality researcher and modeller	22/1/2015 20/2/2015
Elingan (Local NGO)	mr. Deni Riswandani	Founder	4/2/2015 2/3/2015 22/5/2015
West Java EPA (Provincial environmental agency)	ms. Prima Mayaningtias	Head of environmental management planning division	3/3/2015
West Java EPA	ms. Resmiani	Head of monitoring division	3/3/2015 23/4/2015
PJT-II (Reservoir operator)	ms. Lina	Monitoring division	6/3/2015
Bappeda (Provincial planning agency)	ms. Ani Widiani	Head of spatial planning and environment department	6/3/2015
Enviromental pollution control association of Indonesia (Coordinating WWTPs)	mr. Dian Anggara	Secretary general	6/3/2015
Deltares (Host organization BSc-thesis) BBWSC (River Basin Organization)	mr. Muchni	Former employee of BBWS	12/5/2015
DPKLTS (Provincial NGO)	mr. Taufan Suranto	Employee	26/5/2015
Bandung City EPA (District environmental agency)	ms. Windya Wardhani	Head ofenvironmental pollution control division	19/5/2015

APPENDICES

Annex I ADMINISTRATIVE REGIONS BANDUNG BASIN

In this section, the administrative regions in Indonesia will be explained, in order to give the reader an understanding of the different levels of the described data. Indonesia is divided in 34 provinces (Provinsi). The provinces are subdivided in rural districts, or regencies (Kabupaten) and cities (Kota). Regencies and cities are on the same administrative district level, an area is either part of a Kabupaten or a Kota. The regencies and cities are further divided into subdistricts (Kecamatan). Subdistricts are divided in either Desa or Kelurahan. Desa and Keluharan are on the same level, but the term 'Desa' is used within a regency and a 'Kelurahan' within a Kota.

In Figure 36 the administrative boundaries around the Bandung Basin can be seen. The Bandung Basin is located in the province of West Java, and is covered by Kota Bandung, Kotah Cimahi, a large part of Kabupaten Bandung[21], a small part of Kabupaten Bandung Barat and Kabupaten Sumedang.

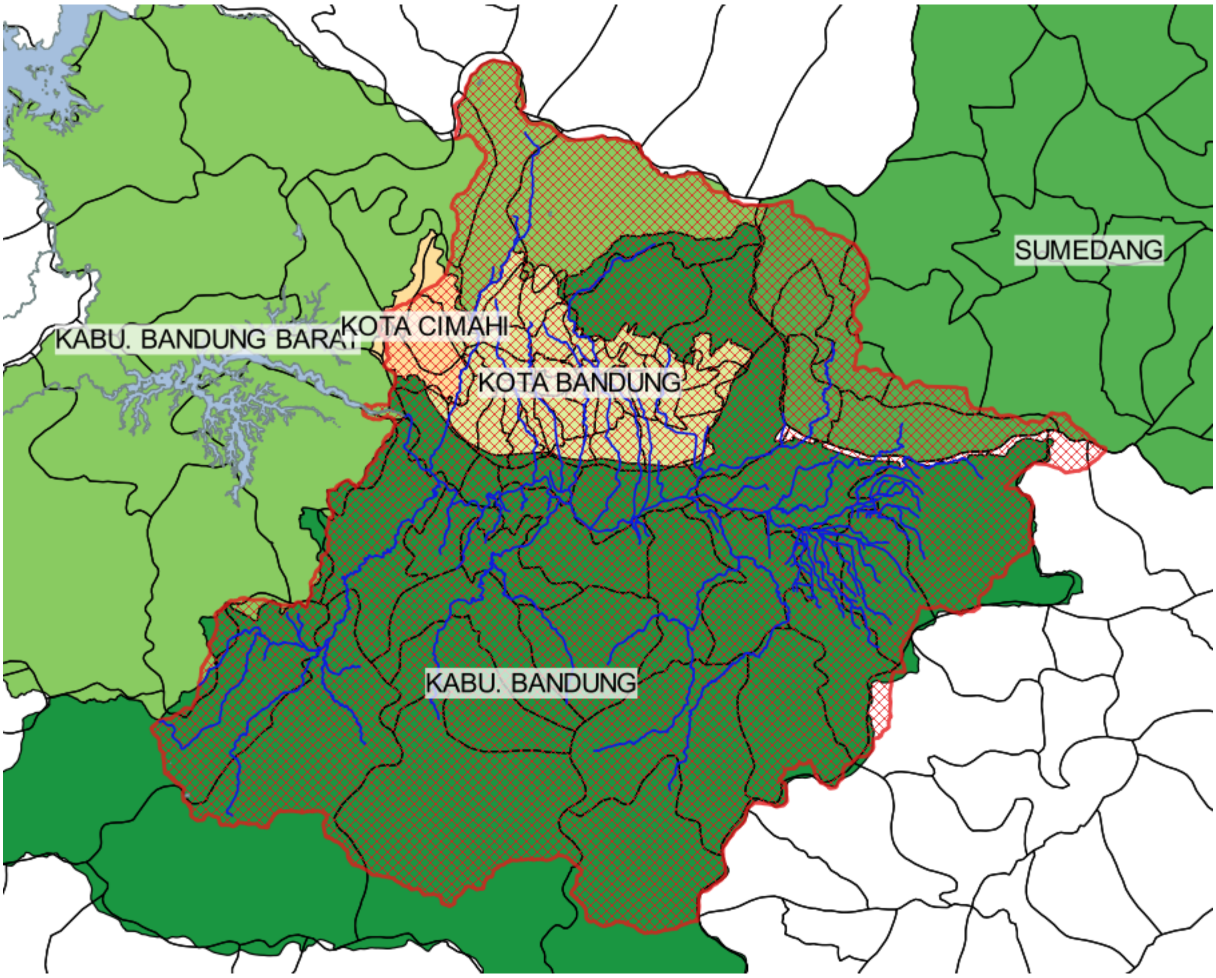


FIGURE 36 ADMINISTRATIVE BOUNDARIES AROUND THE BANDUNG BASIN. THE BANDUNG BASIN IS INDICATED BY SHADING. THE BLACK LINES ARE INDICATING KECAMATAN BOUNDARIES

[21] Before 2007, both Kabupaten Bandung and Kabupaten Bandung Barat where in one Kabupaten, which had the name: Kabupaten Bandung.

Annex II VALIDATION OF DISCHARGE DATA

Discharge data of BBWSC (2010-2013) was validated using two intuitive methods:

1. Plotting of discharge data

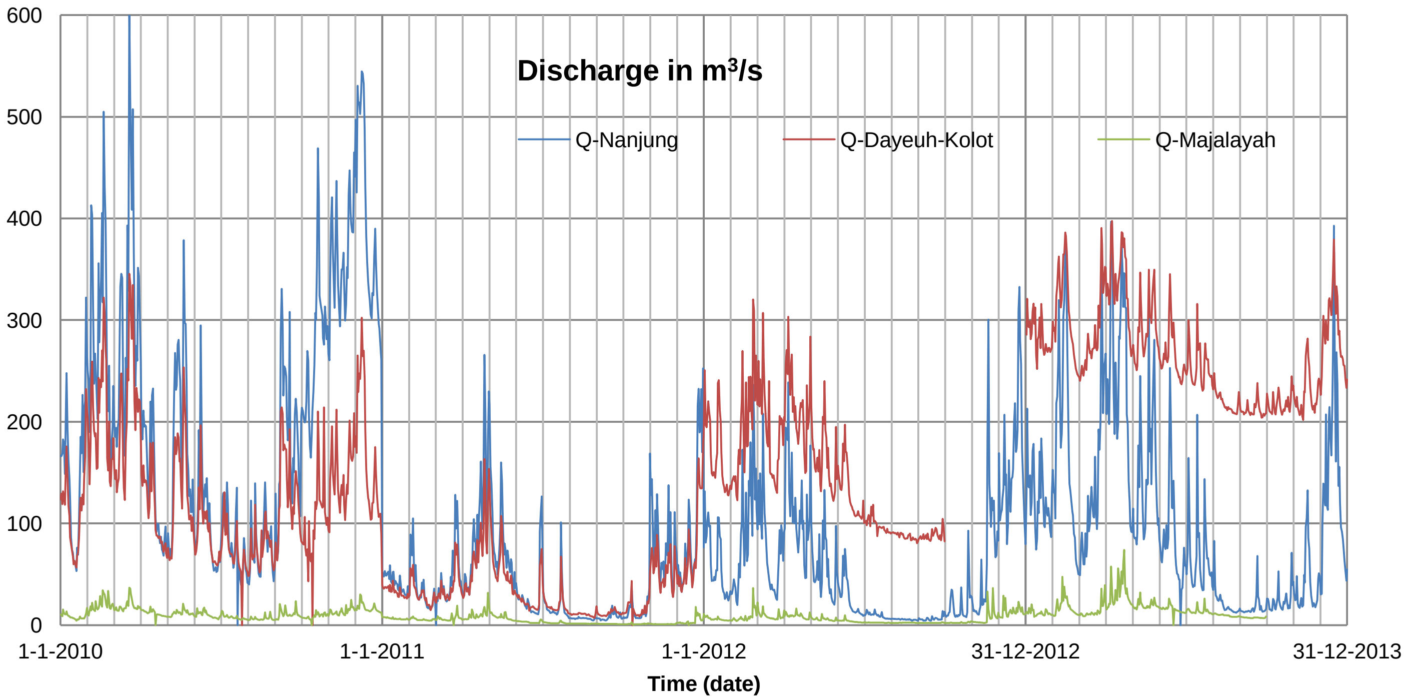


FIGURE 37 DISCHARGE DATA BBWSC AT NANJUNG, DAYEUH-KOLOT AND MAJALAYA

Observations:

- A drop in all three discharge series at 1-1-2011, probably due to correction of the rating curves
- From 1-1-2011 until the end of 2012, Q at Dayeuh-Kolot equals or even exceeds Q at Nanjung, this is impossible given the tributary structure of the Bandung Basin.
- A big ‘gap’ in the data from Dayeuh-Kolot, probably the equipment was broken. After the gap, discharges at this location are unrealistically high.

2. Comparison with water balance

The discharges of the figure above where compared with the data in the water balance report of the BBWSC (Pt Transka Dharma Konsultan, 2013), see Figure 5 in paragraph 0. Observations:
In the period 1-1-2010 until 1-1-2011, order of magnitude of $Q_{Nanjung}$ is unrealistic. In the rest of the graph, it might be correct.
The values for $Q_{Dayeuh\text{-}Kolot}$ are only realistic for the period 1-1-2011 to 1-1-2012.
The values for $Q_{Majalayah}$ have a realistic order of magnitude in the whole dataset.

3. Conclusion

One should be very careful when using the discharge data presented by the BBWSC for the period 2010-2013. The data at Dayeuh-Kolot is obviously wrong. The other data can only be used for comparing relative water heights, but this should only be done for values based on the same rating curve (Q,h-relation).

Annex III WATER QUALITY STANDARDS

The water quality standards are based on national governmental decrees 20/1990 and 82/2001, in which four types of water use are defined: (Syafrul, 2009)

1. Drinking water or any other use with the similar requirements
2. Service water, recreational, gardening or any other use with the similar requirements
3. Fresh water agricultural, farming and any other use with the similar requirements
4. Irrigation and any other use with the similar requirements

During the research, it did not become clear with which class the water quality of the Citarum should comply. After consideration with the West Java EPA, it was decided to use the norms of class 3: 'Fresh water for agricultural, farming etc.' Both national and provincial legislation is applicable on the Citarum River. Because the Citarum was designated as a 'strategic river basin with national importance', it was decided to use the national water quality standards, as written down in decree 82/2001. Interviewed stakeholders indicated that they also did not know which water class is valid for the Citarum River, they are waiting for the national government to clarify this issue.

TABLE 10 WATER QUALITY STANDARD PER WATER USE TYPE ACCORDING TO NATIONAL GOVERNMENT DECREE 82/2001

		water class						water class			
Parameter	**Unit**	**1**	**2**	**3**	**4**	**Parameter**	**Unit**	**1**	**2**	**3**	**4**
Physical						*Anorganic (continued)*					
Temperature	C	± 3	± 3	± 3	± 5	Cyanide	mg/l	0.02	0.02	0.02	
TDS	mg/l	1000	1000	1000	2000	Fluoride	mg/l	0.5	1.5	1.5	
TSS	mg/l	50	50	400	400	Nitrite as N	mg/l	0.06	0.06	0.06	
Anorganic						Sulphate	mg/l	400			
pH		6-9	6-9	6-9	5-9	Free Chlorine	mg/l	0.03	0.03	0.03	
BOD	mg/l	2	3	6	12	Sulfur as H2S	mg/l	0.002	0.002	0.002	
COD	mg/l	10	25	50	100	Microbiology					
DO	mg/l	6	4	3	0	Fecal coliform	Jml/100 ml	100	1000	2000	2000
Total Fosfat sbg P	mg/l	0.2	0.2	1	5	Total coliform	Jml/100 ml	1000	5000	10000	10000
NO 3 as N	mg/l	10	10	20	20	*Radioactive*					
NH3-N	mg/l	0.5				- Gross-A	Bq/l	0.1	0.1	0.1	0.1
Arsen	mg/l	0.05	1	1	1	- Gross-B	Bq/l	1	1	1	1
Kobalt	mg/l	0.2	0.2	0.2	0.2	*Organic chemical*					
Barium	mg/l	1				Minyak dan Lemak	µg/l	1000	1000	1000	
Boron	mg/l	1	1	1	1	Detergen[22]	µg/l	200	200	200	
Selenium	mg/l	0.01	0.05	0.05	0.05	Fenol[23]	µg/l	1	1	1	
Kadmium	mg/l	0.01	0.01	0.01	0.01	BHC	µg/l	210	210	210	
Chrome (VI)	mg/l	0.05	0.05	0.05	1	Aldrin / Dieldrin	µg/l	17			
Copper	mg/l	0.02	0.02	0.02	0.2	Chlordane	µg/l	3			
Iron	mg/l	0.3				DDT	µg/l	2	2	2	2
Lead	mg/l	0.03	0.03	0.03	1	Heptachlor (epoxide)[24]	µg/l	18			
Manganese	mg/l	0.1				Lindane	µg/l	56			
Mercury	mg/l	0.001	0.002	0.002	0.005	Methoxyclor	µg/l	35			
Zinc	mg/l	0.05	0.05	0.05	2	Endrin	µg/l	1	4	4	
Chloride	mg/l	600				Toxaphan	µg/l	5			

[22] Detergen sebagai MBAS

[23] Original text: Senyawa Fenol sebagai Fenol

[24] Original text: Heptachlor & heptachlor epoxide

Annex IV WATER QUALITY ASSESSMENT METHODS

By Environmental Ministerial Decree No. 115/2003, the government of Indonesia stated the use of two methods for evaluating the water quality status in a watershed: the Water Pollution Index (WPI) and Storage and Retrievel (STORET). In this annex, both methods are explained.

1. WPI method

According to Firdaus & Nakagoshi (2013) the WPI-method works as follows:

$$WPI_j = \sum_{i=1}^{n} \sqrt{\frac{\left(\frac{C_i}{L_{ij}}\right)_{max}^2 + \left(\frac{C_i}{L_{ij}}\right)_{avg}^2}{2}}$$

With C_i is the measured concentration of parameter i, where L_{ij} is the water quality standard for parameter i for water use j. The terms designated with ‘max’ and ‘avg’ are the maximum and average values.

TABLE 11 CLASSFICATION BASED ON WPI-SCORE

Score	Class
0.0 ≤ WPI ≤ 1.0	Not Polluted (NP)
1.0 < WPI ≤ 5.0	Lightly Polluted (LP)
5.0 < WPI ≤ 10.0	Moderately Polluted (MP)
WPI >10.0	Highly Polluted (HP)

In the retrieved datasets, it was never observed that the WPI method was used. The method was only found in the law, and the paper of Firdaus & Nakagoshi (2013).

2. STORET

In fact, the use of the name STORET is confusing. STORET is a database system developed by the Environmental Protection Agency of the United States of America, for STOrage and RETrieval of water quality data in the USA. The data from the STORET database in used to evaluate the water quality in the USA (Department of Environmental Protection Florida, 2011)

The evaluating system coupled to the STORET database is adopted by the Indonesian government, as an official water quality assessment tool. According to law PP 115/2003 the STORET procedure is as follows:

1. Collect time series of water quality and discharge data (the method requires more than one measurement, but the law does not specify a minimum amount of measurements)
2. Choose the right water quality standard (belonging to one of the four water use classes) and compare the observed parameter values with the standard.
3. If observed parameter matches with the standard, then give score of 0.
4. If the observed value > standard, give a score give a score:
    a. First determine the amount of parameters (n) used in the analysis (for n <10 and n ≥10, different standards apply)
    b. Than calculate the maximum, minimum and average values of the observed values
    c. Make a distinction between physical, chemical and biological parameters and assign score according to Table 12
5. Sum the individual scores of all parameters, and classify water according to Table 13

TABLE 12 ASSIGNMENT OF STORET SCORES

# param.	Value	Parameter		
n		Physical	Chemical	Biological
<10	Maximum	-1	-2	-3
	Minimum	-1	-2	-3
	Average	-3	-6	-9
≥10	Maximum	-2	-4	-6
	Minimum	-2	-4	-6
	Average	-6	-12	-18

TABLE 13 CLASS PER STORET SCORE

Score	Class
0.0	Not Polluted (NP)
-1.0 to -10.0	Lightly Polluted (LP)
-11.0 to -30.0	Moderately Polluted (MP)
≥ -30.0	Highly Polluted (HP)

Firdaus and Nakagoshi (2013) report that the STORET method is commonly used by governmental and non-governmental agencies. This was confirmed during the stakeholder meetings and by observing the available datasets.

While using the STORET method, a few important issues arise. First of all, the method is based on calculating the minimum, maximum and average values of a series of water quality measurements. However, within regulation 115/2003, nothing is stated about the minimum amount of measurements of which series should exist. In the datasets, it is observed that the STORET method is often used for assessing single measurements (West Java EPA), or a very small number of measurements (PusAir, 2013), instead of a series of measurements. When assessing single measurements, it was observed that only to one value a score was given. This makes the outcome of the score three times smaller than when minimum, maximum and average values are taken into account. Secondly, it should be noted that the outcome of the STORET score is strongly depending on the amount of parameters included in the analysis, for the total score is simply the sum of all individual parameter contributions, and there is only a difference between $n < 10$ and $n \geq 10$. It is only possible to compare different STORET scores, when exactly the same parameters are taken into account. Thirdly, it is important to note that the STORET method only indicates the fact that a parameter is not according to the standard, but it does not show how big the deviation from the standard is. On this aspect: the WPI-method performs better, for it takes into account the deviation of the standard. Finally, a problem of all types of standards is the assessment of the contributions of different parameters. For example: is it really three times worse if the fecal coliform concentration exceeds the standards compared to the amount of zinc of the water, as the STORET-method implies? There is no scientific base for such assumptions.

3. Conclusion

One should be very careful when using the STORET and WPI methods. The WPI-method should be preferred over the STORET-method, for it takes into account to which extent a certain parameter exceeds the standard. When using the method, it should be clearly stated what parameters where measured. Only assessments based on the same set of parameters can be mutually compared. The way the STORET method is currently used by the West Java EPA is inappropriate. However, even if the methods are executed correctly, the results still can veil, distort and misrepresent the real state of the water. Therefore, it would be could practice to publish the real outcome of the water quality measurements, instead of the interpreted STORET or WPI results.

Annex V OVERVIEW OF DATA

In Table 14, an overview of the obtained data is given. The table shows the number of sampling locations, number of measurements per locations and the saved format. Green cells have been converted by the author to csv files using Python scripts. Those csv files can be directly imported in a FEWS database.

TABLE 14 NUMBER OF SAMPLING LOCATIONS, MEASUREMENTS PER LOCATIONS AND AVAILABLE FORMAT CURRENTLY ON THE WATER AND HEALTH HARDDISK (FOLDER 3. OBSERVED CONCENTRATIONS)

	PJT-II			West Java EPA			PusAir			Kab Bandung EPA			Kota Bandung EPA		
year	loc	meas	format	loc	meas	format	loc	meas	format	loc	meas	format	loc	meas	format
1990							7	7	pdf						
1991							7	7	pdf						
1992							7	7	pdf						
1993	not obtained						7	7	pdf						
1994							7	7	pdf						
1995				not obtained			7	7	pdf						
1996							missing								
1997	26	12	xls												
1998	25	12	xls				7	4	pdf	not obtained					
1999	25	12	xls				7	2	pdf				not obtained		
2000	25	12	xls				7	7	pdf						
2001	25	12	xls	7	5	xls	7	4	pdf						
2002	25	12	xls	7	4	xls	7	4	pdf						
2003	25	12	xls	7	5	xls	7	2	pdf						
2004	25	12	xls	7	3	xls	7	2	pdf						
2005	17	12	xls	7	3	xls	7	2	pdf						
2006	34	12	xls	7	3	xls	7	3	pdf						
2007	20	12	csv	7	3	xls	7	2	pdf						
2008	20	12	csv	7	3	xls	7	3	pdf	70	1-3	xls			
2009	20	12	csv	7	3	xls	7	1	pdf	72	1-3	xls			
2010	20	12	csv	7	3	xls	8	1	csv	75	2-3	xls	32	1	xls
2011	20	12	csv	4	5	csv	8	1	csv	75	3	csv	32	1	xls
2012	20	12	csv	4	5	csv	8	2	csv	75	3	csv	32	3	xls
2013	20	12	csv	4	5	csv	8	2	csv	75	3	csv	32	3	xls
2014	20	12	csv	4	5	csv	not yet available								

Annex VI VALIDATION WATER QUALITY DATA

To validate the water quality data obtained from different sources, it is very helpful that there is some overlap in sampling sites, parameters and time span of the data. In this section, the overlapping data is mutually compared. While comparing the data, the following aspects should be kept in mind:

- Sampling and lab procedures might be different for different datasets
- The timing of the measurements among different stakeholders is different, it is therefore expected that there are major differences between observed values
- All organizations, except from PJT-II, tend to take their measurements in the dry season (Figure 11). Assumed that parameter values correlate with discharge, it is expected that the range of the PJT-II data is larger than the range of the other datasets, as it covers both the dry and the wet season.
- Although the obtained GIS-data suggests that the compared locations are almost similar, the actual sampling locations might be slightly different.

It was decided not to use a statistic test for comparing the data, because the number of samples in each set is very different and the sets cannot always be mutually compared for the reasons stated above.

First, the measurements of PJT-II, PusAir and the West Java EPA are compared for the upstream location Wangisagara (28.3 km from spring) and for the downstream location Nanjung (76.5 km from spring, entrance of reservoir). Both sampling sites are located in the main Citarum River. All the samples taken in the period 2010-2013 are taken into account.

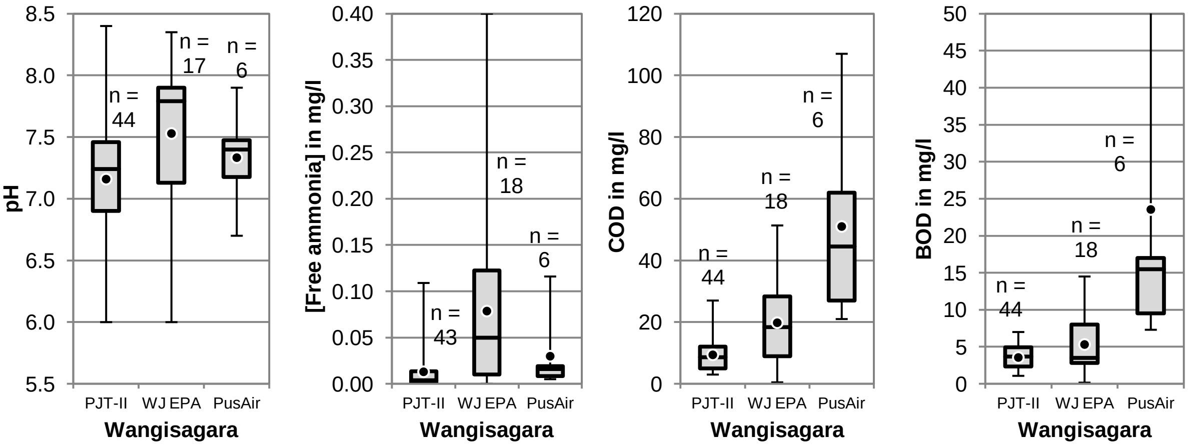


FIGURE 38 BOXPLOTS OF SAMPLING RESULTS OF PJT-II, WEST JAVA EPA AND PUSAIR AT WANGISAGARA IN THE PERIOD 2010-2013

In Figure 38, boxplots of 4 parameters can be seen. The first observation is that the average values of the West Java EPA and PusAir are higher than the averages of PJT-II. This is according to the expectations, for the West Java EPA and PusAir only sample during the dry season, in which the pollution is worse. However, surprisingly the observed free ammonia, COD and BOD concentrations are not within the range of PJT-II. One would expect that almost all West Java EPA and PusAir observations would be within this range, for the PJT-II sample set is much bigger, and spans the whole year. It is suspicious that the few samples taken by the West Java EPA and PusAir show much higher values than the continuous samples taken from PJT-II.

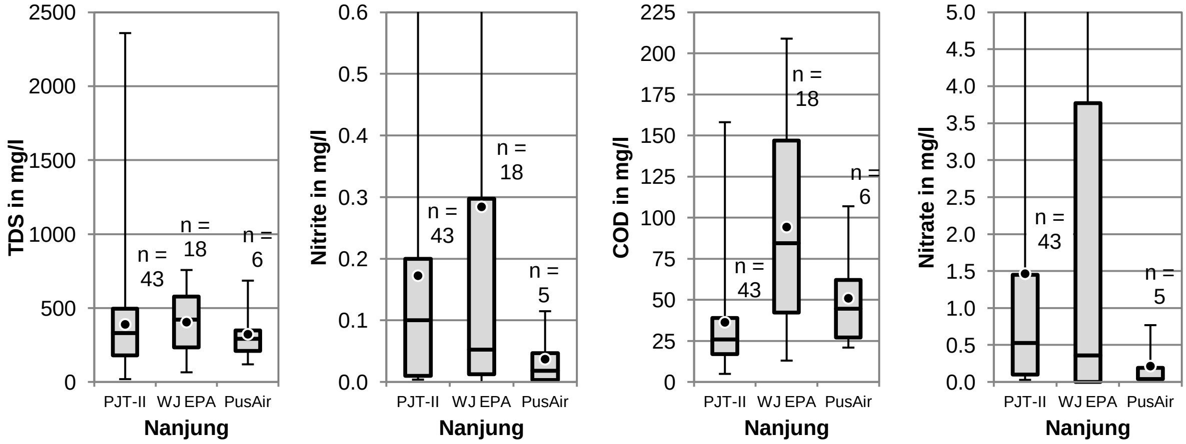


FIGURE 39 BOXPLOTS OF SAMPLING RESULTS OF PJT-II, WEST JAVA EPA AND PUSAIR AT NANJUNG IN THE PERIOD 2010-2013

In Figure 39 can be seen that the values observed by the West Java EPA are within the range of PJT-II, but are higher on average. This is accordance with the fact the West Java EPA is sampling less frequent, and only in the dry season. The nitrite and nitrate concentrations observed by PusAir are much lower than observed by PJT-II and the West Java EPA.

Comparing the third graph of Figure 38 with the third graph of Figure 39 shows that deviation of PusAir values is not consistent: in Wangisagara PusAir observed significantly higer values than the other organizations, but in Nanjung the PusAir observations fit well within the range of PJT-II and the West Java EPA.

Second, the data of PJT-II is compared with the data of Kabupaten Bandung EPA, at the locations Situ Cisanti (spring of Citarum) and the tributaries Citarik and Cikapundung (see Section 5.4). As Kabupaten Bandung EPA is only available for 2012 and 2013, the time span is limited to these years.

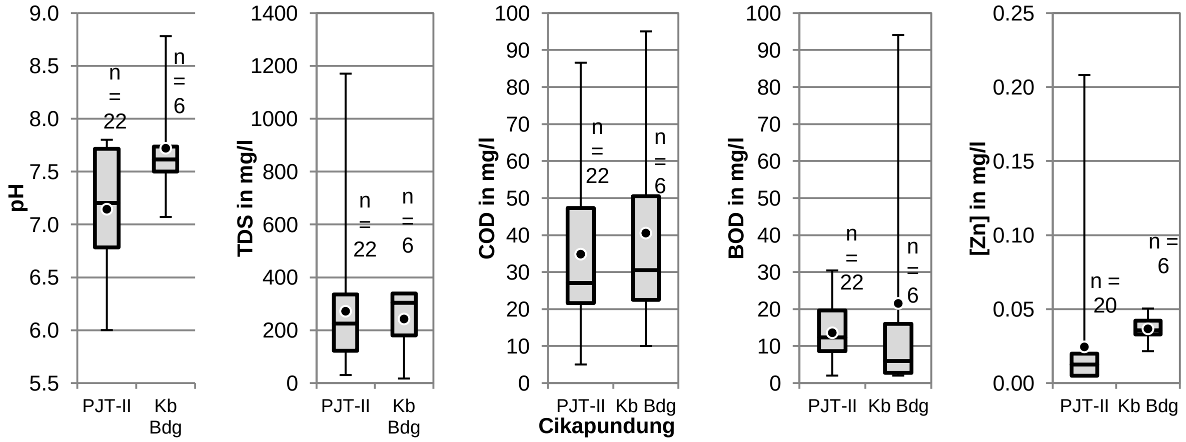


FIGURE 40 BOXPLOTS OF SAMPLING RESULTS OF PJT-II AND KABUPATEN BANDUNG EPA AT CIKAPUNDUNG (DAYEUH-KOLOT) IN THE PERIOD 2012-2013

In Figure 40 the sampling results of PJT-II and Kabupaten Bandung EPA in the Cikapundung are compared. It should be noted that the sample sizes are smaller compared then in Figure 38 and Figure 39, and the expected differences thus should be bigger. The observed TDS, COD, BOD an Zn concentrations match really well. The pH measured by Kabupaten Bandung EPA is higher than PJT-II. As the pH values are very easy to determine, and the observed values are all within reasonable range (between 6 and 9), this might be due to coincidence.

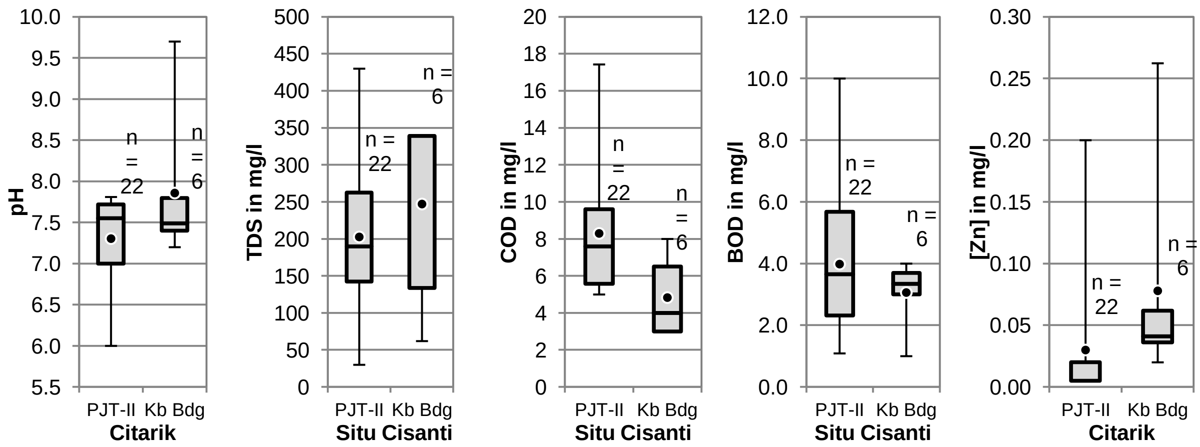


FIGURE 41 BOXPLOTS OF SAMPLING RESULTS OF PJT-II AND KABUPATEN BANDUNG EPA AT CITARIK AND SITU CISANTI IN THE PERIOD 2012-2013

Figure 41 it can be seen that again, the pH measured by Kabupaten Bandung EPA is higher than PJT-II. However, this observation is mainly based on one outlier. The observed COD concentrations by Kabupaten Bandung EPA are low, but because this deviation is not found for in the Cikapundung (Figure 40), this probably is coincidence.

Annex VII SENSOR SETTINGS

1. General issues

Three Leveloggers where used in the project. They are all of the type: Solinst® LTC Levelogger Junior model 3001, with ‘instrument type’ M10/C50, running on firmware version 2,005. An overview of the serial numbers and corresponding sensor locations is given in Table 15.

TABLE 15 SENSOR LOCATION WITH CORRESPONDING SERIAL NUMBER (COORDINATES IN DECIMAL DEGREES)

Location name	Serial number	Latitude	Longitude
Majalayah_1	1070978	-7.046429	107.738468
Majalayah_2	1070979	-7.031393	107.727116
Majalayah_3	1070983	-7.029633	107.732200

The used Levelogger device can only take linear samples: with a constant frequency. The sampling rate can be any number between 0.125 seconds and 99 hours. At a sampling rate of 5 seconds, the battery will be depleted in 2.5 months. At a rate of 1 reading per 5 minutes, battery life is long enough: 5 years. Finally, an interval of 10 minutes was chosen. At this frequency of 6 measurements an hour, the saving capacity of 16,000 measurements will be used in 111 days, which is almost 16 weeks. This time is enough to store all the data during the period of the B-thesis.

2. Calibration procedure and results

The calibration procedure was done following the steps described in the Levelogger manual. The Leveloggers were rinsed in demiwater, and then rinsed in the calibration solution. Special attention had to be paid to the air bubbles that clang to the sensor opening; those could only be removed by frequent tipping of the sensor to the measuring jug. The calibration was done at temperatures between 26.6 and 27.2ºC, within the acceptable range of 20 to 30ºC. During the calibration procedure, the following error (Figure 42) occurred while calibrating the first and the third sensor at the 5,000 µS/cm:

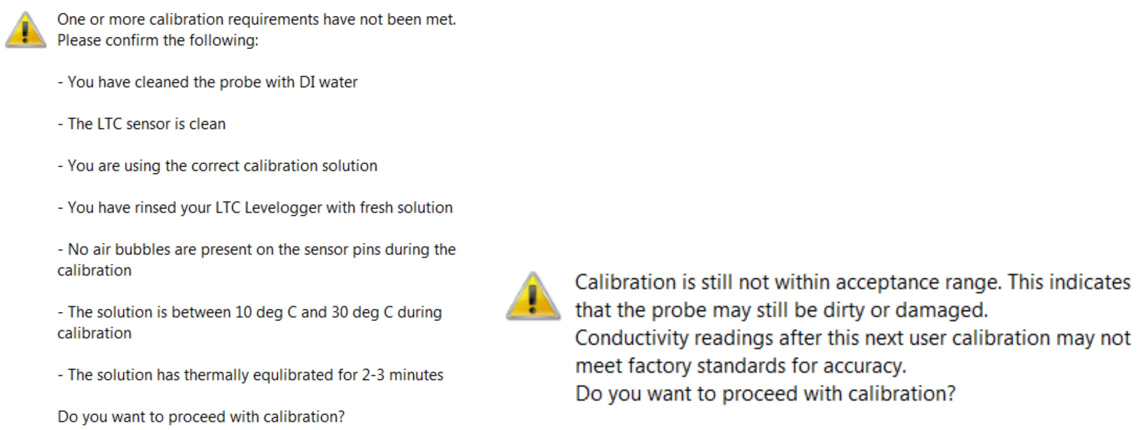


FIGURE 42 POP-UP WINDOWS INDICATING ERRORS AT THE SECOND CALIBRATION SOLUTION

For both errors occurred at different sensors using the 5,000 µS/cm solution, and everything went fine while using the 1,413 and the 12,880 µS/cm, the most likely explanation for the error is inaccurate preparation of the 5,000 solution. The solution was prepared by someone of ITB’s laboratory. It was decided to use the calibration results anyway, for the calibration curve was based on three solutions, and not only on the wrong one. Moreover and no better solutions were available, so we had no choice.

After calibration, a ten-minute experiment was done in a bucket, during which all three sensors where exposed to the same circumstances. The used sampling interval was 10 seconds. The graph can be seen in Figure 43. The temperature measurements of Levelogger 1 and 2 show exactly the same values. The temperature of Levelogger 3 is following the same pattern, but the curve seems to be somewhat delayed. The conductivity patterns of Levelogger 1 and 2 are very similar, but the values of 2 are consequently slightly higher than the values of 1. The pattern of logger 3 is deviating again: it is strongly oscillating before stabilizing at values slightly lower than logger 2.

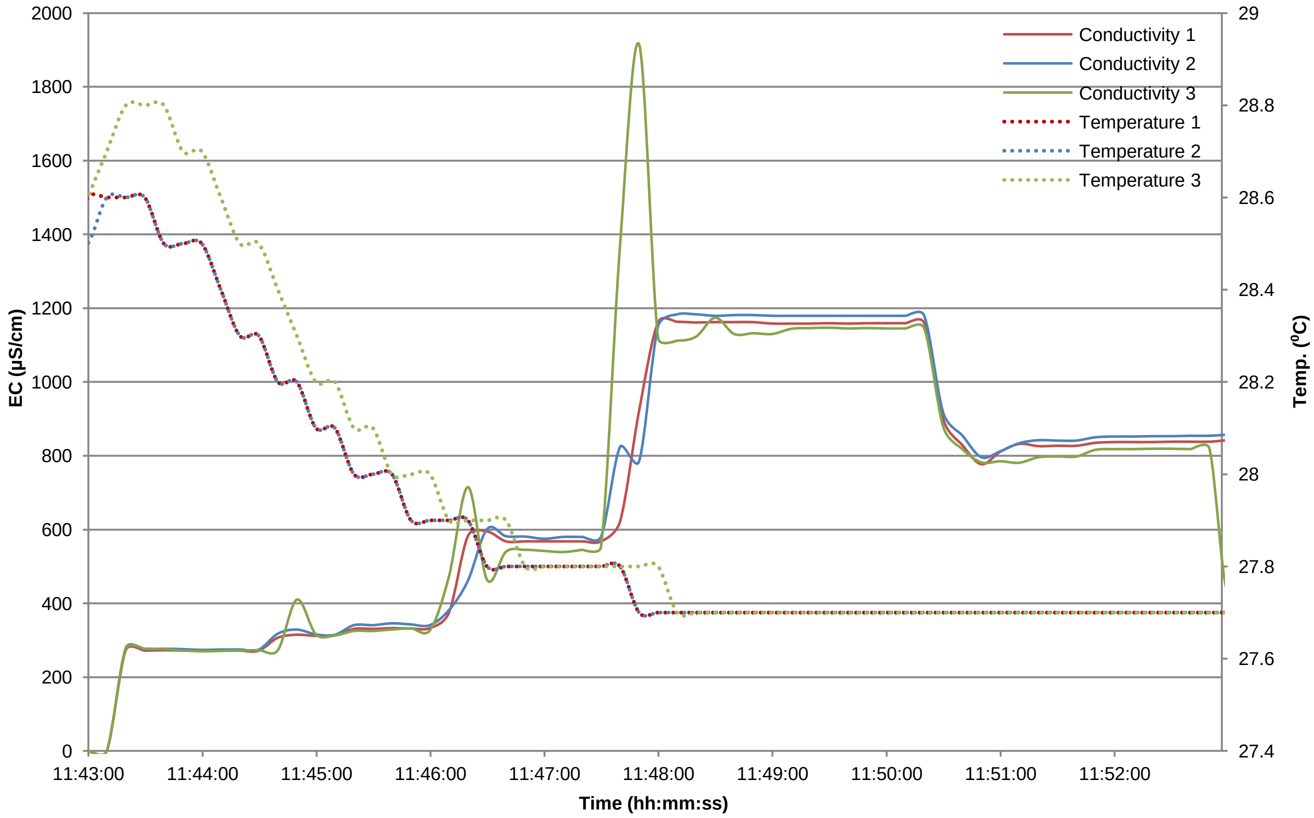


FIGURE 43 SENSOR BEHAVIOUR AFTER CALIBRATION

It was hard to validate water height measurements, for the used bucket was only very shallow and the sensor was taken out of the water several times. The observed values can be seen in Figure 44.

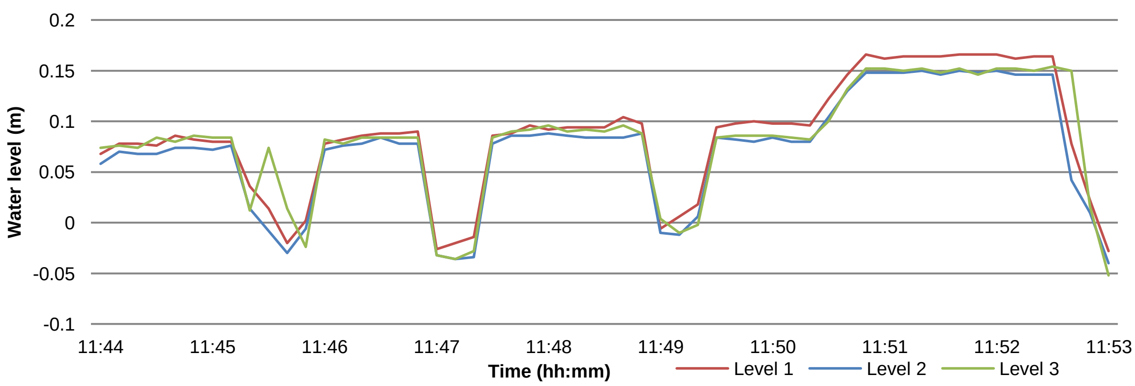


FIGURE 44 WATER LEVEL SENSOR BEHAVIOUR

3. Conclusion

The temperature measurements of the three devices are very similar, and in accordance with the specifications very accurate. The conductivity measurements are less accurate, due to a not well prepared calibration solution. However, the three conductivity sensors show a very similar pattern during the calibration test, only sensor three is showing some oscillating, probably due to the very small time interval. With the time interval used during the field measurements, this effect is not observable anymore.

Annex VIII DETAILS SENSOR LOCATIONS

1. Photos sensor locations

FIGURE 45 FIRST LOCATION OF SENSOR 1: 2/3/2015 - 7/4/2015 (PHOTO 2/3/2015, BY LUFIANDI)

FIGURE 46 FINAL LOCATION SENSOR 1: 7/4/2015 – 22/5/2015 (PHOTO 22/5/2015)


FIGURE 47 LOCATION SENSOR 2 (PHOTO BY RIGT VENEMA, 2/3/2015)


FIGURE 48 LOCATION SENSOR 3 (22/5/2015)

FIGURE 49 POLLUTION OF SENSOR 1 (22/5/2015)

FIGURE 50 POLLUTION OF SENSOR 2 (22/5/2015)

FIGURE 51 POLLUTION OF SENSOR 3 (22/5/2015)

2. Cross-sections and discharge estimations

In Figure 52 an overview of the (simplified) cross sections is given. For sensor 1, only the cross-section of the final location is given.

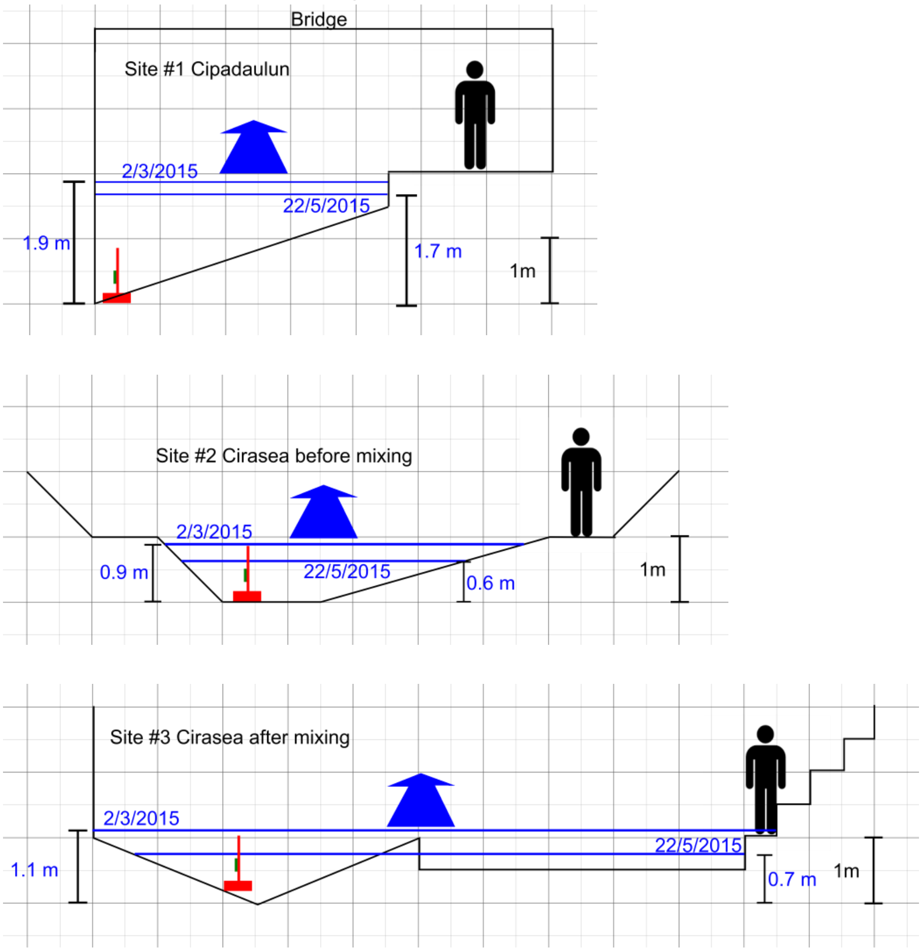


FIGURE 52 SIMPLIFIED CROSS-SECTIONS OF THE THREE SENSOR LOCATIONS

During field work on 2/3/2015 and 22/5/2015, the flow velocity, cross section and water level was determined. This data is used to estimate the discharge of the rivers, using equation 3:

$$Q = A_{cross\ section} * v_{surface} * f_1 * f_2 \qquad \text{Equation 3}$$

With f_1 being the surface velocity factor, 0.7 according to Shaw *et al.* (2011, p. 112), and f_2 a factor to correct for the differences in observed surface velocity at site 3 in the two different sections of the cross section, see Figure 52. The results of the calculations are presented in Table 16.

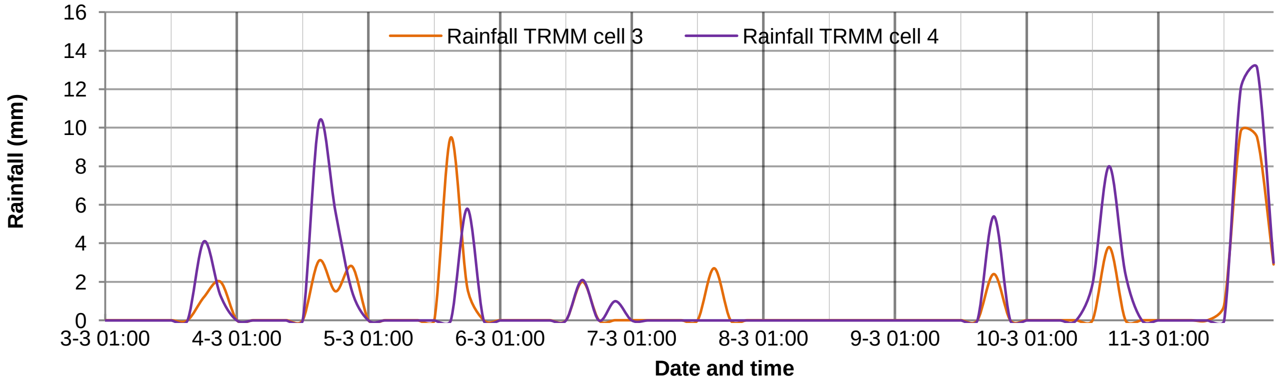
TABLE 16 DISCHARGE ESTIMATION

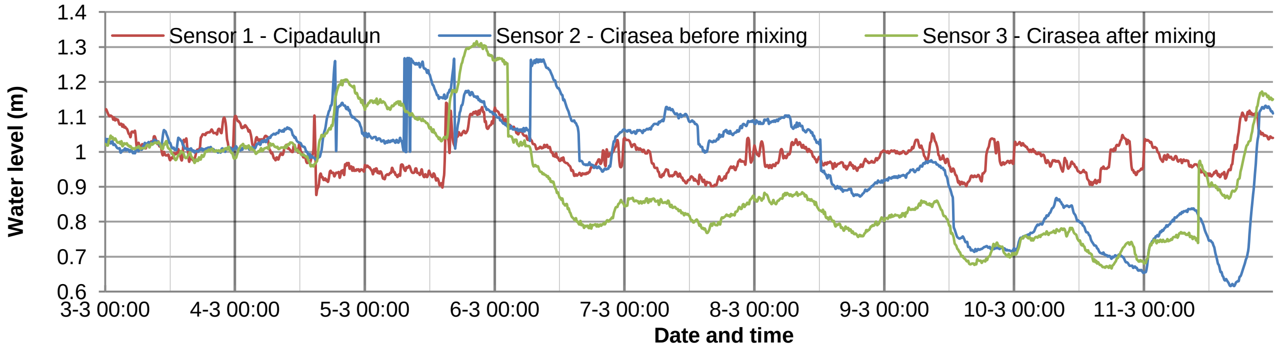
		Site 1	**Site 2**	**Site 3**	**Site 1**	**Site 2**	**Site 3**
Date *Time*	dd-mm-yy hh:mm	2-3-2015 12:30	2-3-2015 16:30	2-3-2015 15:00	22-5-2015 17:00	22-5-2015 14:00	22-5-2015 15:30
$Area_{cross\ section}$	m^2	4.3	3.2	5.3	4.3	1.8	3.4
Surface velocity	m/s	0.33	0.61	0.9	.26	.17	0.60
Surface velocity factor	-	0.7	0.7	0.7	0.7	0.7	0.7
Correction factor	-	1	1	0.8	1	1	0.9
Q	m^3/s	1.0	1.3	2.6	0.8	0.2	1.3

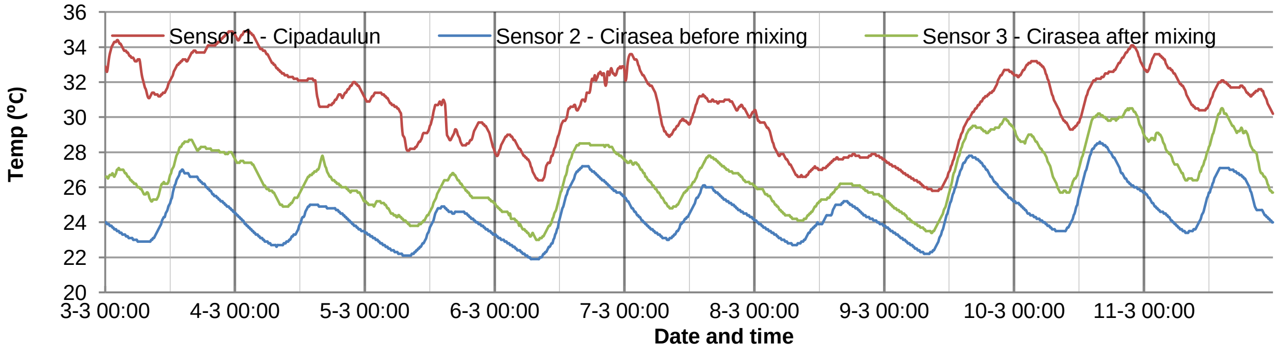
Annex IX ALL LEVELOGGER DATA

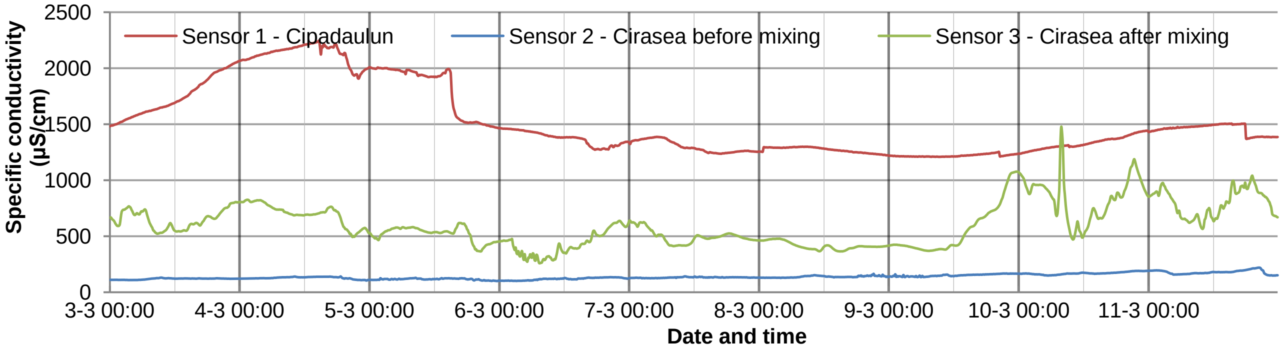
In this Annex, an overview of all collected Levelogger data is given, for each period between two field visits. The TRMM 3-hourly rainfall data is added as a reference.

1. Period 1: 2/3/2015 – 13/3/2015

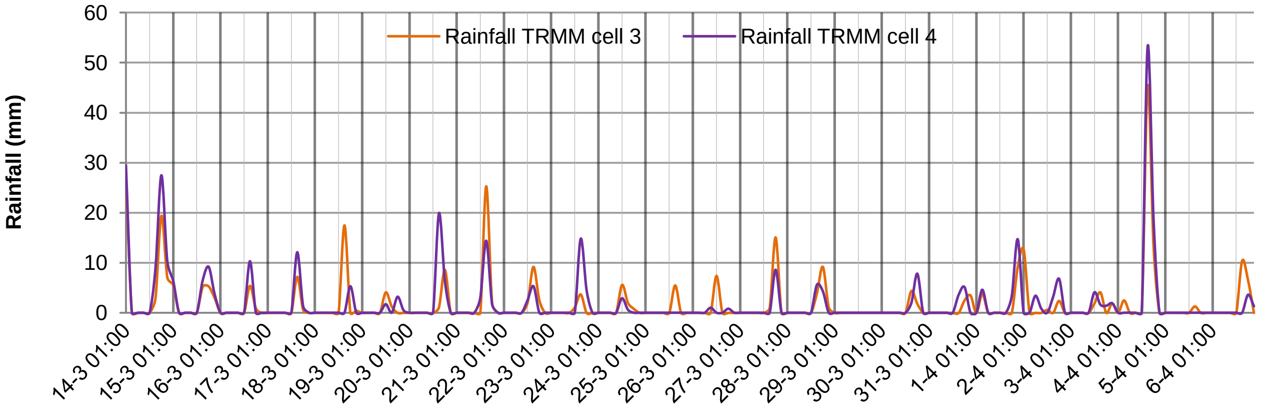


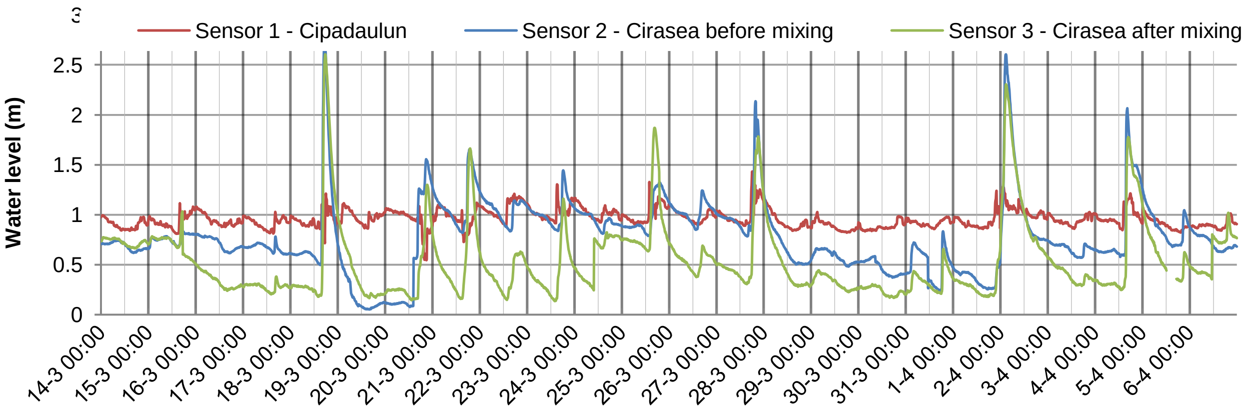


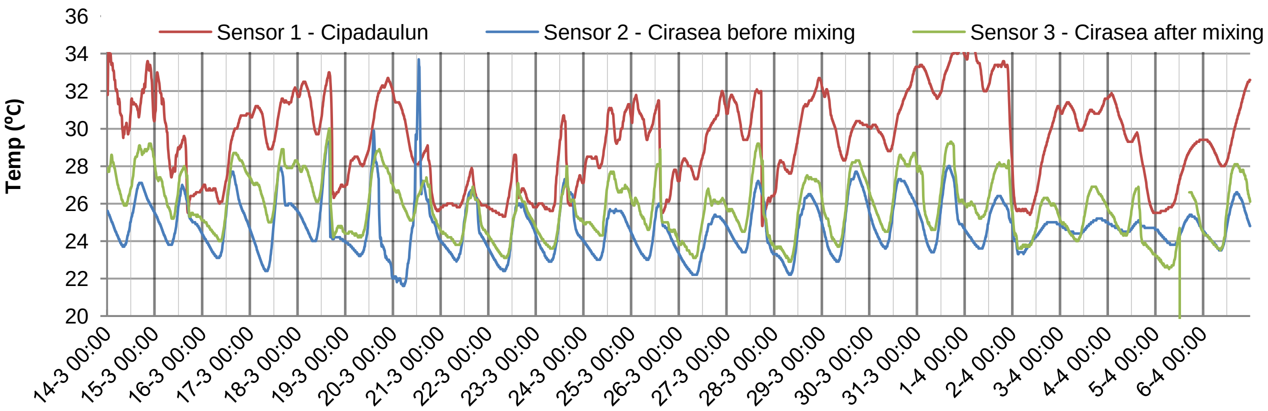


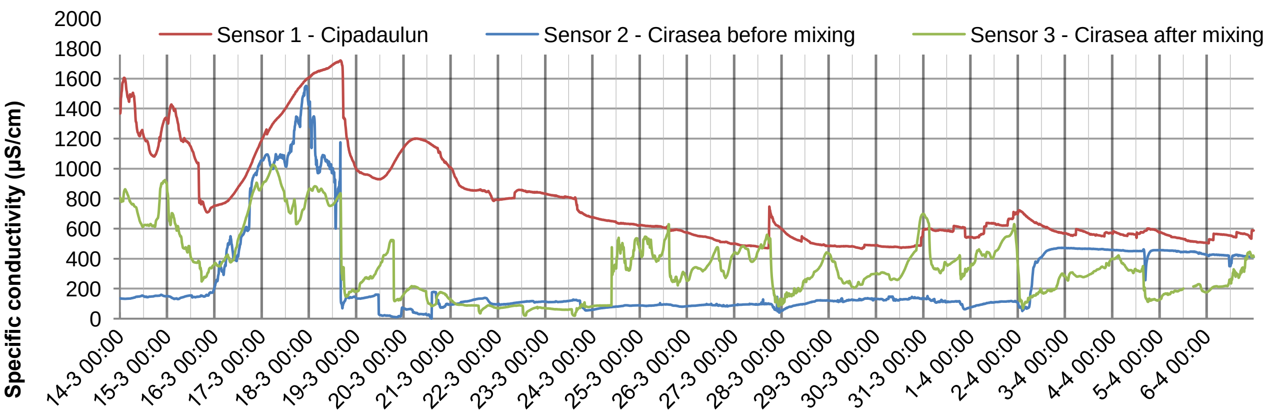


2. Period 2: 13/3/2015- 7/4/2015

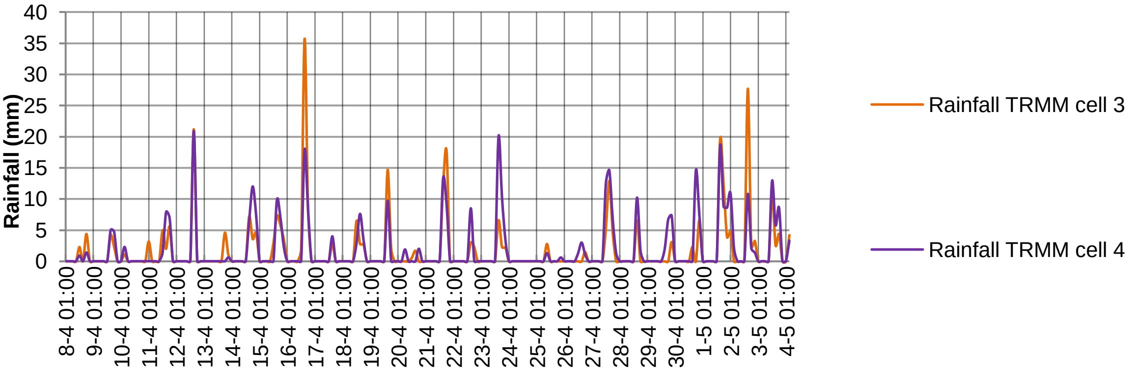


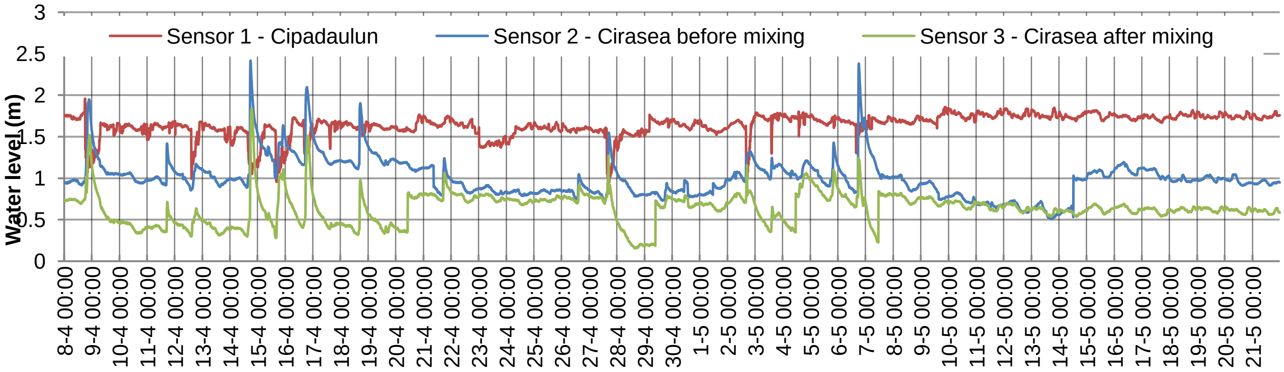


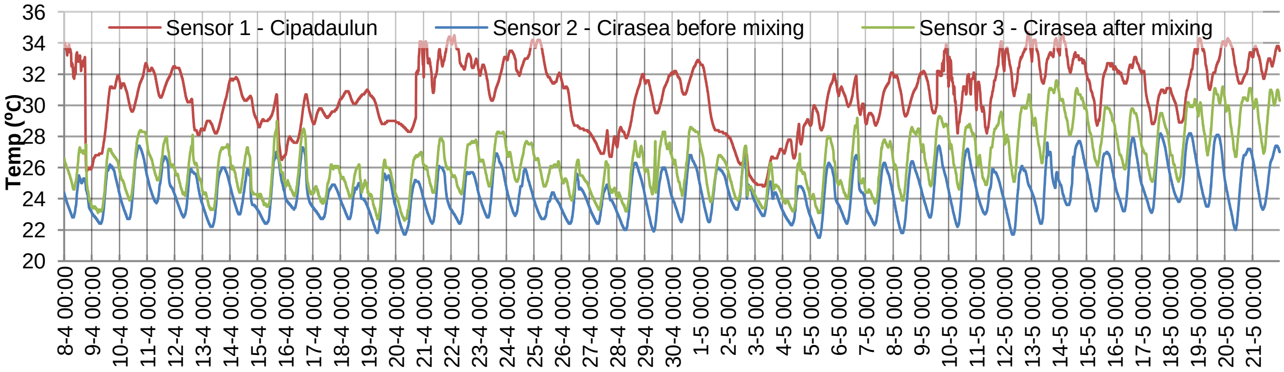


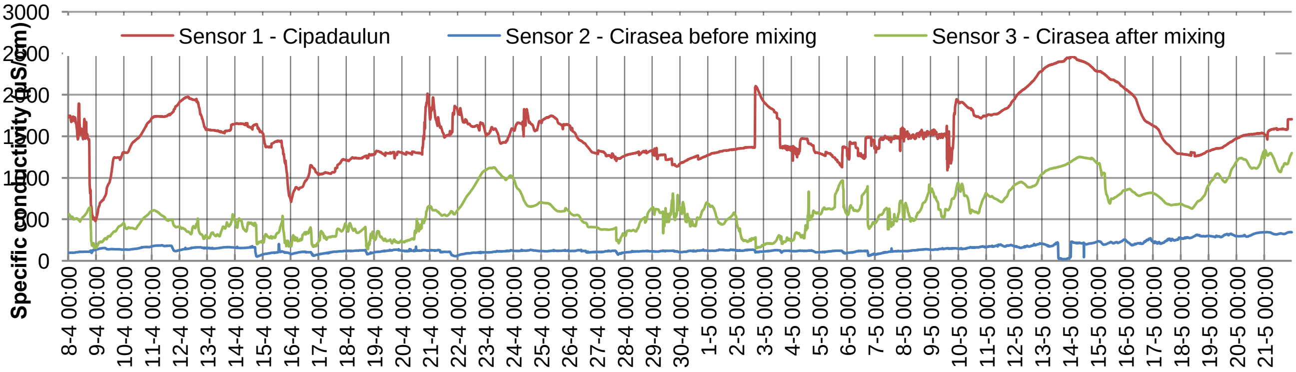


3. Period 3: 7/4/2015 – 22/5/2015









4. Motivation of statements

In this section, the statements of section 4.5 are motivated with examples from the data:

1. *There is a strong relation between the rainfall data from the TRMM-satellite and the observed peaks in water level data.* Example period 1: the rainfall peaks between 4/3 and 6/3 coincide with a sudden increase in water level from all the three sensors. Another example can be found in the end of the same period. For another long series of nice examples, see how the green peaks of sensor 3 match with the TRMM-rainfall in period 2.

2. *A dry period according to TRMM-rainfall data correlates with a gradual decrease in water level of the Cirasea before mixing (location 2)*. This is most clearly seen in period 1: 6/3 until 11/3.

3. *A dry period according to TRMM-rainfall data correlates with a gradual increase in temperature of the Cirasea before mixing and after mixing.* Two nice examples of this can be found in the available data: period 2: 29/3 until 1/4 and period 3: 5/5 until 21/5.

4. *Intensive rainfall is leading to a decrease in conductivity and temperature of the Cipadaulun, but does not influence the conductivity of the Cirasea*. A nice example of the decrease in conductivity can be seen during the rainfall between 4/3 12:00 and 7/3 00:00 in period 1. Surprisingly, the dry period which follows this rainfall is not coupled with an increase in conductivity. However, one should keep in mind that the conductivity data gets less reliable as the days after cleaning pass by. Therefore, the observed trend cannot be denied based on older EC-measurement in which the trend is not observed. Two other examples of the first part of the statement are found in period 3: at 9/4 00:00 and at 16/4 00:00. The decrease in temperature of the Cipadaulun as a result of rainfall cannot be observed in period 1, but is a high frequency event during the daily showers in period 2.

Annex X BOXPLOTS UNSELECTED PARAMETERS AT LOCATIONS NEAR LEVELOGGERS SENSORS

In section 5.2, the data obtained with the Levelogger device was compared with the observations of Kabupaten Bandung EPA. However, this was only done for a small selection of parameters. For completeness, the rest of the box plots is shown in this annex.

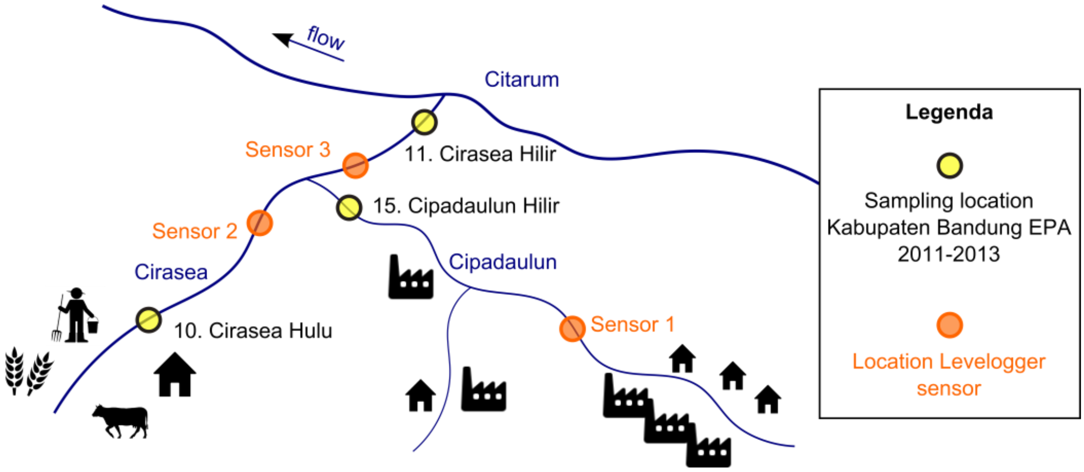


FIGURE 53 SCHEMATIC OVERVIEW OF LANDUSE, LOCATIONS OF LEVELOGGER SENSORS AND SAMPLING

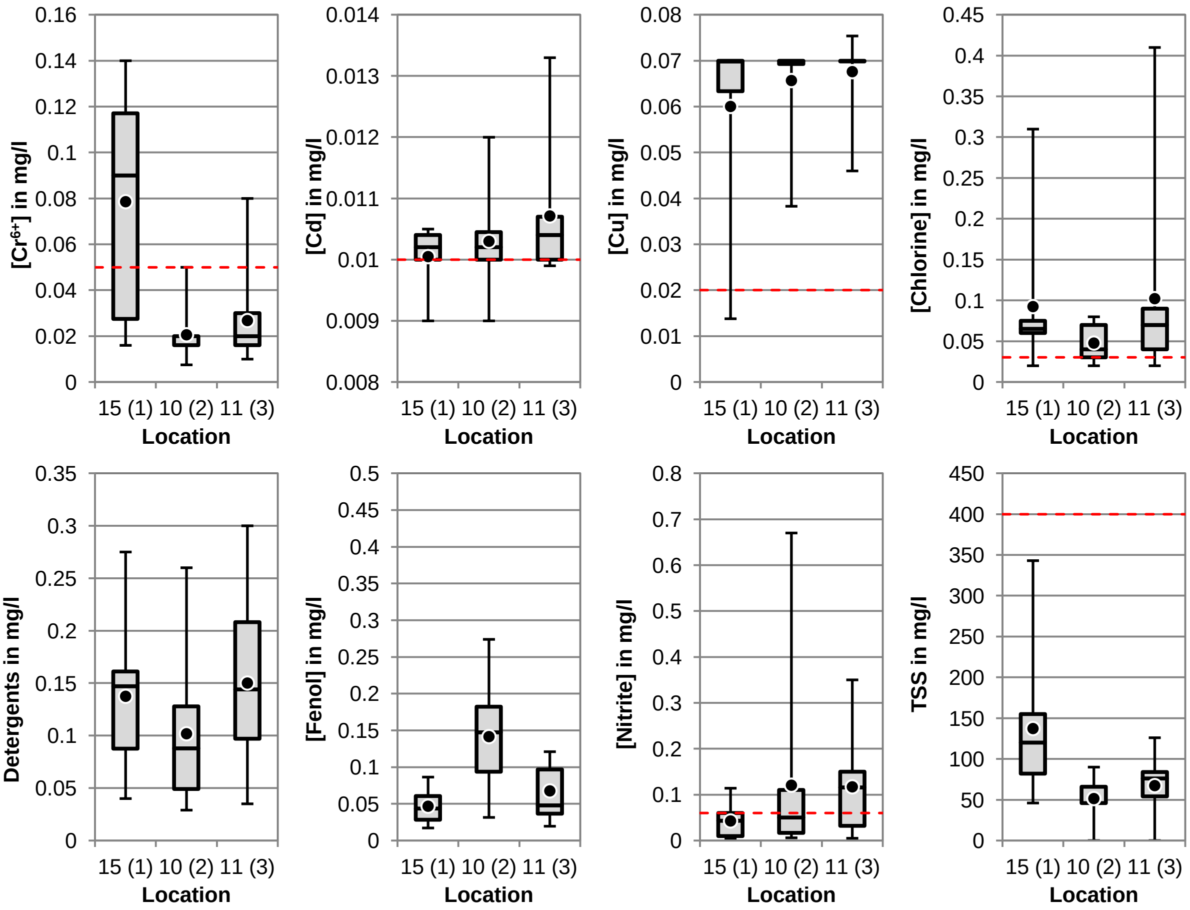
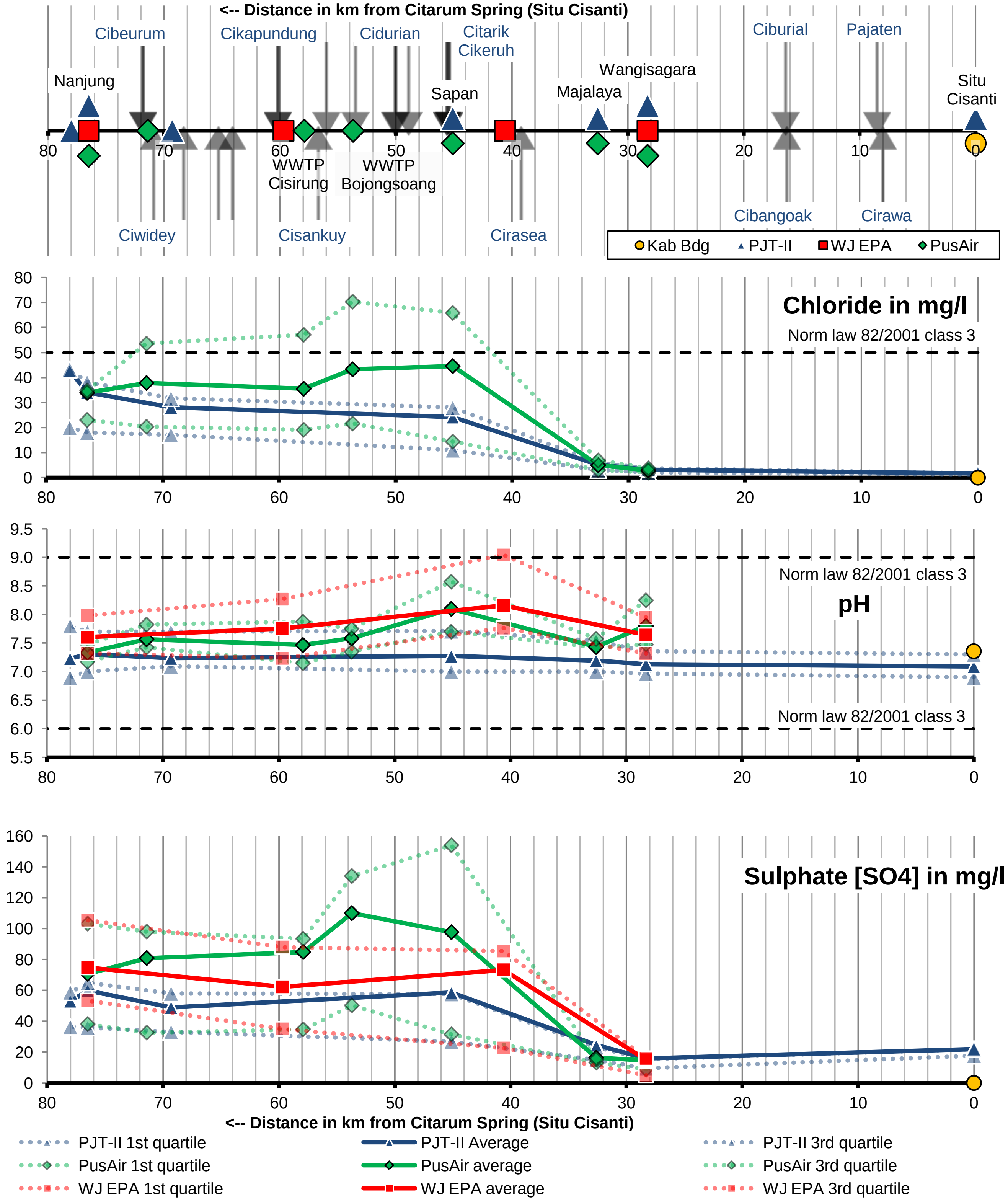
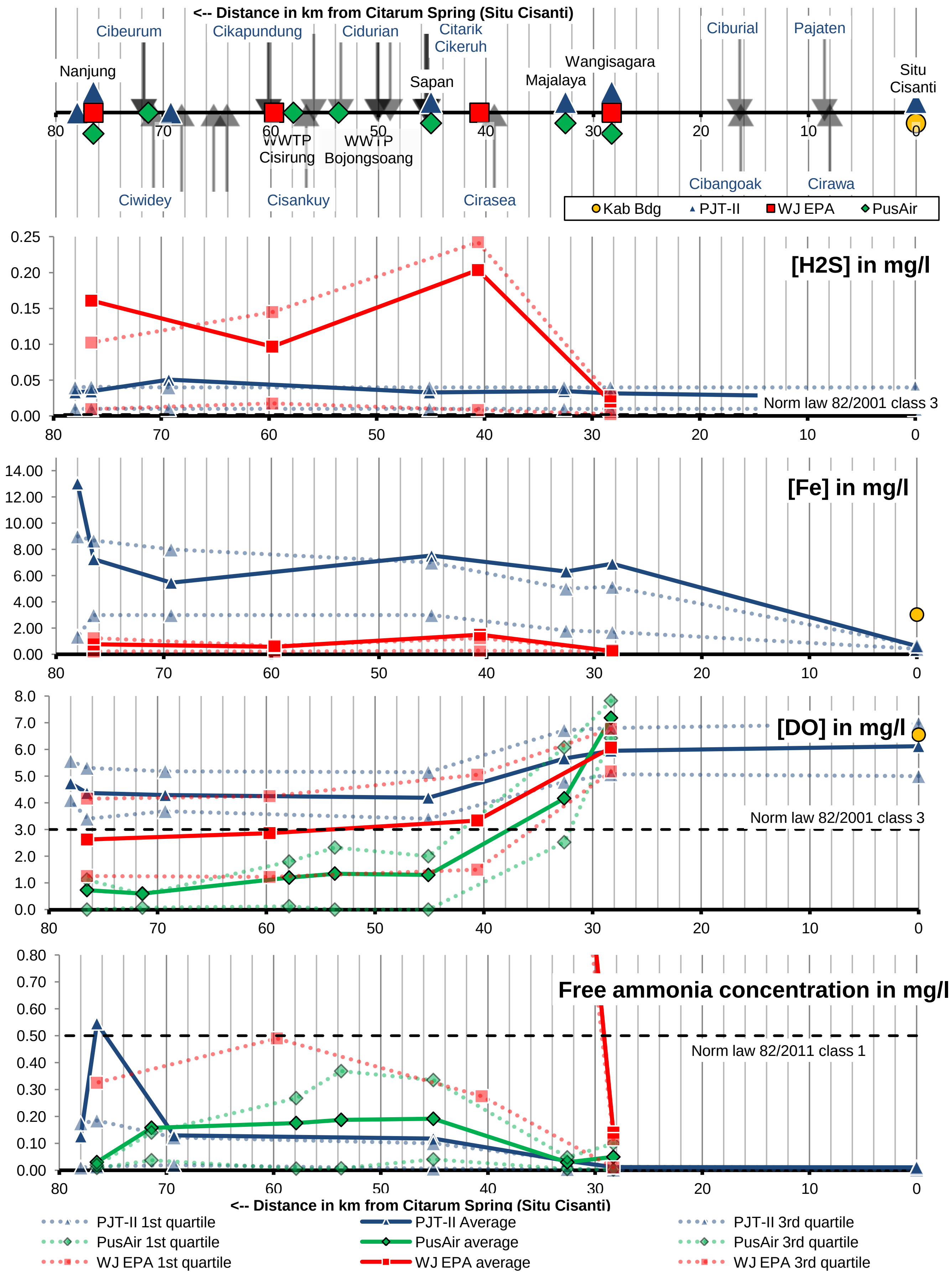


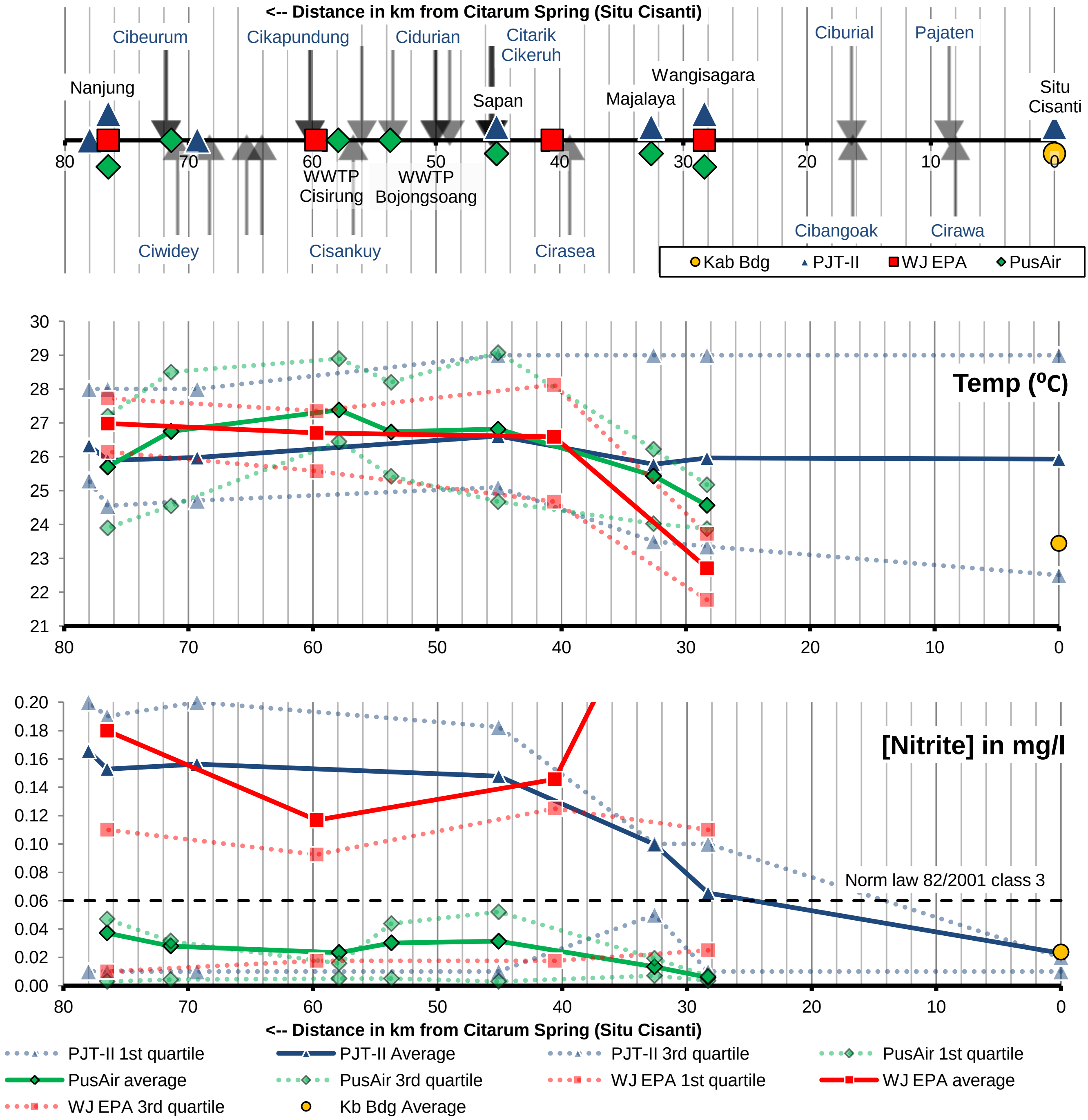
FIGURE 54 ADDITIONAL BOXPLOTS WITH OBSERVED CONCENTRATIONS BY KABUPATEN BANDUNG NEAR THE LEVELOGGER SENSOR LOCATIONS. DASHED RED LINES ARE INDICATING WATER QUALITY NORMS ACCORDING TO LAW 7/2001 WATER CLASS 3.

Annex XI UPSTREAM-DOWNSTREAM DEVELOPMENT

In this annex, the upstream-downstream graphs for parameters not included in section 5.4 are shown.




<-- Distance in km from Citarum Spring (Situ Cisanti)
Cibeurum
Cikapundung
Cidurian
Citarik
Cikeruh
Ciburial
Pajaten
Nanjung
Sapan
Wangisagara
Majalaya
Situ Cisanti
WWTP Cisirung
WWTP Bojongsoang
Cibangoak
Cirawa
Ciwidey
Cisankuy
Cirasea
Kab Bdg
PJT-II
WJ EPA
PusAir
[H2S] in mg/l
Norm law 82/2001 class 3
[Fe] in mg/l
[DO] in mg/l
Norm law 82/2001 class 3
Free ammonia concentration in mg/l
Norm law 82/2011 class 1
<-- Distance in km from Citarum Spring (Situ Cisanti)
PJT-II 1st quartile
PJT-II Average
PJT-II 3rd quartile
PusAir 1st quartile
PusAir average
PusAir 3rd quartile
WJ EPA 1st quartile
WJ EPA average
WJ EPA 3rd quartile



<-- Distance in km from Citarum Spring (Situ Cisanti)
Cibeurum
Cikapundung
Cidurian
Citarik
Cikeruh
Ciburial
Pajaten
Nanjung
Sapan
Wangisagara
Majalaya
Situ Cisanti
WWTP Cisirung
WWTP Bojongsoang
Cibangoak
Cirawa
Ciwidey
Cisankuy
Cirasea
Kab Bdg
PJT-II
WJ EPA
PusAir
Temp (°C)
[Nitrite] in mg/l
Norm law 82/2001 class 3
<-- Distance in km from Citarum Spring (Situ Cisanti)
PJT-II 1st quartile
PJT-II Average
PJT-II 3rd quartile
PusAir 1st quartile
PusAir average
PusAir 3rd quartile
WJ EPA 1st quartile
WJ EPA average
WJ EPA 3rd quartile
Kb Bdg Average

Annex XII TRIBUTARY DATA

In this annex, graphs displaying the water quality in the tributaries described in section 5.4 can be found.

1. Situ Cisanti (0 km) to Wangisagara (28.3 km)

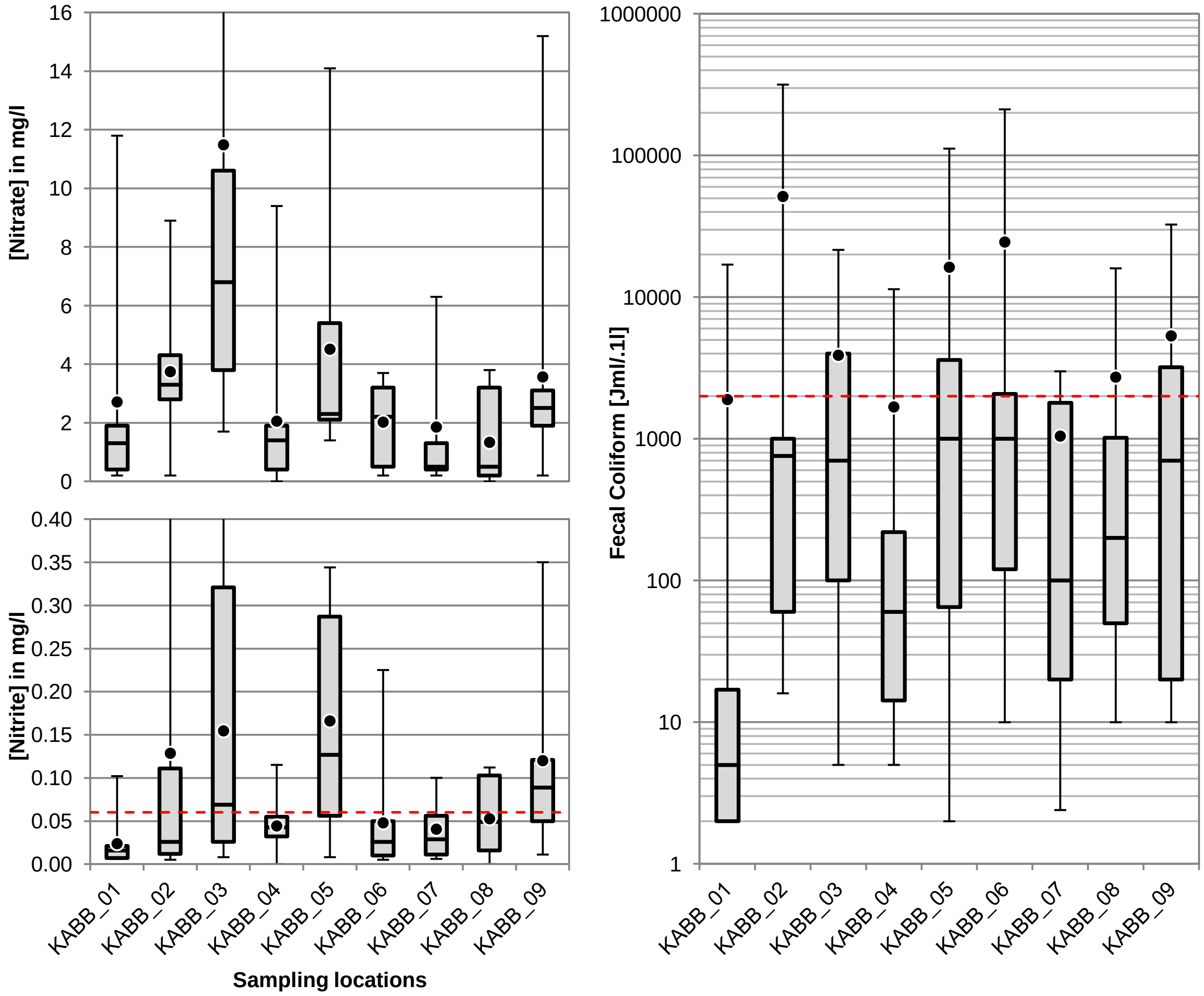
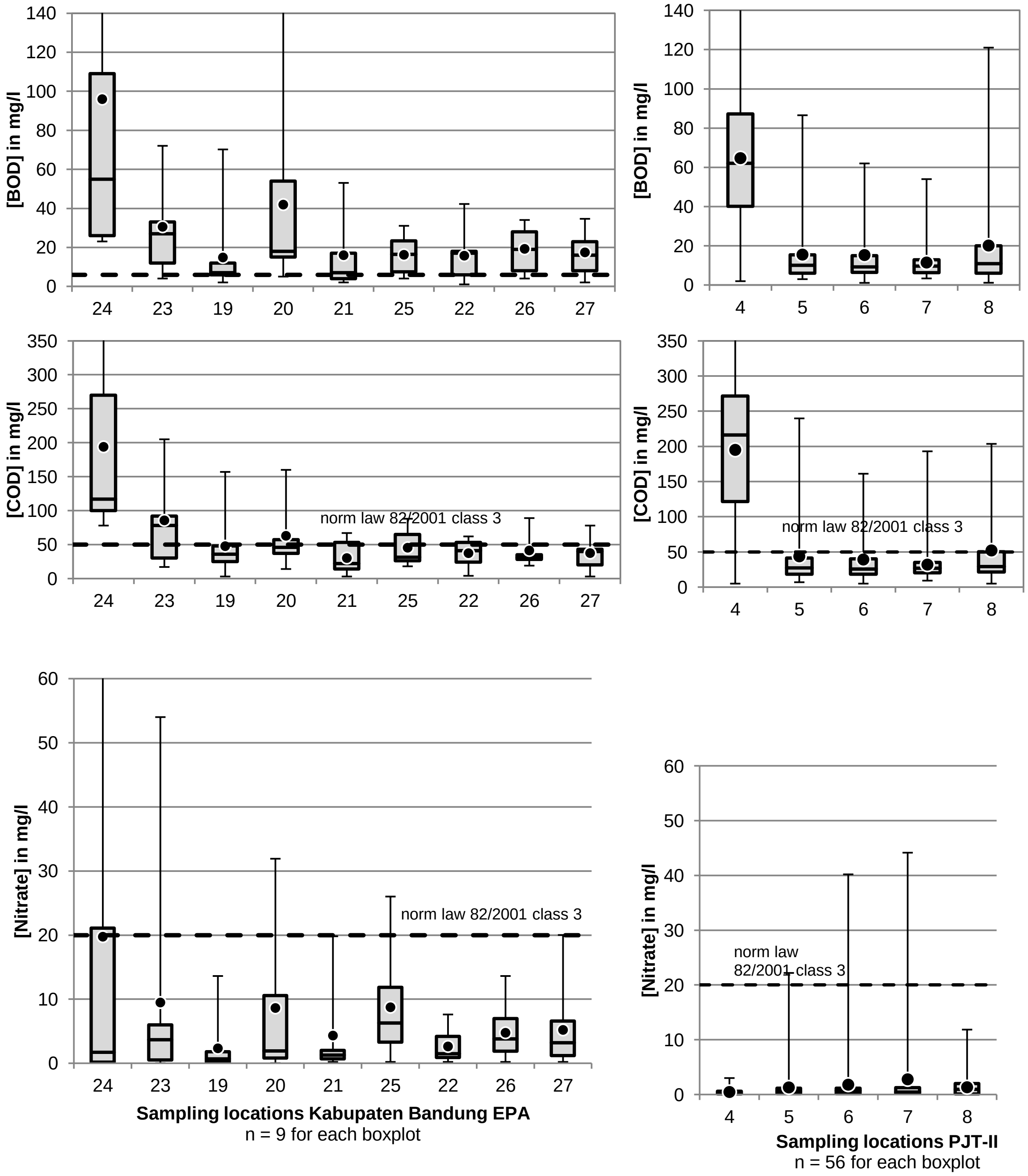


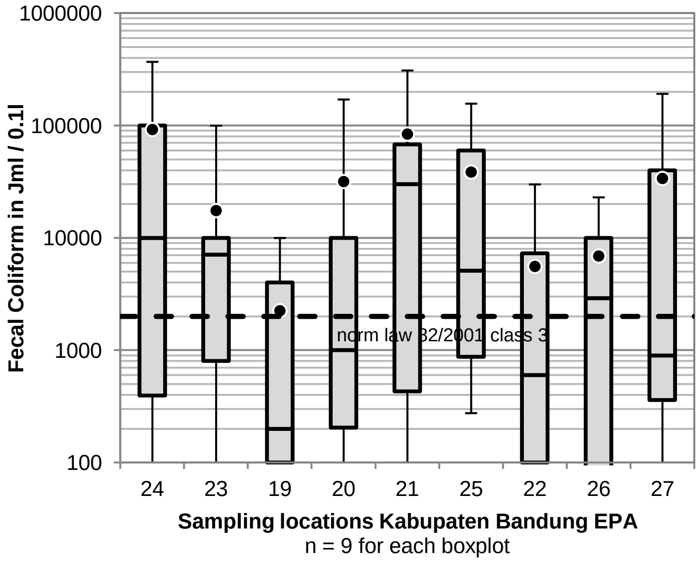
FIGURE 55 STOCKBREEDING RELATED PARAMETERS IN TRIBUTARIES OF THE CITARUM BETWEEN SITU CISANTI AND WANGISAGARA

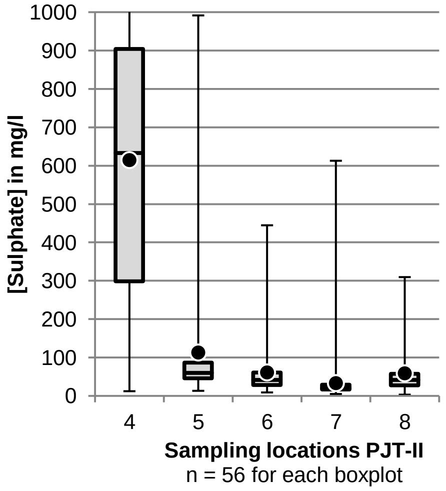
2. From Wangisagara (28.3 km) to Sapan (45.6 km): Majalaya industry cluster

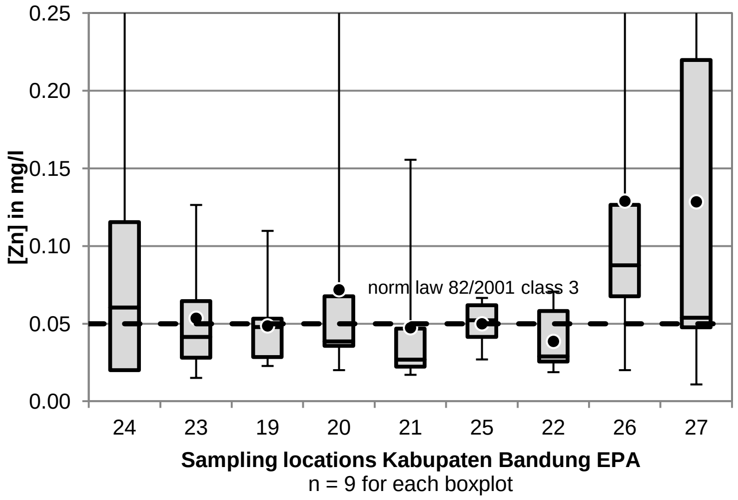
No graphs to show for this area. For the water quality in the Cirasea, see section 5.2.

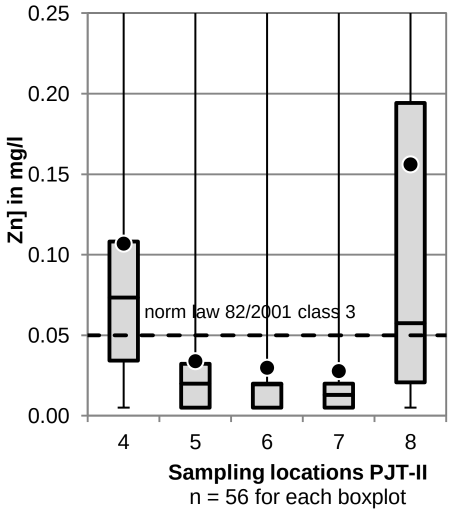
3. Sapan area (45.6 km to 50 km)



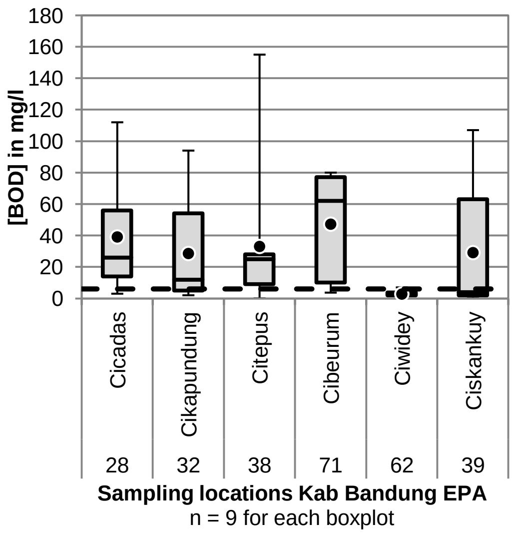


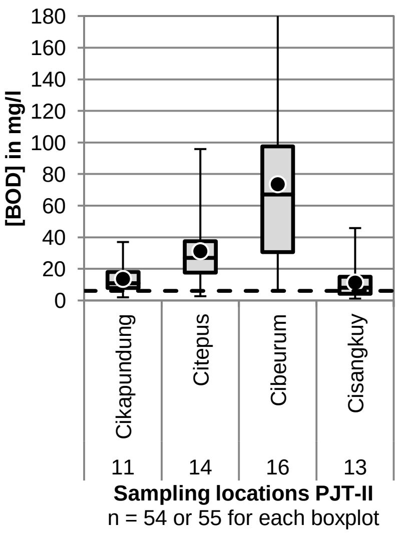


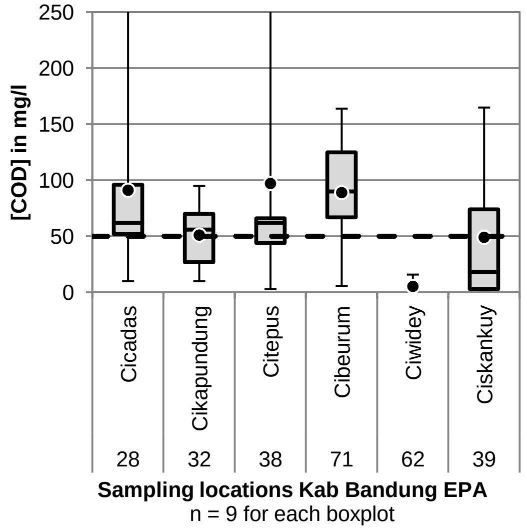


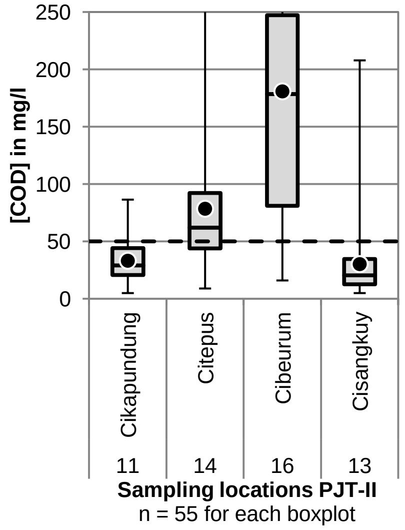


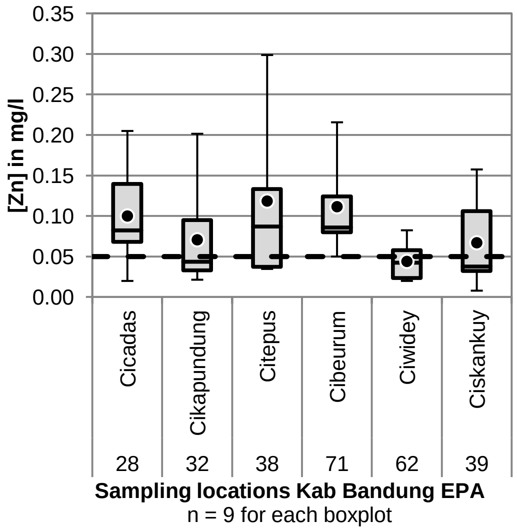
4. From Sapan (50 km) to Saguling reservoir (76.5 km)

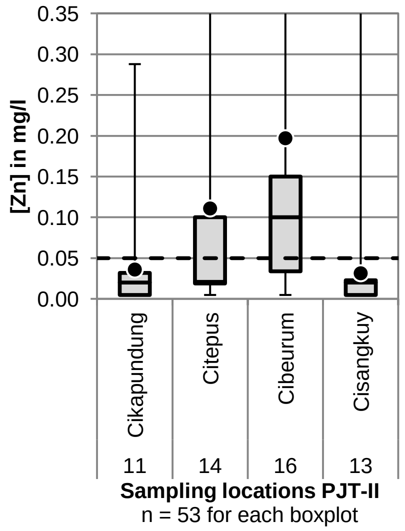


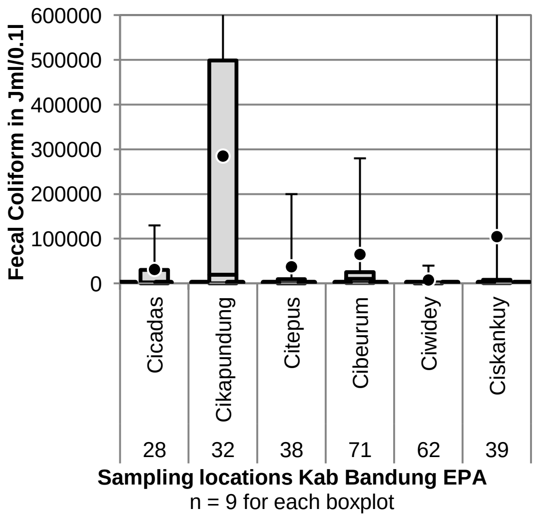


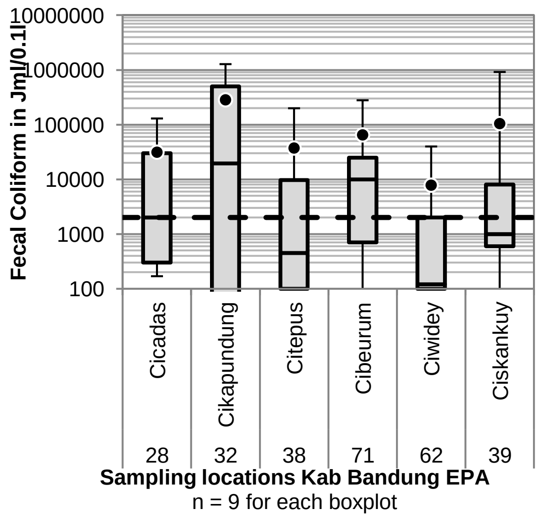

250
200
150
100
50
0
[COD] in mg/l
Cicadas
Cikapundung
Citepus
Cibeurum
Ciwidey
Ciskankuy
28
32
38
71
62
39
Sampling locations Kab Bandung EPA
n = 9 for each boxplot


250
200
150
100
50
0
[COD] in mg/l
Cikapundung
Citepus
Cibeurum
Cisangkuy
11
14
16
13
Sampling locations PJT-II
n = 55 for each boxplot


0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
[Zn] in mg/l
Cicadas
Cikapundung
Citepus
Cibeurum
Ciwidey
Ciskankuy
28
32
38
71
62
39
Sampling locations Kab Bandung EPA
n = 9 for each boxplot


0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
[Zn] in mg/l
Cikapundung
Citepus
Cibeurum
Cisangkuy
11
14
16
13
Sampling locations PJT-II
n = 53 for each boxplot


600000
500000
400000
300000
200000
100000
0
Fecal Coliform in Jml/0.1l
Cicadas
Cikapundung
Citepus
Cibeurum
Ciwidey
Ciskankuy
28
32
38
71
62
39
Sampling locations Kab Bandung EPA
n = 9 for each boxplot


10000000
1000000
100000
10000
1000
100
Fecal Coliform in Jml/0.1l
Cicadas
Cikapundung
Citepus
Cibeurum
Ciwidey
Ciskankuy
28
32
38
71
62
39
Sampling locations Kab Bandung EPA
n = 9 for each boxplot

Annex XIII COMPARISON DRY AND WET SEASON

In this Annex, samples taken during the dry season are compared with samples from the dry season, in order to test the hypothesis: 'The water quality during the dry season is significantly worse than during the wet season'.

1. Methodology

The analysis is based on PJT-II data, as PJT-II is the only organization who is measuring frequently both during the dry and wet season. The PJT-II data is restricted to the period 2010-2014, for two reasons: 1) the location set within this period is consistent (before 2010, some different sampling locations are used), 2) discharge data was available for this period.

First, a series of dry and wet months was selected. This was done by carefully studying the discharge data described in Annex II and by studying the rainfall patterns in the basin described by Deltares (2010a). An overview of the selected 'dry' and 'wet' months is given in Table 17.

TABLE 17 RELATIVELY DRY AND WET MONTHS IN THE YEARS 2010-2014

Year	Wet months	Dry months
2010	2, 3, 5, 10, 11, 12	6, 7, 8
2011	3, 4, 5, 11, 12	6, 7, 8, 9, 10
2012	1, 2, 3, 4, 5, 12	7, 8, 9
2013	1, 2, 3, 4, 5	8, 9, 10, 11
2014	1, 2, 3, 4, 11, 12	6, 7, 8, 9

Second, a statistical test had to be selected to analyse the distributions of the 'wet' and 'dry' population of each parameters. The different samples can be considered independent. In Figure 56 it can be seen that the populations are often not normally distributed for two reasons: 1) the upper whisker is often much bigger than the lower whisker 2) the average value is often much higher than the median value. Therefore, the normal t-test (which assumes that the values are normally distributed) could not be used. It was decided to the use the test of Wilcoxon-Mann-Whitney (also called the Mann-Whitney or the Wilcoxon test). However, this test assumes that the variance of both populations are the same, this requirement is not always met. It was decided to use alpha = 0.05 to compare with the z-value. The test was done by importing the data into SPSS (Non-parametric tests -> 2 independent samples -> Mann-Whitney U).

Thirdly, it was decided for which locations and which parameters the test was to be executed. As executing the test is time-consuming, only two locations where selected, both in the Citarum river. The first is completely downstream: Nanjung. The second location is more upstream, Sapan: 45.1 km from the spring. The results of the analysis is presented on the next two pages.

2. Results Nanjung, Citarum

TABLE 18 DISTRIBUTION DESCRIPTION AND SCORE USING TEST OF WILCOXON-MANN-WHITNEY AT CITARUM NANJUNG, PJT-II DATA 2010-2014

Parameter	TDS		BOD		COD		Turbidity (NTU scale)		Sulphate		Iron (Fe)		Nitrite		Free ammonia	
	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
# samples	24	17	24	17	25	18	24	18	25	18	24	18	24	18	24	18
Average (mg/l)	272	471	8.1	21.8	24	49	139	63	41	64	8.8	5.1	.17	.15	0.046	0.231
Stan. dv. (mg/l)	176	219	4.2	13.7	16	29	103	64	12	25	8.2	6.6	.22	.30	0.057	0.262
1st quarter (mg/l)	150	283	5.2	10.9	14	28	64.5	235	31	46	3.8	2.1	.03	.01	0.010	0.020
Median (mg/l)	290	480	7.9	17.0	22	47	100	47	7.4	12.6	6.8	3.0	.10	.01	0.017	0.096
3rd quarter (mg/l)	380	643	11.8	36.0	31	53	235	67	12.0	19.1	2.1	2.8	.21	.12	0.058	0.427
Mann-Whitney	107		57		80		194		176.5		138.5		164		193	
Wilcoxon	407		357		405		365		501.5		309.5		317		493	
Z-value	-2.771		-3.891		-3.570		-5.720		-1.194		-1.972		-1.637		-0.586	
Sign 2-tailed	0.006		0.000100		0.000357		0.567		0.232		0.049		0.102		0.558	
Significant?	yes		yes		yes		no		no		yes		no		no	

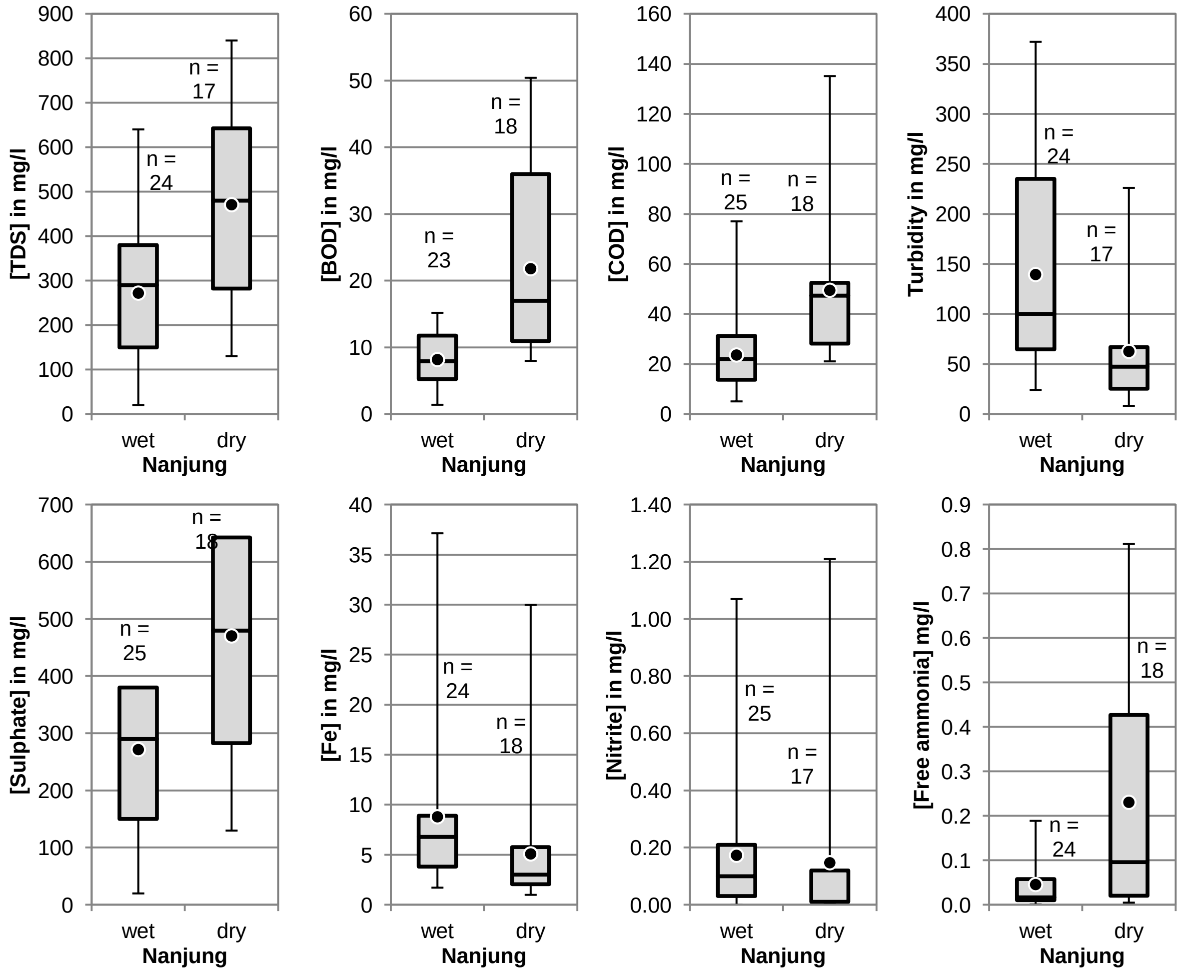


FIGURE 56 BOXPLOTS OF PARAMETERS AT NANJUNG IN THE DRY VERSUS THE WET SEASON (DATA PJT-II 2010-2014)

3. Results Sapan, Citarum

TABLE 19 DISTRIBUTION DESCRIPTION AND SCORE USING TEST OF WILCOXON-MANN-WHITNEY AT CITARUM SAPAN, PJT-II DATA 2010-2014

Parameter	BOD (mg/l)		TDS (mg/l)		Temp (ºC)		Turbidity (NTU)	
	wet	**dry**	**wet**	**dry**	**wet**	**dry**	**wet**	**dry**
# samples	26	18	26	18	25	17	23	18
Average	12	31	195	470	26.0	27.0	103	47
Standard deviation	23	26	95	316	2.9	3.6	83	31
1st quarter	5	12	135	228	24.3	26.2	54	20
Median	7	21	185	385	26.0	28.0	81	42
3rd quarter	11	45	230	643	28.3	29.0	130	86
Mann-Whitney	78		93.5		214.5		200.5	
Wilcoxon	429		444.5		592.5		371.5	
Z-value	-3.725		-3.358		-0.364		-0.603	
Asymp Sig (2-tailed)	0.000196		0.000786		0.716		0.546	
Significant?	yes		yes		no		no	

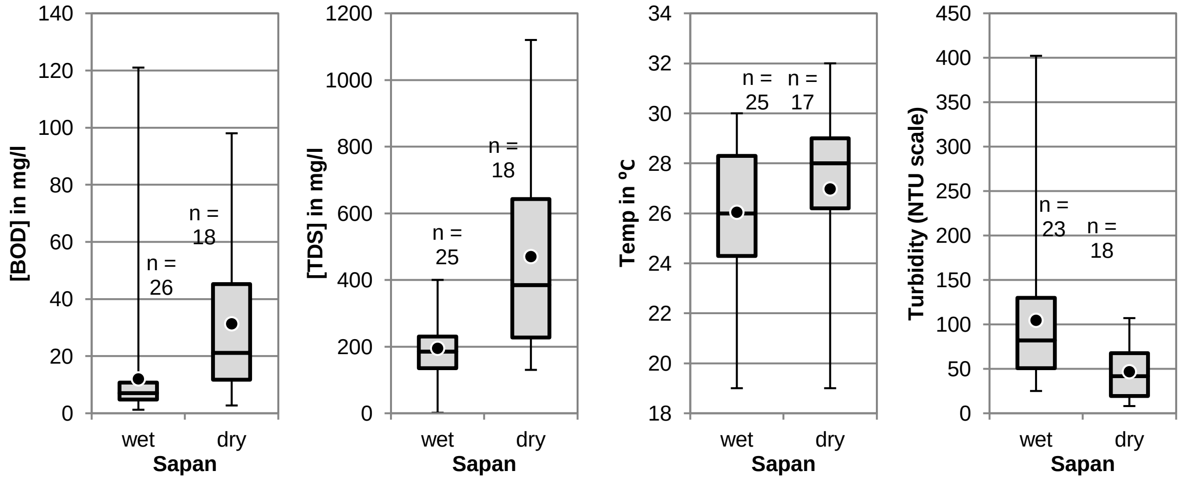


FIGURE 57 BOXPLOTS OF PARAMETERS AT SAPAN, CITARUM IN THE DRY VERSUS THE WET SEASON (DATA PJT-II 2010-2014)

4. Conclusion

The hypothesis 'The water quality during the dry season is significantly worse than during the wet season' can only be accepted for some parameters.

- The TDS, BOD- and COD-concentrations are on average more than two times higher during the dry season, compared with the wet season. The test of Wilcoxon-Mann-Whitney shows that these concentrations are significantly higher during the dry season, compared with the wet season.
- The sulphate and free ammonia concentration seems to be much higher during the dry season as well, but this is not significant according to Wilcoxon-Mann-Whitney.
- The iron and nitrite concentration are even lower during the dry season compared with the wet season, but this is not significant according to Wilcoxon-Mann-Whitney.
- The temperature at Sapan during the wet season is not significantly different during the wet season, compared with the dry season.
- The turbidity at Nanjung seems to be much higher during the wet season, where the turbidity at Sapan seems to be much higher during the dry season. However, both differences are not significant according to Wilcoxon-Mann-Whitney.

Annex XIV COMPARISON LAND USE MAPS

In this annex, Google Earth satellite images are compared with two different land use interpretations, in order to determine which land use map is most suitable for researching the link between water quality and land use in the Bandung Basin. The used satellite images are retrieved from Google Earth (11 May 2015). The first land use map was obtained from the Bappeda and is based on an interpretation in 2011 of LandSat satellite images of 2010. The second land use map is also obtained from the Bappeda and was interpreted based on SPOT satellite images of 2014.
All selected locations where visited by the author of this thesis, during field work.

Majalaya industry cluster, with surrounding agricultural area

Tea plantations and dry crops around the **Tilu mountain** (Gambung Teh & Kina research center)

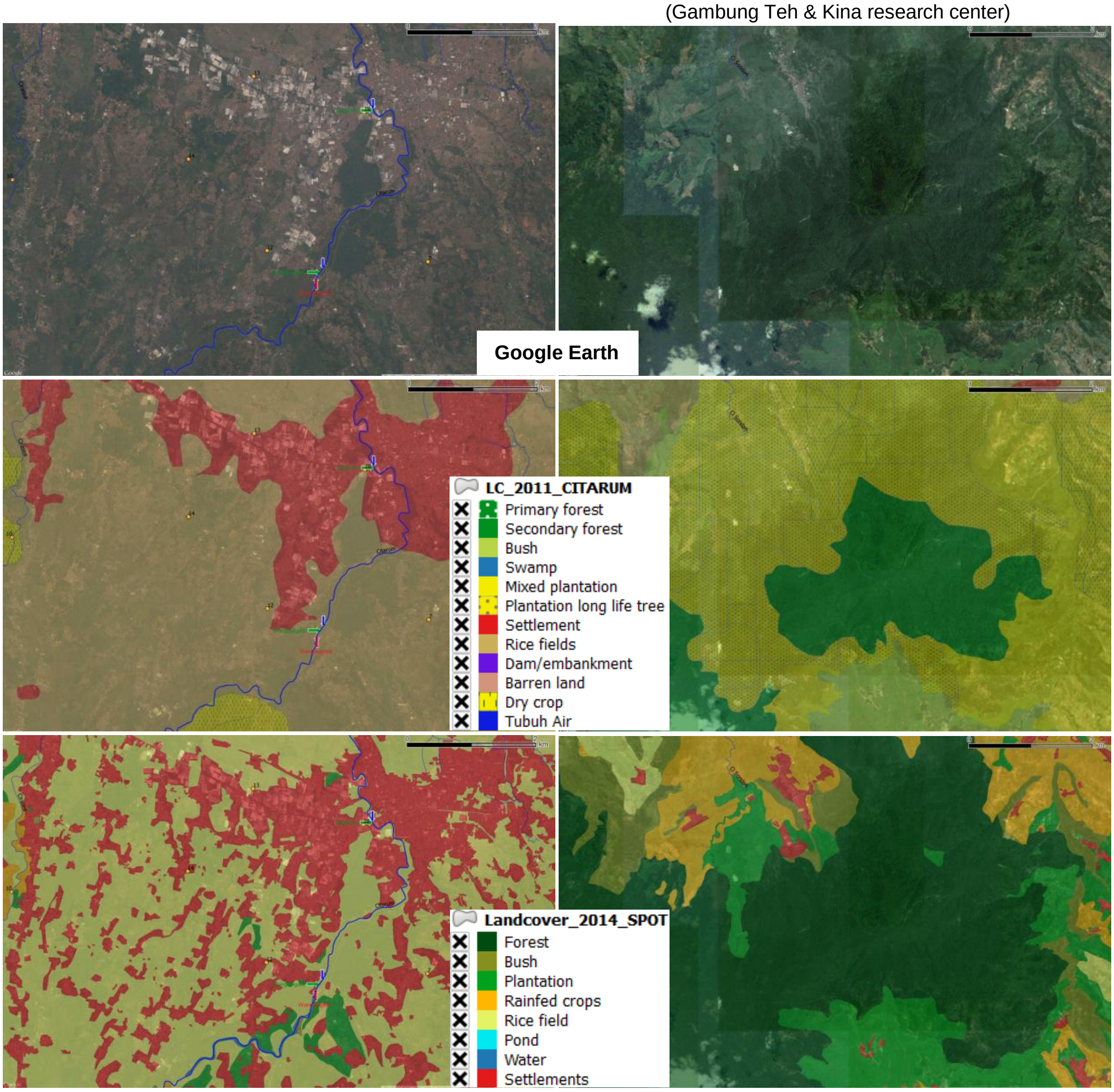


FIGURE 58 COMPARISON GOOGLE EARTH SATELLITE IMAGE WITH LANDUSE MAPS BASED ON LANDSAT (2010, INTERPRETATED IN 2011) AND SPOT (2014)

Agricultural area and national park Juanda (forest) between the **north of Bandung and Lembang**

Irrigated rice fields (Sawa's) between **South Bandung and Soreang**

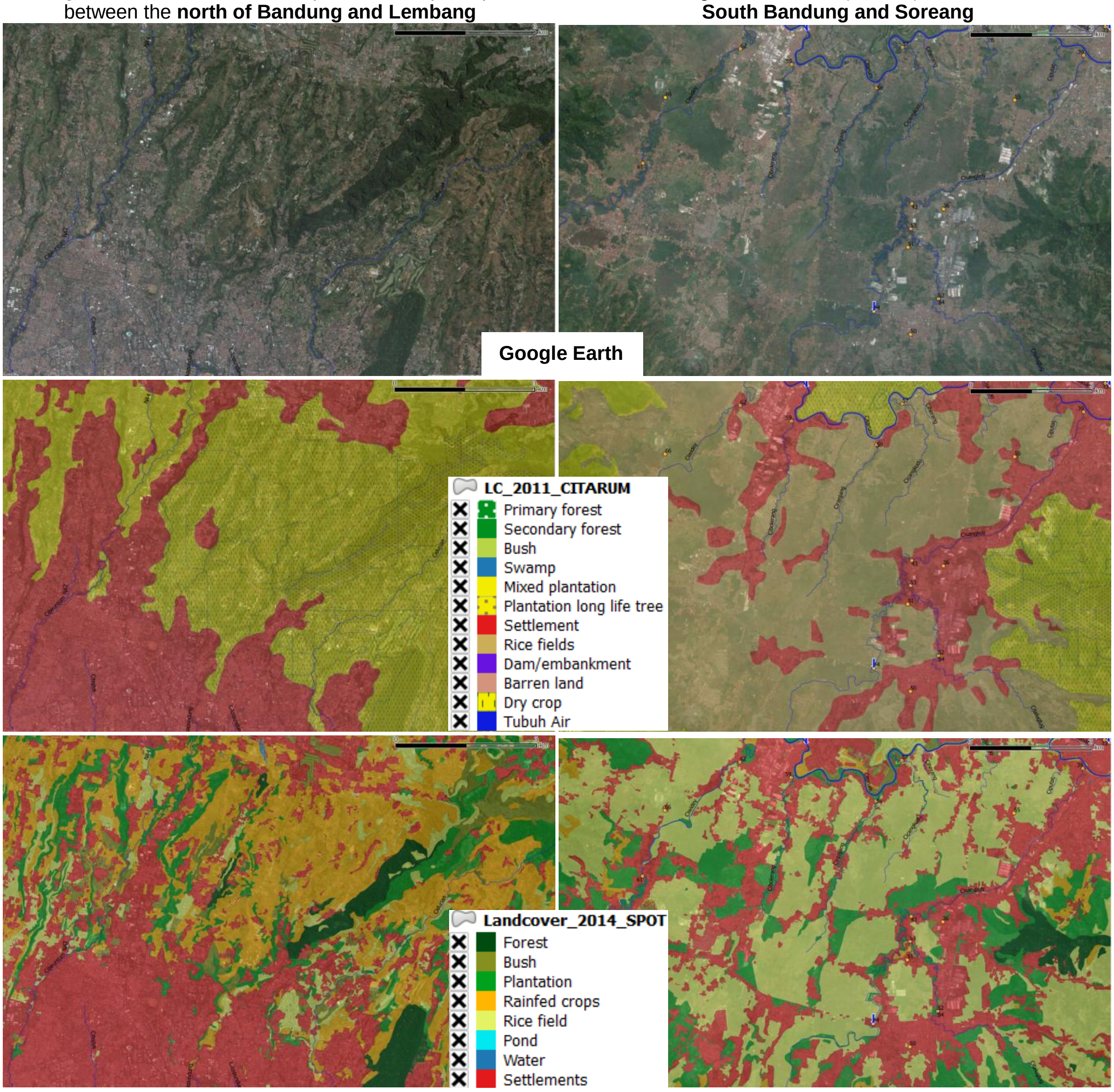


FIGURE 59 COMPARISON GOOGLE EARTH SATELLITE IMAGE WITH LANDUSE MAPS BASED ON LANDSAT (2010, INTERPRETATED IN 2011) AND SPOT (2014)

In Figure 53 and Figure 54 the following things can be observed:

- The Spot-2014 images are consisting of many small polygons, the LandSat-2011 images are more course.
- In the Majalaya image can be seen that the SPOT-2014 map shows many small settlements, where the LandSat-2011 just calls the whole area 'rice fields'.
- The locations of the forests, tea plantations and settlements around the Tilu mountain are much more accurate at the SPOT-2014 image than at the LandSat-2011 image.
- In the Majalaya, Bandung/Lembang and Bandung/Soreang images it can be seen that SPOT-2014 is interpreting a lot of 'plantations' area. From the field work, it is known that in these locations not always tea or coffee plantations are located. The SPOT map seems to interpret bush/forest as 'plantations'.

It was decided to use the Spot-2014 images because they give a more accurate representation of the buildings in the basin and because the images are more up-to-date.

Annex XV CORRELATIONS WITH LANDUSE

In this annex, the relation between land use and water quality is researched. The idea for this analysis was taken from Firdaus (2013, 2014). The analysis is based on data from Kabupaten Bandung, 2011-2013. The used method can be summarized as follows: 1) selection of sampling locations; 2) calculation of catchment of each sample location; 3) calculation of land use per catchment; 4) calculation of regression per parameter for each sampling location and 5) synthesis of results. The flow of data and the used tools are displayed in Figure 60.

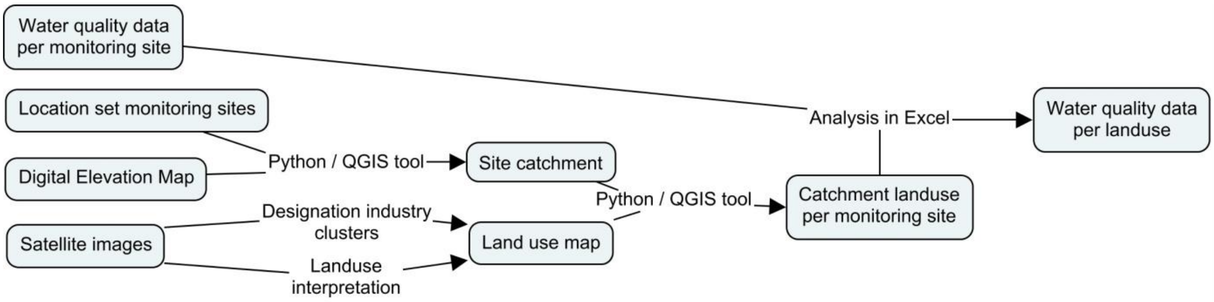


FIGURE 60 USED DATA AND STEPS TAKEN TO CORRELATE LANDUSE WITH WATER QUALITY

1. Selection of sampling locations

Out of the 75 sampling locations of Kabupaten Bandung, 20 locations were selected for further analysis. The selection was based on the following criteria:

- The location of the sampling site and the accompanying catchment can be clearly indicated, i.e. it is clear in what tributary the sample is taken.
- The catchment areas of different sites should not overlap.
- Each land use type is represented in multiple locations. For example, a few locations are chosen in the city of Bandung, a few include an industry cluster, others contain mainly forest while others mainly contain agricultural areas.
- The selected locations are a representative sample of the whole basin.

2. Calculation of catchments per sampling sites

For every sampling site selected by step 1, the corresponding catchment was calculated. Based on the Digital Elevation Map (DEM), a river network shapefile and the inlet of the Saguling reservoir, a Local Drain Direction (LDD) map was calculated using W-tools. This LDD-map shows the drainage direction for all cells in a grid covering the whole Bandung basin. Based on the LDD-map, it was calculated which cells are draining to the cell in which the sampling site is located. The collection of this cells form the catchment area of this sampling site. This was done for all sampling sites. An overview of the selected sampling sites and the corresponding catchments is given in Figure 61.

3. Calculation of land use per catchment

Now, the land use in each catchment was calculated using QGIS. The land use calculation was based on the SPOT-2014 satellite images. For an extensive discussion on the differences between land use maps and a motivation of the choice for SPOT-2014, see Annex XIV. The result of the calculation is presented in Table 19.

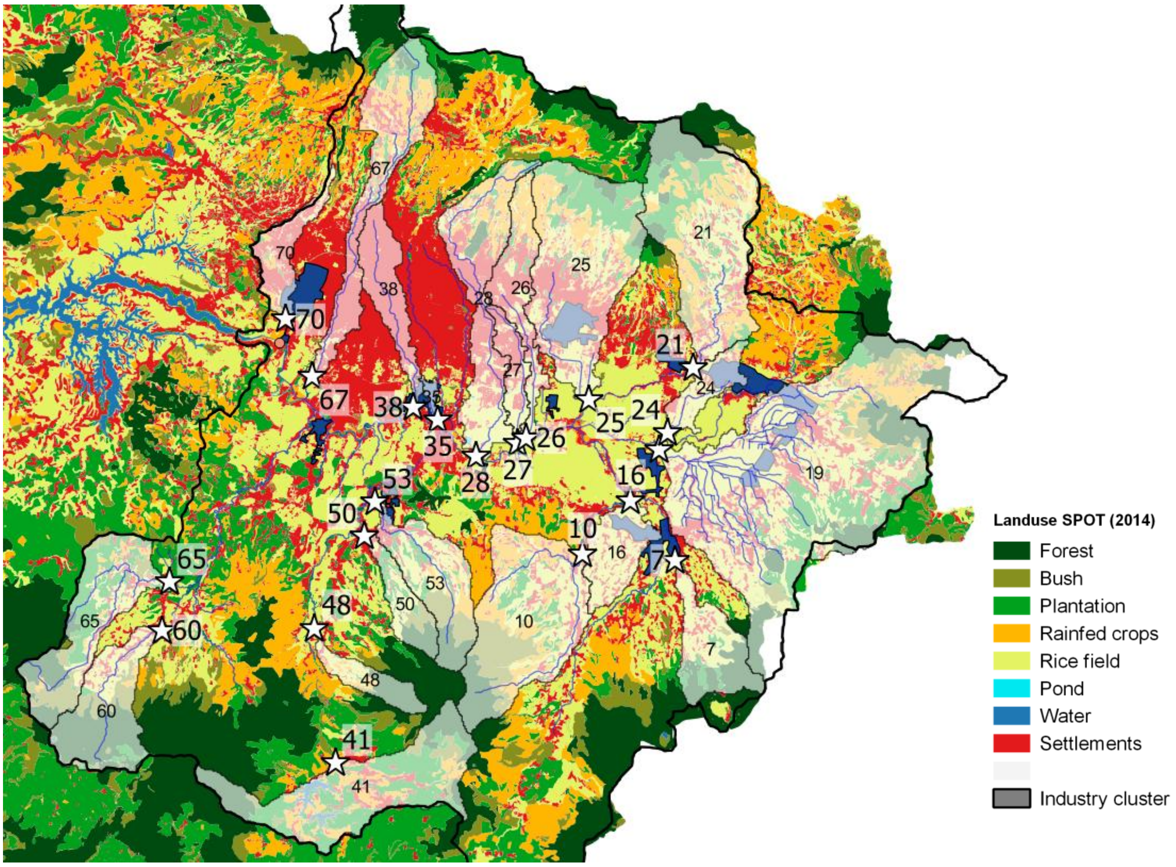


FIGURE 61 SELECTED SAMPLING SITES OF KABUPATEN BANDUNG AND CORRESPONDING CATCHMENTS (NUMBERS REPRESENTING THE SAMPLING SITE ID). BACKGROUND IMAGE: LANDUSE SPOT-2014 AND IN BLUE THE INDUSTRY CLUSTERS.

TABLE 20 LAND USE AND SURFACE AREA PER SELECTED SUBCATCHMENT. INDUSTRIAL DENSITY IN THREE CATEGORIES: 0 = NO INDUSTRY, 1 = LITTLE INDUSTRY, 2 = MODERATE INDUSTRY, 3 = INTENSIVE INDUSTRY

ID	Forest	Plantations[25]	Rainfed crops	Rice fields	Bush	Settlements	Water	Total	Area (km^2)	Industrial intensity
7	41%	10%	0%	38%	0%	12%	0%	100%	25	0
10	11%	11%	25%	27%	17%	8%	0%	100%	67	0
16	0%	1%	0%	87%	0%	12%	0%	100%	20	3
19	15%	14%	7%	44%	6%	14%	0%	100%	185	3
21	13%	23%	25%	25%	6%	9%	0%	100%	75	0
24	0%	4%	3%	73%	2%	17%	0%	100%	13	3
25	4%	23%	14%	29%	3%	26%	0%	100%	76	3
26	0%	7%	20%	27%	2%	43%	0%	100%	24	0
27	0%	1%	1%	49%	2%	48%	0%	100%	11	0
28	3%	6%	18%	33%	1%	38%	1%	100%	47	0
35	0%	0%	2%	14%	0%	83%	0%	100%	2	3
38	0%	0%	0%	2%	0%	97%	0%	100%	20	2
41	21%	41%	16%	0%	8%	11%	3%	100%	62	0
48	48%	2%	16%	24%	3%	8%	0%	100%	11	0
50	28%	23%	2%	26%	13%	8%	0%	100%	14	0
53	14%	13%	9%	27%	19%	17%	0%	100%	31	1
60	49%	6%	2%	20%	16%	8%	0%	100%	36	0
65	20%	34%	5%	16%	17%	8%	0%	100%	43	0
67	3%	17%	25%	5%	6%	44%	0%	100%	43	3
70	0%	1%	9%	12%	7%	71%	0%	100%	15	2

[25] This does not only cover tea and coffee plantations, but also other types of dry crops, see Annex XV for an extensive discussion on the meaning of the different types of land use.

4. Calculation of regression per land use

Knowing the land use of each subcatchment, the land use can now be related to the observed water quality parameters at the corresponding sampling location. To simplify the calculation, only the average of each parameter was calculated for each location and for each parameter. The results of this calculation are shown in Table 22.

TABLE 21 AVERAGE OBSERVED PARAMETER VALUES PER MONITORING LOCATION OF KABUPATEN BANDUNG 2011-2013. MOST AVERAGES ARE BASED ON 9 OBSERVATIONS (3 TIMES A YEAR IN THREE YEARS)

ID	pH	TDS	TSS	Temp.	Nitrat	Nitrit	DO	BOD5	COD	P_{total}	Fenol	Sulfida	CL2	CN	Cd	Cr6+	Cu	Zn	F	Pb	Fecal
		mg/l	*mg/l*	*ºC*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*Jml/0.1l*
7	7.4	197	65	23	1.9	0.0	5.9	2	3	0.3	.04	.06	.04	.016	.009	.026	.051	.046	.043	.249	1047
10	7.7	628	51	26	8.8	0.1	5.6	18	30	0.2	.05	.14	.05	.013	.009	.021	.058	.036	.137	.248	36857
16	8.8	516	170	30	4.0	0.1	1.0	91	166	1.4	.07	.08	.12	.040	.010	.031	.068	.742	.119	.263	17859
19	7.7	986	104	28	2.3	0.2	3.7	15	48	0.8	.03	.21	.09	.007	.011	.023	.052	.048	.253	.244	2253
21	7.2	212	43	26	4.3	0.1	2.6	16	30	0.7	.09	.29	.05	.011	.009	.014	.051	.047	.080	.248	84187
24	7.7	2083	416	27	8.7	0.1	2.2	96	194	1.6	.07	.37	.13	.030	.011	.019	.059	.308	.400	.256	92403
25	7.7	503	56	29	8.7	0.6	3.2	16	45	0.5	.06	.19	.06	.014	.013	.019	.051	.050	.358	.257	38622
26	7.6	285	96	31	4.7	0.4	3.1	19	41	0.3	.05	.13	.06	.028	.012	.018	.057	.129	.177	.264	6916
27	7.7	236	57	29	5.2	0.4	3.9	17	37	0.9	.08	.16	.08	.013	.010	.032	.049	.128	.149	.242	33880
28	7.6	385	113	29	5.8	0.1	2.5	39	91	1.5	.12	.14	.10	.019	.079	.015	.050	.100	.123	.246	31446
35	9.1	795	144	28	2.3	0.1	1.8	68	157	1.0	.04	.47	.09	.013	.007	.023	.111	.223	.204	.279	48938
38	7.6	308	80	27	5.6	2.3	1.6	33	97	1.5	.13	.24	.12	.012	.009	.079	.038	.119	.192	.270	37486
41	7.3	220	76	23	5.9	0.3	6.3	5	18	1.0	.06	.05	.06	.010	.008	.013	.050	.035	.063	.262	2793
48	7.3	202	100	25	2.6	0.1	6.2	2	6	0.4	.05	.08	.04	.011	.010	.014	.052	.064	.103	.262	19461
50	6.9	205	71	25	2.4	0.1	3.4	24	40	0.8	.06	.10	.09	.030	.011	.027	.043	.033	.049	.262	118958
53	7.0	299	206	27	2.0	0.1	1.9	112	218	0.4	.09	.18	.07	.036	.009	.022	.046	.052	.064	.292	65001
60	7.3	268	56	24	5.2	0.1	5.3	4	8	0.3	.11	.18	.04	.016	.010	.018	.048	.057	.146	.248	8072
65	8.0	230	74	26	1.6	0.0	5.1	3	7	0.4	.09	.20	.06	.008	.009	.016	.047	.041	.064	.260	748
67	7.7	858	132	27	2.4	0.9	1.2	43	96	0.8	.06	.15	.23	.011	.007	.097	.053	.111	.643	.253	500578
70	8.0	992	57	31	2.5	0.1	2.1	86	177	1.5	.07	.30	.11	.020	.008	.026	.054	.215	.192	.589	358748

Now, regressions between the land use percentage (Table 20) and the observed parameter averages (Table 21) were analysed using the linear regression function of Excel. Two examples of these regressions are given in Figure 57.

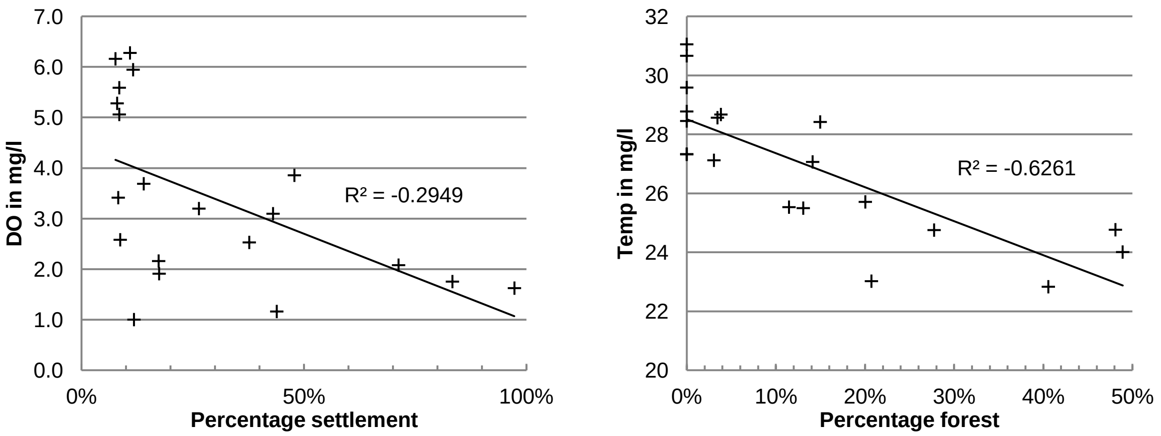


FIGURE 62 REGRESSION BETWEEN DO AND % SETTLEMENTS, AND TEMPERATURE AND % FOREST

An overview of all the regressions is given in Table 22. This table was constructed using different calculations:

- For *Settlements*, *Forest*, *Rice fields* a direct regression was plotted between these land use types and the parameters.
- Because the SPOT-2014 images often misinterprets the classes 'bush' and 'plantations' (see discussion Annex XIV), a new group 'mixed agriculture' was made: the sum of the percentages 'bush', 'plantations' and 'rainfed crops', but excluded the rice fields.
- Because the industry clusters are not included in the SPOT-2014 images, another approach had to be used for researching the relation with industrial land use.

- First, the industry within each catchment was graded in one of the following three categories: 0 = no industry, 1 = little industry, 2 = moderate industry, 3 = intensive industry. See the last column of Table 19 for the assigned categories. These values were taken as x-values while researching the correlation of parameters with the industry. The results are in the column *industry graded* of Table 22.
- Secondly, the industry was binary graded, in two categories: 0 = no industry and 1 = any type of industry. Again, those values were chosen as x-values. The results can be found in the column *industry yes/no* of Table 22.

- Because the industrial discharges strongly influenced the results in certain subcatchments, the regressions were also calculated while leaving out the catchments with heavy industrial (category 3 in the last column of Table 20).

TABLE 22 REGRESSION VALUES (R^2) OF SEVERAL LAND USE TYPES. NEGATIVE R^2 INDICATE A NEGATIVE CORRELATION.

	Settlements	**Settlements without industry**	**Forest**	**Forest without industry**	**Rice fields**	**Rice fields without industry**	**Mixed agriculture**	**Mixed agriculture without industry**	**Industry graded**	**Industry yes/no**
pH	0.19	0.29	-0.25	-0.20	0.06	0.01	-0.21	0.00	0.32	0.20
TDS	0.02	0.40	-0.18	-0.13	0.00	-0.09	-0.06	0.00	0.46	0.36
TSS	0.00	0.00	-0.08	-0.01	0.28	0.00	0.08	0.00	0.23	0.23
Temp.	0.31	0.79	-0.63	-0.60	0.08	0.02	-0.15	-0.12	0.27	0.29
Nitrat	0.00	0.00	-0.09	-0.21	0.04	0.00	0.00	0.01	0.00	0.00
Nitrit	0.39	0.23	-0.10	-0.39	-0.13	-0.17	-0.04	-0.21	0.07	0.10
DO	-0.29	-0.33	0.56	0.41	-0.04	0.00	0.11	0.07	-0.44	-0.52
BOD5	0.08	0.23	-0.28	-0.47	0.13	0.00	-0.12	-0.01	0.31	0.49
COD	0.16	0.28	-0.34	-0.47	0.09	-0.01	-0.14	0.02	0.39	0.58
Total P	0.23	0.40	-0.33	-0.18	0.07	-0.11	-0.22	-0.10	0.23	0.22
Fenol	0.04	0.00	0.00	-0.02	-0.02	-0.05	-0.01	-0.04	-0.06	0.00
Sulfida	0.27	0.17	-0.19	-0.08	0.00	-0.04	-0.09	-0.01	0.24	0.25
CL2	0.16	0.51	-0.29	-0.33	0.00	-0.07	-0.03	-0.15	0.42	0.37
CN	-0.02	0.05	-0.04	-0.02	0.33	0.06	-0.07	0.00	0.02	0.06
Cd	0.00	0.05	-0.02	-0.12	0.00	0.05	0.00	0.00	-0.04	0.05
Cr6+	0.27	0.19	-0.09	-0.01	-0.07	-0.08	-0.02	-0.33	0.17	0.19
Cu	0.10	0.12	-0.09	-0.11	0.00	0.08	-0.11	0.05	0.17	0.09
Zn	0.02	0.94	-0.18	-0.31	0.45	0.00	-0.29	-0.36	0.26	0.20
F	0.08	0.54	-0.18	-0.16	0.00	0.02	0.00	-0.27	0.48	0.34
Pb	0.16	0.47	-0.05	0.03	-0.04	0.09	-0.02	-0.03	0.03	0.10
Fecal	0.10	0.39	-0.08	-0.02	-0.08	0.03	0.01	-0.02	0.13	0.15

5. Synthesis of results

In this section, the regressions of Table 22 are interpreted.

BOD AND COD

The correlations found for COD and BOD are about the same. Both parameters have a very strong correlation with the presence of industry clusters: 30 to 60% of the observed concentrations can be explained from the presence of an industry cluster (Table 22). Areas with settlements also contribute to high BOD and COD values, the percentage of settlements explain approximately 25% of the observed concentrations, but only when the catchments containing intensive industry clusters are not included in the analysis. Big areas of rice fields and agriculture are sometimes found in areas with big industry clusters. If these catchments are not included in the analysis, there is no correlation with these land use types. As a result of the positive correlations with industry and settlements, there is a negative correlation between forest and BOD and COD.

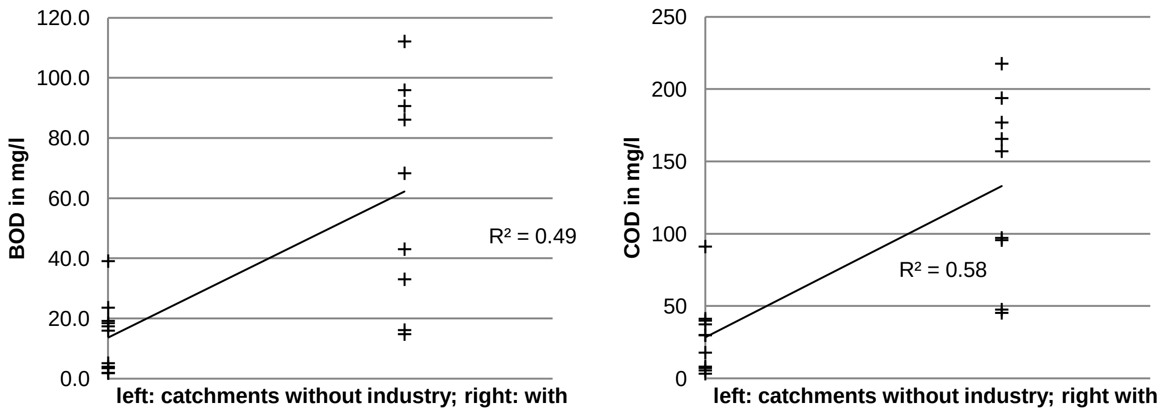


FIGURE 63 BOD AND COD IN CATCHMENTS WITHOUT INDUSTRY (X=0) COMPARED WITH BOD AND COD IN CATCHMENTS CONTAINING INDUSTRY

NITRATE

Contrary to all expectations, there is no positive correlation between agricultural areas and Nitrate. The only clear correlation between Nitrate and land use is a strong negative correlation with forest (without industry). This means that it is not very clear from which land use type the Nitrate is coming, maybe all types of land use contribute to high Nitrate concentrations. We can only be sure that little Nitrate is coming from the forest.

SULPHATE

Sulphate is not included in the Kabupaten Bandung dataset, but Sulphite is. There are positive correlations of Sulphite with industry (R^2 = 25%) and settlements without industry (17%).

FECAL COLIFORM

There only is a strong correlation between observed fecal coliform concentration and the percentage of land use covered with settlements. With industry neglected, almost 40% of the observed fecal coliform can be explained from the presence of settlements. However, this correlation is strongly determined by one outlier. If this outlier is deleted, the correlation is slightly negative (-2%).

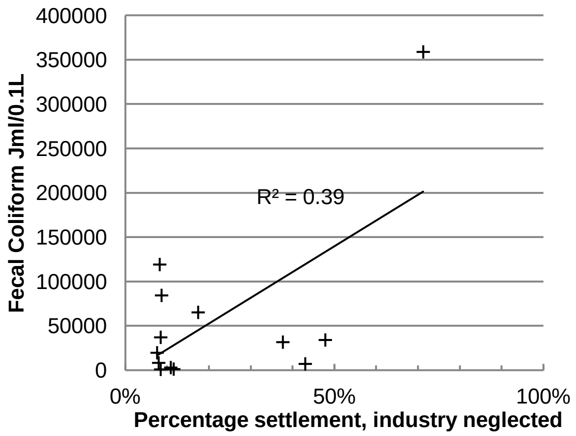


FIGURE 64 CORRELATION BETWEEN FECAL COLIFOM AND SETTLEMENTS, NEGLECTING CATCHMENTS CONTAINING INDUSTRY CLUSTERS

ZINC

High Zinc concentrations correlate with the presence of industry clusters, see Figure 60. However, this is really depending on the type of industry clusters. As in some industry clusters very high Zn concentrations are observed, and in others only small concentrations, the R^2 is only 26%. Also, a very strong correlation between [Zn] and percentage of settlements was found (R^2 = 94%).

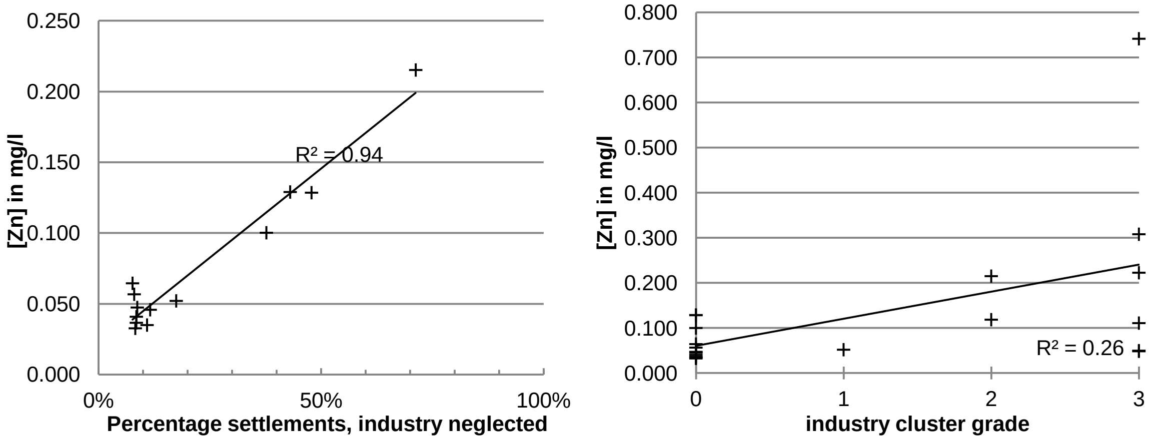


FIGURE 65 CORRELATIONS BETWEEN ZINC AND PERCENTAGE OF SETTLEMENTS WITH INDUSTRY CLUSTERS NEGLECTED (LEFT) AND WITH INDUSTRY CLUSTERS GRADED TO INTENSITY

6. Conclusion and discussion

Most land use types correlate with the parameter concentrations according to the expectations. Agricultural areas have a much better water quality then other areas. However, one should keep in mind that the correlation tests have many constraints:

- The R^2 is only indicating to what extend a parameter value can be predicted based on the land use type in the basin. It does not say if the contribution of this land use type to the contribution is significant. For example: in Figure 60 it can be seen that R^2 is much higher for settlements than for industry clusters. However, in reality, the concentrations observed in industry clusters can be much higher than in settlement areas.
- The amount of used data is limited, it would be better to base the analysis on more sampling locations over a longer period.
- There are errors in the land use maps of SPOT-2014 (Annex XIV) and there might be errors in the LDD and thus in the selected basins. This is influencing the results.

Despite all the constraints, the presented method seems to be promising approach for analysing the relation between water quality and land use. It can be used to check if the assumptions underlying the modelling with respect to this relation are correct.