Water quality in the Upper Citarum River Basin: towards a better understanding of a heavily polluted catchment

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ABSTRACT
The Upper Citarum River Basin is a heavily polluted catchment on West Java, Indonesia. Policy makers and scientist show increasing interest for the issue, but there is no recent scientific study that gives an overview of the current state of the river basin. In this paper, the six drivers of the water quality problem are described by system analysis, tracing them back to weak social and governmental institutions. Stakeholder analysis reveals a strong mismatch between responsibilities, authorities and resources among monitoring stakeholders. Data analysis shows that the industry is the largest polluter of the basin, followed by pollutants from domestic origin.

Keywords
Water Quality, Pollution, Upper Citarum River Basin, Bandung Basin, Integrated Water Resources Management

Accompanying video
www.tiny.cc/BandungBasin

INTRODUCTION

Water quality is an important aspect of river basin management, especially in countries like Indonesia where rapid development and industrialization is leading to large environmental problems. The Citarum River, located on West Java, Indonesia, is often ranked among the most polluted rivers of the world. It is an important water supply for the greater Jakarta area, in which 25 million people live (ADB and World Bank, 2013). The catchment upstream of the first reservoir in the river, known as the Upper Citarum River Basin (UCRB) or Bandung Basin, is probably the most polluted part of the whole river. The UCRB measures 45 x 45 km and consists of a large floodplain surrounded by volcanic mountains (Figure 1). The length of the Citarum from spring (Situ Cisanti) to the first reservoir (Saguling) is 78 km. Annual rainfall varies from 1200 to 3000 mm with 100 to 500 mm per month in the wet season and less than 50 mm per month in the dry season (Deltares, 2012). The inflow in the reservoir is 120 m^3/s during the wet and 20 m^3/s during the dry season (TDK, 2013).

Large population growth is taking place in the UCRB; in 1995 it had 2.5 million inhabitants, which grew to 7.8 million by 2010 (Deltares, 2012). This led to an enormous increase of settlements in the basin, accompanied by a rapid growth of mainly textile industry. Indonesia's decentralization policy, that started in the late 90's has led to governmental fragmentation and to the growth of 'local egocentrism' (Hudalah et al., 2013). As a result, the task distribution among water quality monitoring stakeholders is unclear and monitoring practices are generally poor.

The problems in the basin are under increasing interest of policy makers and scientist, but there is no recent scientific study giving an overview of the current state of the UCRB. Three problems will be addressed in this paper: 1) lack of clarity about the drivers (main causes) of the water quality deterioration; 2) insufficient overview of water quality monitoring stakeholders, and the data obtained by their activities; 3) lack of knowledge on how available data can be used to assess the current state of the basin.

The objective of this paper is to increase the understanding of the water quality problem of the UCRB by approaching it from a technical and a governance perspective. The paper builds on the technical perspective from the authors' BSc-thesis (Ginkel, 2015a) and the stakeholder analysis he carried out simultaneously (Ginkel et al., 2015b).

RESEARCH QUESTIONS AND METHODOLOGY

The first question is: What are the drivers of the water quality problem and how do they influence the water quality in the river? This is answered by constructing a system diagram, based on field observations, interviews, literature review and exploratory data analysis.

The second question is: What is the involvement of different stakeholders in the monitoring of the water quality in the UCRB? This question is answered by analyzing the actor network of monitoring stakeholders using the framework of Ernstson et al. (2010). In this framework, the physical system (i.e. the ecological system of the UCRB) is linked to a multi-layer actor network (all actors concerned with water quality monitoring of the UCRB). Actor data was collected by interviewing, attending stakeholder meetings, participant observation and a literature review.

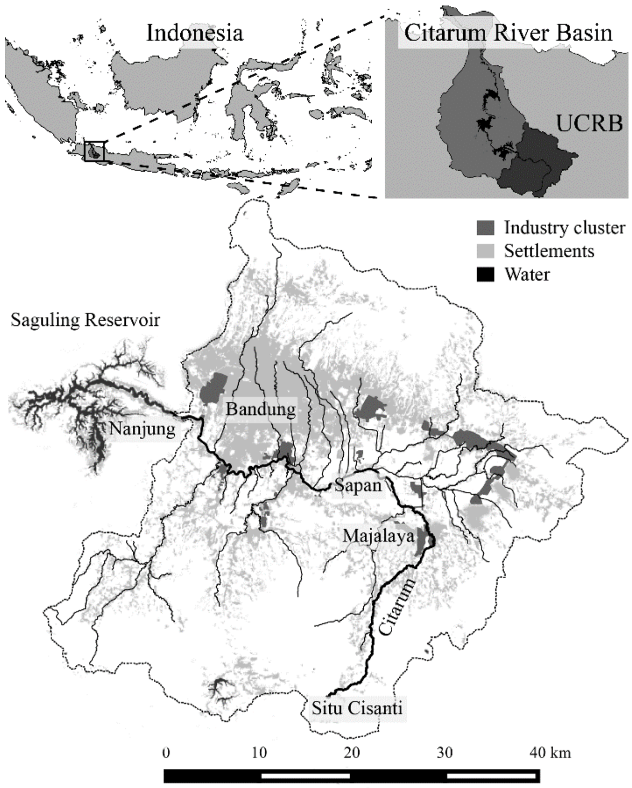


FIGURE 1: LOCATION AND OVERVIEW UCRB

SRC 2016, November 30, 2016, The Netherlands.

The third question is: what does the water quality data reveal about the state of the UCRB? Answering this question comprehends the analysis of data obtained from the monitoring stakeholders and during field work. Five water quality datasets were obtained from monitoring stakeholders, covering the period 2010 to 2014 for 130 locations, with 1-12 samples per year describing 16-33 water quality parameters. First, the data was validated by mutual comparison of sets. Second, the UCRB was schematized and descriptive statistics were used to show the upstream-downstream development of different water quality parameters. Third, statistical tests were used to explore the differences between the wet and the dry season. Finally, the relation between water quality and land use was investigated using tools from GIS-software.

RESULTS

The water quality drivers, stakeholder involvement and result of the data analysis will be presented in this section.

Water quality drivers

Six main drivers of the water quality in the UCRB can be distinguished (Figure 2).

1) The natural system of the basin: geo-hydrological conditions and rainfall-discharge patterns influencing the water quality. The surrounding volcanic mountains are highly erosive, causing high turbidity due to high concentrations of suspended solids.

2) Industrial effluents: the amount of industries is estimated at 1500, of which only the largest 300 (mainly textile) are registered. The effluents exceed the carrying capacity of the water system by far. In general, wastewater treatment is insufficient due to weak governmental institutions and poor infrastructure and maintenance. Moreover, there are many unregistered home industries that produce semi-manufactures for the textile industry, discharging small but heavily polluted (untreated) effluents.

3) Domestic waste is the most eye-catching factor contributing to the pollution; piles of domestic waste can be found everywhere in the basin, finally ending up in the water system. Factors leading to the problem are citizen behavior and a lack of infrastructure, related to poor city planning, weak governmental institutions and rapid population growth.

4) Domestic sewage: only 35% of Bandung is connected to a (ineffective) wastewater treatment plant (Prihandrijanti and Firdayati, 2011). Households often discharge directly to the surface water or use (often leaking) septic tanks.

5) Crop growing activities gradually change in the basin: on the steep hills mainly perennial trees (tea, coffee) and rainfed dry crops are found (vegetables), while the central plain in the basin is dominated by paddy fields (rice). Perennial trees stabilize the soil but dry crops are very prone to erosion. Hence, flushing of pesticides and fertilizer is mainly a problem for the dry crops. Emissions from paddy fields are very hard to estimate, and mainly depend on local farming practices (Yoshinaga et al., 2007).

6) Stockbreeding activities locally have a major contribution to water pollution, as the manure is often directly discharged to the surface water.

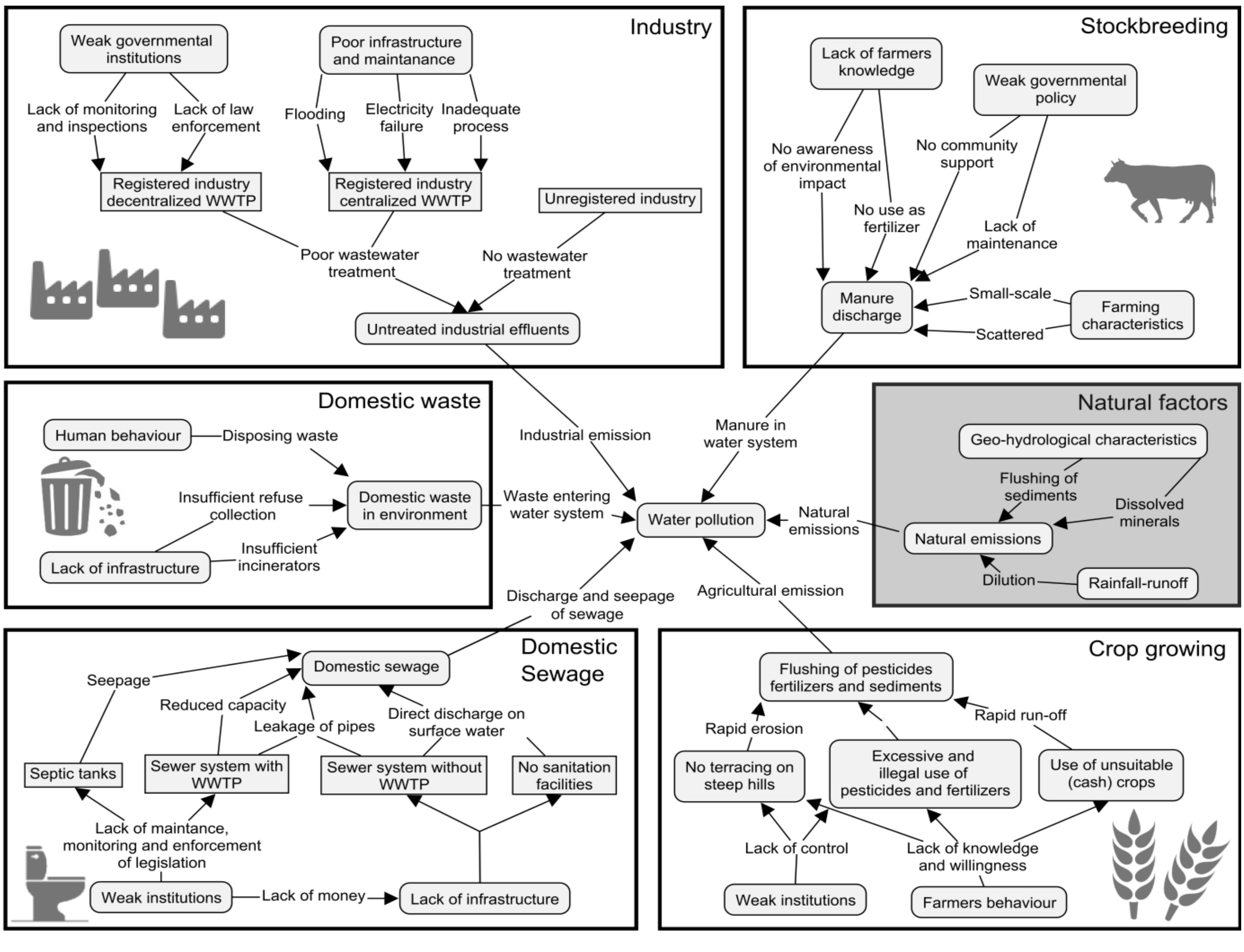


FIGURE 2: SYSTEM DIAGRAM OF WATER POLLUTION UCRB

Stakeholder involvement in monitoring

A variety of stakeholders is involved in water quality monitoring of the UCRB. The main branch of the river is monitored by the national government (PusAir), but on a very irregular basis. The most extensive monitoring is done by a state-owned-enterprise: the operator of the reservoir (PJT-II). The river basin organization (BBWSC) is not doing any water quality monitoring at all. All actors claim that the provincial government (West Java Environmental Protection Agency) should have the lead in the monitoring process, as it is responsible for all environmental issues in the West Java province. However, most of the responsibilities of the West Java EPA have been delegated to the district level government, so that the organization itself is only doing limited monitoring. In fact, most of the monitoring is done by the five different district level EPAs. There is very little collaboration between the district EPAs, as a result of several upstream-downstream conflicts. The district EPA's are supposed to report their data to the West Java EPA, but in practice there is no proper storage of the data.

Data analysis

The spatial distribution of water pollution through the basin is correlated with the land use types: settlements, industry and agriculture (Table 1). Therefore, the water quality in the basin is best understood by first characterizing three types of streams: rural, industrial and urban streams.

Table 1 Impact of land use on water quality parameters

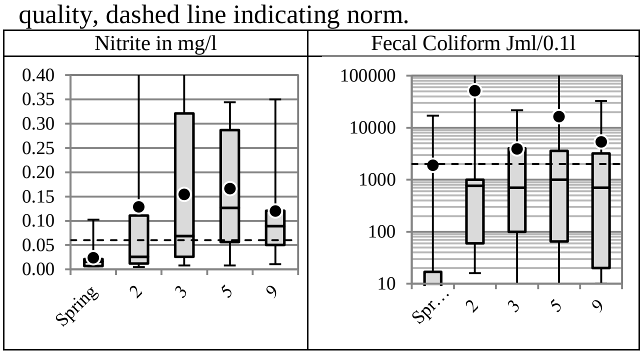
	Domestic	Industry	Stockbreeding	Crops	Forest
BOD	medium	large		No relations found	Positive influence on water quality
COD	medium	large			
Nitrate		small	medium		
Sulphate		medium			
Fecal Coliform	large		medium		
Zinc	large	medium			

Typical rural, industrial and urban streams

Contrary to the expectations, in rural areas no correlations were found between crop growing and water quality indicators. This is most likely due to the limited amount of parameters included in the study. It is commonly assumed that bad farming practices lead to large erosion and flushing out of sediments, pesticides and fertilizers (Calderon et al., 2011). Stockbreeding activities, taking place in small barns, are clearly linked to high Fecal Coliform, Nitrite and Nitrate concentrations (Table 2), confirming that manure is often directly discharged to the surface water.

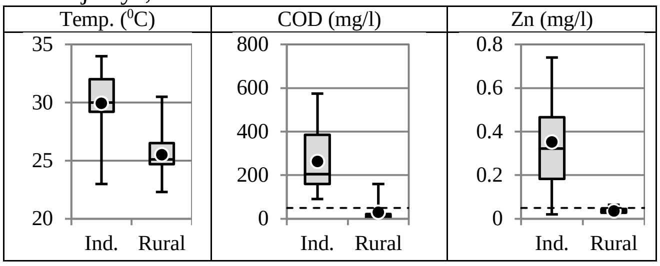
The ten industry clusters in the UCRB lead to large deterioration of water quality. Significant regression was

Table 2: Concentrations in four streams polluted by stockbreeding actitvities, compared with spring water quality, dashed line indicating norm.



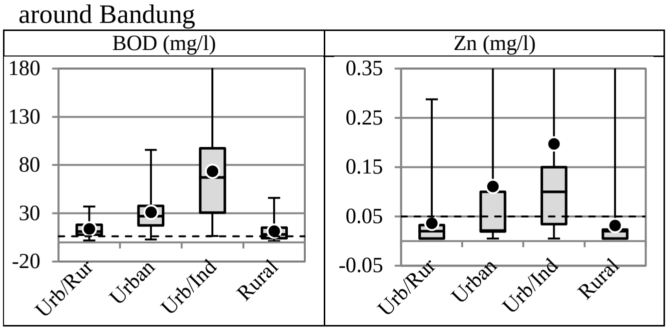
found between presence of industry clusters and pH, TDS, TSS, temperature, BOD, COD, Sulfide, Cl_2, Zn and F concentrations. In Table 2, a rural and an industrial stream are compared to illustrate the deterioration of the water quality in Majalaya industry cluster.

Table 2: Water quality in a typical industrial and rural stream in Majalaya, dashed line indicates norm.



The UCRB is highly urbanized, especially in the North-West, where the city of Bandung is located. Clear correlations were found between high BOD, COD, Fecal Coliform and Zinc concentrations and the presence of settlements, see Table 3.

Table 3 BOD and Zn in urban, rural and industrial streams around Bandung



Spatial variability of water quality

Having characterized the three types of polluted streams, the spatial variability of the water quality through the whole basin will now be described. It was found that the course of the Citarum can be roughly divided in three sections:

1) The first 28 km, from spring to Majalaya (Figure 2) is a rural area with water of reasonable quality. The influence of stockbreeding activities can be clearly noticed in this section; Nitrate-concentrations rise from 0.5 to 2.0 mg/l.

2) From 28 (Majalaya) to 50 km (Sapan), both rural and industrial streams confluence with the main river. A sudden increase in most parameters can be observed, e.g. median BOD values increase from 4.3 to 11.0 mg/l. The BOD standard of 6.0 mg/l is exceeded in 75% of the measurements. Similar patterns are found for the other parameters listed in the 'industrial stream' section.

3) From 50 (Sapan) to 78 km (Nanjung), many rural urban and industrial streams confluence to the main river. Most parameter values remain relatively stable in this section, indicating that concentrations in these tributaries are roughly comparable with that of the main river. The development of the BOD along the river is provided as an example of the upstream-downstream development, see Figure 3.

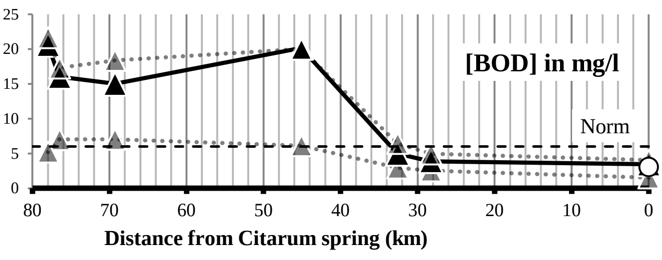
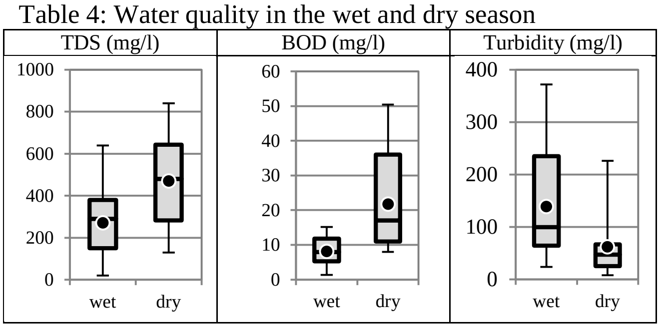


FIGURE 3: 1ST, 3RD QUARTILE AND MEAN BOD

Temporal variability of water quality

As stated in the introduction, the discharge during the dry season is very small compared to the wet season. Two patterns were found with respect to this phenomenon. 1) Low discharge corresponds with large concentrations of TDS, BOD, COD, Sulphate and Free Ammonia. This is because emissions from industry and settlements are roughly similar during the wet and dry season, but the river discharge is variable. Therefore, the concentration during the dry season is roughly two times the concentration during the wet season. 2) An opposite pattern was found for the turbidity of the water, which is generally higher during the wet season. This is because severe rainfall is causing a lot of erosion, and the larger discharges create more turbulence in the water. As a result, the amount of suspended solids will be much higher during the wet season. It is reasonable to assume that this will also bring more pesticides and fertilizer in the water during the wet season.

Table 4: Water quality in the wet and dry season



CONCLUSION

The UCRB naturally is a vulnerable area. Rapid population growth is causing deforestation, leading to large erosion and flooding. The five unnatural drivers of pollution can all be traced back to weak social and governmental institutions. Most inhabitants are either unaware of the impact of their behavior, or unable or even unwilling to change it. The government is not able to execute policy effectively as it lacks knowledge, community support and power to enforce law. Hence, the problem is a mainly non-technical issue.

Two decades of reforms in the Indonesian water sector, made the organization of water quality monitoring in the UCRB very unclear. Monitoring is done by several stakeholders, and the collected data is scattered among them. The provincial government is still believed to be responsible for the monitoring. However, its official authority is transferred to the national government and the actual monitoring is done by the district level government as a result of the decentralization policy. Obviously, there is a strong mismatch between responsibilities, authorities and resources concerning water quality monitoring.

The water quality in the UCRB exceeds the governmental standards for almost all parameters at most locations during a large part of the year. The largest deterioration is caused by the industry clusters, but domestic areas also contribute significantly. The impact of stockbreeding activities is also noticeable. No relation was found with the agricultural areas. Forest has a positive impact on the water quality.

RECOMMENDATION

In the authors' opinion, the position of the (provincial) West Java EPA should be strengthened, so that it has the power, authority and resources to carry out its tasks. Law enforcement towards industries should have the highest priority for three reasons: 1) The data shows that they contribute the most to the pollution. 2) Industrial emissions are concentrated in space and can thus more easily be traced. 3) As legal bodies, industries can relatively easy be held liable for their behavior, in contrast to citizens. Further, the West Java government should provide proper sanitation and waste collection for Bandung City. Reduction of industrial and domestic emissions will take away the principal part of the pollution of the UCRB.

ROLE OF THE STUDENT

Kees van Ginkel was an undergraduate student and carried out his research for the *Alliance of Water, Health and Development* (Radboud University, Institut Teknologi Bandung and Deltares). Datacollection from monitoring stakeholders was mainly done by the local supervisor, Lufiandi. Kees had the lead in the datacollection from the field using a new type of sensors and carried out the system analysis and data analysis himself. He independently interviewed stakeholders and presented the results to local governments, NGOs and ITB students. He also made a short documentary to give an impression of the problems in the UCRB: www.tiny.cc/BandungBasin.

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