Assessing the Impact of Agriculture on Water Quality in the Brantas Catchment

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Mentored by
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Delft University of Technology & Universitas Brawijaya
December 2023

Abstract

In this study, the relationship between water quality and agriculture in the upstream region of the Brantas catchment has been investigated, with a focus on Electric Conductivity (EC), Dissolved Oxygen (DO), pH, nitrate, Biological Oxygen Demand (BOD), phosphate and ammonia concentrations. The EC concentrations ranged from 120 to 570 µS/cm, the DO concentrations from 3.15 to 8.57 mg/L, the nitrate concentrations from 0 to 20 ppm, the nitrite concentrations from 0 to 3 ppm, the BOD concentrations from 6.22 to 6.87 mg/L, the phosphate concentrations from 0.25 to 1 mg/L and the ammonia concentrations from 0 to 0.25 mg/L. Using detailed land use data, the correlation between land use classes and water quality parameters was analyzed. Nitrate concentrations of streams of which the catchment area consists of over 70% Ladang area ranged from 2.5 to 11 ppm, while catchment areas consisting of over 70% of Kebun area featured nitrate concentrations of up until 4 ppm. Regarding EC, this difference is 200 to 475 µS/cm versus 200 up until 375 µS/cm. Certain parameter concentrations, in particular BOD, raise potential concern. While this research provides some insights into water quality in the Brantas catchment, it also underlines the need for further investigations employing improved methodologies, increased sampling over a larger timescale and area, and comprehensive, multidisciplinary approaches. It is recommended that further studies in the area focus more on different parameters, in particular BOD.

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1. Introduction

1.1. Problem Statement

Agriculture is an essential industry in many regions, both supporting millions of people and shaping the environment. However, agriculture also disrupts freshwater systems from their natural states (Moss, 2008). The Brantas river plays a fundamental role in rice cultivation (Hayati et al., 2017) as well as in other agricultural activities in East Java, but is also affected by farming practices. The area's agricultural industry therefore poses a clear example of agriculture's dual roles, as a provider of income and food and as a potential disruptor.

While the Brantas river provides the necessary freshwater resources for rice, sugar, fruits and vegetables cultivation, agricultural activities in the basin often redirect nutrient losses into water systems, which can disrupt a rivers natural balance (Grant et al., 1996; Kronvang et al., 1997; Ulén and Mattsson, 2003; Chapman et al., 2005; Chardon and Schoumans, 2007; Heathwaite et al., 2005; Nelson et al., 2005; Schoumans et al., 2014). Together with the impact from sewage -which is often poorly treated- and industry, such disruption can lead to heightened levels of nitrate, phosphate or other pollutants. The consequence is a surge in BOD, initiating eutrophication. This process enhances the growth of aquatic plants and reduces the DO levels in the water which in turn, is harmful to aquatic life.

Given the vital role of the river and its resources, the agricultural practices in the basin and the resulting pollution have significant negative effects (Widiatmono et al., 2017). This is because the river is not only vital for agriculture, it also provides a large part of the areas inhabitants with drinking water and the rivers resources are essential for local fisheries (Hayati et al., 2017).

Moreover, with 18% of Indonesian households relying on surface waters, water quality is not just an environmental issue, but also a public health concern, making the public vulnerable to contamination problems (Statistics Indonesia, 2014; Komarulzaman et al., 2017). Water-borne diseases like diarrhea, which is still a major health concern in Indonesia, responsible for 31% of post-neonatal mortality and 25% of child mortality (UNICEF, 2012; Komarulzaman et al., 2017) is a harsh reminder of this interdependence.

Therefore, there is a serious need to understand the agricultural pollution dynamics in the Brantas catchment. Insights in the interactions between agricultural land use and water quality can lead to a better understanding of pollution sources and pathways, forming a base for effective management and mitigation strategies.

In this study, the pollutants potentially resulting from agriculture have been identified by researching the existing literature. With this information, suitable indicators have been determined, which can be used to measure the state of pollution in the catchment. Subsequently, a Water Quality Monitoring Plan (WQMP) was developed to assess the impact of agriculture on water quality in the Brantas catchment. The goal of this plan is to monitor, assess and describe the pollution load caused by agricultural activity. In this manner, the theory about the effect of agriculture on water quality will be tested and the severity and the spatial variety and distribution of the problem will be assessed. Finally, the data was used to identify in which way different land uses affect water quality. With this information, policy makers could make informed decisions in order to mitigate the effect of agriculture on water quality.

1.2. Research Objectives

To develop an understanding of what has been mentioned in the introduction above, the main research question is *"How does agriculture affect water quality in the Brantas catchment?"*. In order to provide a concrete understanding of how agriculture affects the water quality in the Brantas catchment, the sub-questions have been defined as follows.

- What pollutants can be ascribed to agricultural activity?
- What are good indicators for agricultural water pollution?
- What is the share of pollution that can be ascribed to agricultural activity?
- What are effective solutions to reduce the impact of agriculture on water quality?

1.3. Study Area

The Brantas Catchment, of which an overview is provided in figure 1, lies within the province of East Java, Indonesia. The catchment has an approximate area of 12 000 km^2 (Aldrian and Djamil, 2008). The river is 320 km long, which makes it the longest in the province. As described by Jennerjahn et al. (2004), the origin of the Brantas River lays near the volcano Arjuno and it has three branches, of which the Porong and the Wonokromo are the two major ones, both discharging into Madura Strait. The smaller branch, called Mas River also discharges into the Madura Strait, but after passing the city of Surabaya (Jennerjahn et al., 2004). Approximately 16 million people live in the Brantas area and are dependent on its resources (Jennerjahn et al., 2004). The focus area of this study does not consist of the whole Brantas River basin, but is limited to the area around the city of Malang, located in the eastern part of the catchment. The city is denoted as "Kota MALANG" in Figure 1 and the greater Malang area, which is considered for this study, is labeled as "MALANG". Positioned as the second-largest city in the province after Surabaya, Malang is situated between the Kawi-Bukat and Tengger mountain ranges, at approximately 450 meters above mean sea level.

The reason that this specific location is selected is its abundance of tributaries connected to the Brantas River. The upstream areas, or sub-basins of these tributaries cover a diverse range of farmland types, providing an ideal setting for this research. Furthermore, the area has a good accessibility, making it convenient for research activities. Malang also offers a range of logistical services, further facilitating the execution of this study.

Another important factor influencing the choice for this area is the presence of numerous end-users who rely on the water from the Brantas River, underlining the importance of understanding and monitoring water quality in this region. Additional descriptions on the region, including on its geology, soils, climate as well as on local farming practices are provided in Appendix B. More information on water quality monitoring is provided in Appendix C and a detailed description of the expected pollution and the differences between pollution derived from agriculture and from urban sources can be found in Appendix D.

2. Methodology

2.1. Data Analysis

A common approach of water-quality research involves statistical methods, which are typically used for processing raw quantitative data using mathematical models, formulas, and techniques to extract information and generate meaningful output (Mainali et al., 2019). Regressions are an example of these statistical techniques. They are a tested approach to developing an understanding of the relationship between water quality and watershed characteristics (Chang, 2008; Shi et al., 2016; Zhou et al., 2012; Mainali et al., 2019).

Using regression analysis to compare land use and water quality is a valuable method in environmental research. The purpose is to identify and quantify the relationships between land use patterns like urban, agricultural or forested areas and water quality indicators such as nutrient levels, pollutants or the pH. These can then be used to predict water quality in different scenarios of land use changes, which in turn helps policy makers in planning and the management of resources. Various types of regression models exist. The simplest form is the linear regression which is used to explore direct linear relationships between variables. Next, multiple regression involves several independent variables, for example different types of land use to explain the variation in water quality. Logistic Regressions are used when the dependent variable is categorical, like the presence or absence of a certain water quality criterion. A key consideration is the model complexity. A regression model should be simple enough to be interpreted, but complex enough to capture the reality.

Examples of other statistical methods are cluster analysis, principal component analysis, factor analysis and discriminate analysis which aim to identify influential factors affecting water quality and predict future trends. These multivariate statistical techniques have been used extensively for the analysis of pollution sources, interpretation of water quality data and management of surface water quality (Shrestha and Kazama, 2007; Huang et al., 2010; Zhang et al., 2011; Bu et al., 2013; Edet et al., 2013).

In this study, linear regression models were fitted to connect land use to water quality data. This method was chosen to assess the relationship between water quality and unique land uses. It was thought that this strategy would paint the clearest image of how a single land use impacts water quality parameters and especially, how the effects of the considered land uses differ from one another. The rationale was that by using a large

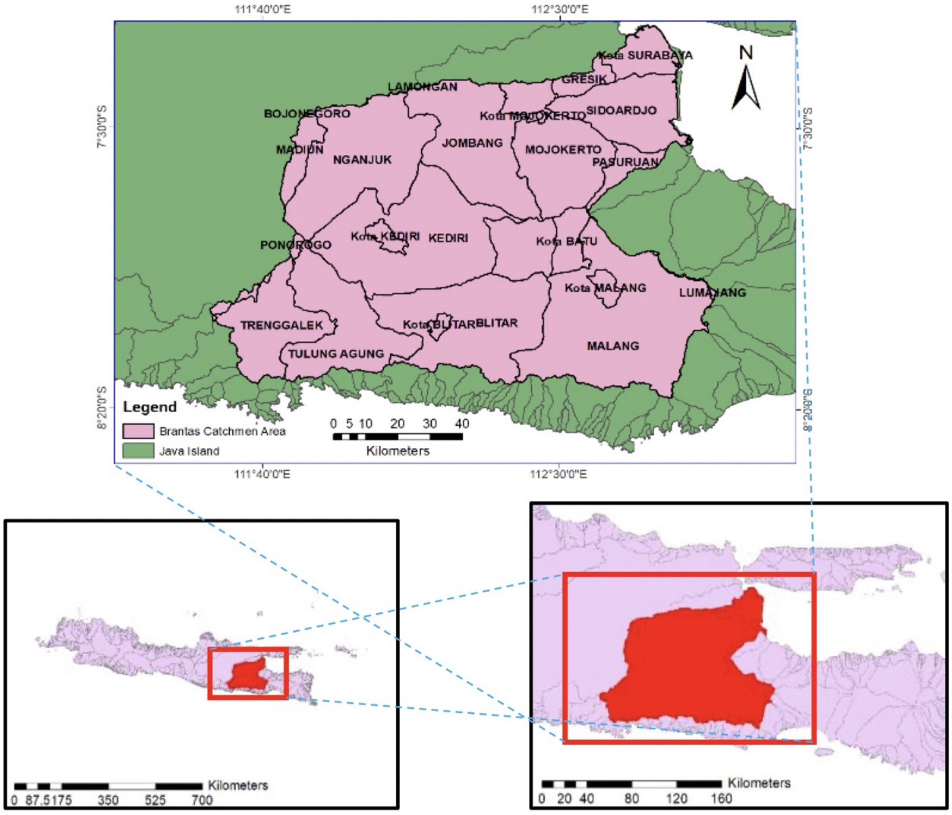


Figure 1: Brantas Catchment (Krishna et al., 2020)

data-set, other types of impact, for example the geology would be factored out. However, in order to obtain an idea about the influence alternative factors pose, these were also considered in separate analyses.

The data analysis is done with a Python script, which functions as follows. The data was imported from Excel to Python using ’Pandas’. Values outside of the 0.01 and 0.99 percentile are removed, so that extreme values, which are likely to be the result of point-source pollution and therefore not representative for this research are not taken into consideration. Next, the data on land use area (’x’) is transformed using a natural logarithm ($t = log(x)$) to analyse the correlation between the water quality parameters and the total areas. A linear fit is then performed on the transformed ’x’ and the original water quality parameters ’y’, using a first-degree polynomial with ‘np.polyfit‘. This returns the slope ’a’ and intercept ’b’ of the line, along with the covariance matrix ’V’. With the linear model parameters ’a’ and ’b’ determined, the script then calculates fitted ‘y‘ values (‘y_fitted‘) using the linear model parameters (‘a‘ and ‘b‘) for a set of ‘x‘ values (‘x_fitted‘). This results in a function in the form $y_{fitted} = a * log(x_{fitted}) + b$.

Next, the coefficient of determination, R^2, is calculated using ‘r2_score‘ from scikit-learn, which measures the proportion of the variance in the dependent variable that is predictable from the independent variable, providing an indication of how well the model fits the data. The mathematical function to determine R^2 is $R^2 = 1 - SS_{res}/SS_{tot}$. Here SS_{res} is the sum of squares of residuals, or the squared differences between observed and predicted y-values, while ss_{tot} is the total sum of squares (the squared differences between observed y values and their mean). R^2 ranges from 0 to 1, where a value closer to 1 indicates a better fit of the model to the data.

Besides the R^2, the script calculated the Pearson correlation and the corresponding P-values per regression, by using the ’pearsonr’ function from the ’stats’ module. The Pearson correlation is essentially a degree of linear relationship between two variables. The corresponding P-value is calculated to determine the statistical significance of the observed Pearson correlation coefficient.

Finally, a scatter plot is created of the original data together with the fitted curve. The x-axis represents the absolute area of the various land uses while on a logarithmic scale due to the transformation applied to the ‘x‘ data. On the y-axis, the water quality parameters are depicted. This is then repeated, but instead of using the natural logarithm of the total upstream area for each land use class, the fraction of area taken up by each land use class compared to the total upstream area is considered.

The upstream areas used as input data were determined by delineating the watersheds of each sampling site in QGIS. A visualization of the watersheds of the sampling locations is given in figure E.21. Then it was calculated per sampling point how large the delineated upstream area overlapping with each land use class was. These calculations resulted in the upstream area per land use class covering the watershed of each respective sampling point. In other words, the result was a data-set which described how much area per land use class was upstream of each sampling point. The fraction of area per land use class could then be determined by dividing the area of each upstream land use class by the total upstream area. The parameters for which the regression analyses are made are EC and pH values and DO and nitrate concentrations. The land use classes used for the regressions are described in 2.1.1.

2.1.1. Land Use Classes

The land use classes in which the area has been divided are based on the data from Tanahair Indonesia (2020). Tanahair Indonesia (2020) differentiates between multiple agricultural and non-agricultural land use classes. The ones used for this research include sawah, ladang, kebun and urban area. As these classes can not be translated directly to English, brief descriptions are provided below.

The Bahasa word "sawah" refers to a type of land use in Indonesia and other Southeast Asian countries. It specifically denotes rice paddy fields or wet rice cultivation. Sawah fields are typically flooded or irrigated to cultivate rice. These fields are organized into a series of terraces or paddies to control water levels and promote optimal rice growth. Examples as observed in the research area are shown in Appendix M.1.

The Bahasa word "ladang" represents a type of dryland or upland farming where crops are grown without the need for continuous irrigation or waterlogged conditions. Unlike the flooded sawah fields, ladang typically involves the cultivation of crops like corn, soy, cassava, or other upland crops that do not require constant inundation. Ladang farming often requires slash-and-burn or shifting cultivation practices, where farmers clear a piece of land and burn the vegetation (subfigure M.28b) to release nutrients. Crops are typically planted for a few seasons, after which the area is abandoned and a new field is cultivated. This agricultural system is often practiced by indigenous communities. Ladang farming systems are important for providing subsistence crops and maintaining traditional agricultural practices in the region. Some examples can be found in Appendix M.2.

The Bahasa word "kebun" refers to a garden or orchard type of land use. It represents an area dedicated to growing a variety of crops, often fruits, vegetables, and other plants, in a more organized and deliberate manner compared to ladang or dryland farming. kebun areas are often situated near homes or villages and can be cultivated for personal consumption or for selling produce in local markets. Kebun gardens or orchards can include a diverse range of plants, such as mango trees, banana plants, papaya, vegetables, herbs, and other edible plants. This type of farming is often characterized by sustainable, long-term cultivation as opposed to the ladang type of agriculture, where the area is typically abandoned after a few seasons. Some examples are provided in Appendix M.3.

The final land use class in this study is urban area. These areas feature settlements, in most cases of limited size, but there are also larger towns and villages in the region. The largest settlement that was taken into account in the data analysis is the city of Batu, while the smallest urban areas are settlements consisting of only a few houses, like in subfigure M.30b. For some more examples, see Appendix M.4.

In order to obtain a good image of how various land uses influence the water quality parameters, some combinations of land use classes are taken into consideration in the data analyses. These are total agriculture, in which the sawah, ladang and kebun land use classes are combined and total wet agriculture, which is a combination of the sawah and ladang areas.

2.2. Water Quality per Catchment

In order to determine the difference in water quality per catchment, the sampling sites have been labeled per catchment. Next, the data has been plotted using box-plots. The sub-catchments in which the area has been divided and for which the data was plotted are the areas as described in subsection 2.7.2 The parameters which are considered for this type of analysis are EC values, pH and nitrate and DO concentrations. As for the latter, measurements taken with the Greisinger and Horiba device are both considered in separate analyses.

2.3. Water Quality per Weather Condition

Similarly to section 2.2, the weather condition at the time of each measurement have been labeled and the water quality parameters were plotted using box-plots. Each box-plot describes a parameter for a specific weather condition. Like in the section above, the parameters for which the this was done are EC, pH, DO and nitrate concentrations.

2.4. Water Quality and Geology

In order to assess the influence of geology and soil type on water quality, the Food and Agriculture Organization (FAO) soil classes were used. Per sampling site it was determined in which FAO soil class the sampling site was situated. Then, box-plots were made per soil class, per parameter. For a map of the sampling sites and the soil types of the area, see figure B.18.

2.5. The Republic of Indonesian Water Quality Standards

The Indonesian Government Index Djaman (2021) as briefly described in Appendix C.2 consists out of 4 classes. The concentration of a total of 50 parameters determine to which class the water quality adheres to. For the complete list of parameters, see Appendix J. Per measurement, it has been determined to which class the sample belongs.

However, it is important to note that only a limited amount of parameters has been measured for each sample. Therefore, the result is only based on the parameters used and not for all parameters which lead to the final characterization. As described in section 2.7.3 the parameters temperature EC, pH, and DO, nitrite and nitrate concentrations are determined for every sample. As for some samples, the BOD levels and phosphate and ammonia concentrations are also measured. This analysis does therefore not offer the full surface water characterization for which water samples have to be tested for all 50 parameters, but merely an indication.

The index works with a ”one out all out principle”, meaning that the criteria of all parameters have to be met in order for a sample to classify as a certain water quality class. In line with this principle, every measurement has been assessed separately and the percentage of samples meeting the criteria per class will be calculated. The parameters that are not measured for every sample have received an additional assessment in a qualitative way to account for the limited sample size.

2.6. *World Health Organization Guidelines for Drinking-Water Quality*

The World Health Organization (WHO) index consists of guidelines concerning water quality. These were compared with the obtained data. Then, it was calculated what percentage of the data meets the standards of these WHO guidelines.

2.7. *Water Quality Monitoring Plan*

When designing a WQMP, the following elements need to be considered: (i) identification of monitoring objectives, or the data which needs to be produced, see 2.7.1; (ii) determination of a sampling site network, see 2.7.2; (iii) selection of the water quality parameters, see 2.7.3; (iv) establishment of sampling frequencies and recurrence, see 2.7.4; (v) estimation of human, technical and financial resources, see 2.7.5 and 2.7.9; (vi) preparation of the logistics, including on the field work, laboratory work, quality control and assessment, data handling, data storing, data analysis, see 2.7.6, 2.7.7 and 2.7.8; (vii) identification of information diffusion channels and (viii) an assessment if the information generated has been put to use (Bartram and Ballance, 1996; Harmancioglu et al., 1998; Strobl and Robillard, 2008; Gray, 2017; Behmel et al., 2016). In this paper, elements 1 to 6 are described below. The final two should be considered in a future study.

2.7.1. *Objectives*

This WQMP was set up to assess the impact of agriculture on the water quality in the Brantas catchment. It should result in enough information to both qualitatively and quantitatively determine the pollution load caused by different types of agricultural land uses. Besides, it should result in a data-set through which the pollution load originating from agriculture can be distinguished from the load caused by other sources. Due to the formidable size of the complete Brantas catchment in combination with the limited available resources, the testing was conducted on a finite section of the catchment. Namely, its origin around the city of Malang, described in 1.3.

2.7.2. *Sampling Site Network*

For this research, the water quality has been assessed sporadically over a large spatial distribution. A limited number of sampling sites leaves room for spatial factors causing noise in the data. Therefore, the sampling sites and sampling intervals were chosen such that the variation between land cover and weather are as large as possible given the finite number of covered sites. As most, if not all streams were challenging to reach, the limiting factor of the amount of measurement sites was the physical reachability of the sampling spots. Samples were taken with a bucket on a rope, which was lowered in the water from a bridge, or when possible from the side of the river, stream or channel. This is visualized in figure N.31 in Appendix N. The surface water bodies from which samples were taken varied considerably in size. Some were taken from large tributaries of the Brantas River, such as the Metro River and others were taken from small streams for optimal variability.

In figure 2 one can see the streams, irrigation channels, subcatchments and land use of the upstream area of the basin. The sub-catchments on the upper left side is the Upper Brantas sub-catchment. Clockwise from there, only covering the sub-catchments that feature sampling locations we encounter the Bango-Sari, Amprong, Manten and Metro sub-catchments. A map with labelled sub-catchments is shown in figure E.20. A map of the land use classes in the area can be found in figure 3. The land use classes ladang, kebun and sawah are described in detail in sub-section 2.1.1. In order to distinguish between water pollution caused by the various kinds of agricultural land uses as well as water pollution from other sources, the upstream area as well as the upstream area per land use was measured for each sampling location by using QGIS.

2.7.3. *Water Quality Parameters*

The water quality parameters which were systematically measured for each sampling location are pH, water temperature, DO, EC, nitrate and nitrite concentrations. These parameters were selected because they can be conveniently measured in-situ in such a way that a large data-set can be obtained with a limited amount of time and financial resources. Additionally, ten samples with varying upstream areas and upstream land uses were brought to a laboratory to measure their BOD concentrations. This is only done in one sub-catchment, due to logistical constraints. Finally, six samples were tested for phosphate and ammonia concentrations.

2.7.4. *Sampling Frequencies and Recurrence*

The fieldwork has been conducted for 8 weeks. Per week, 3 field trips were conducted on average during which approximately 10 sites were be visited to perform in-situ measurements.

2.7.5. *Instruments*

The instruments that were used in this research for in-situ measurements are a Hanna Instruments HI991301, which is able to measure EC, temperature and pH. Two DO metres, the Greisinger G1610 and the Horiba LAQUA DO220. An additional multi-meter, an Horiba U-50 was used in a laboratory. Furthermore, The AquaChek 641426E nitrate/nitrite test strips were used to measure the nitrate content of the water. To test for BOD, samples were brought to a laboratory.

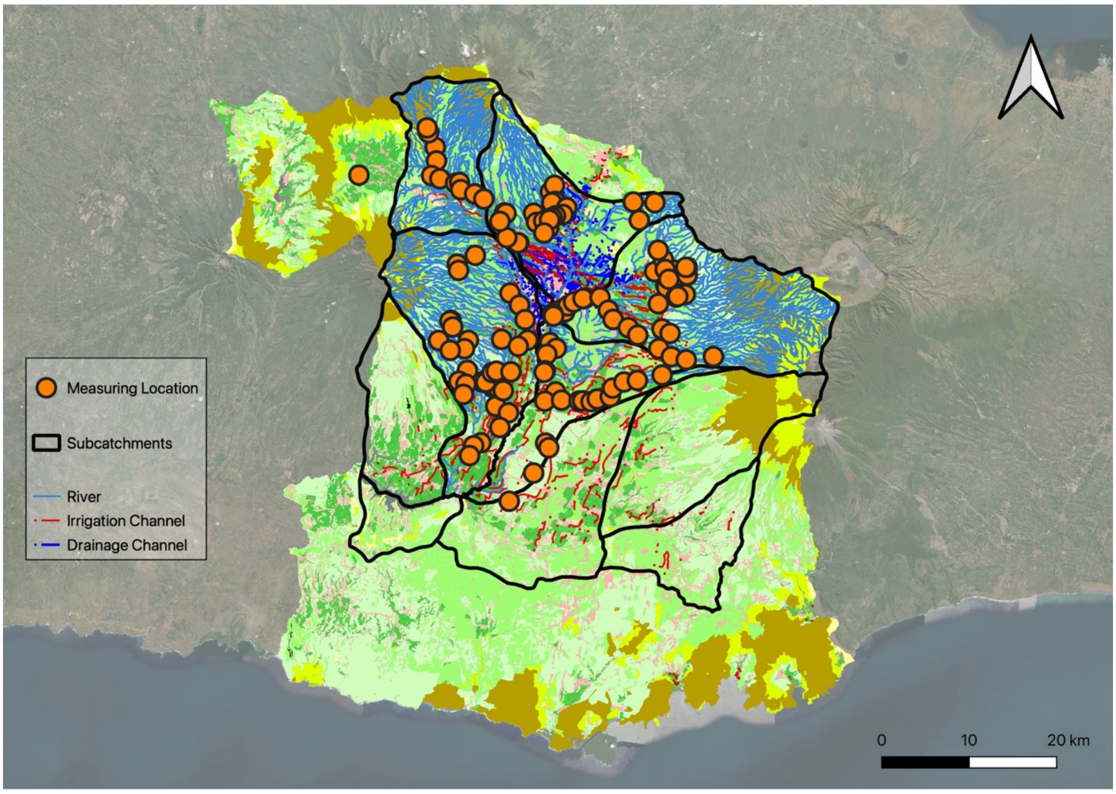


Figure 2: Measuring Sites

2.7.6. *Logistics*

The sampling locations as defined in figure 2 are all reachable by moped. The equipment suitable for in-situ measurements was taken along as well as multiple bottles so that samples could be taken to the laboratory for BOD measurements.

2.7.7. *Accuracy and Quality Control*

The accuracy of the used instruments according to their respective documentation can be found in table G.3 in Appendix G. The accuracy of the measurements was assessed by taking a water sample of the same stream 20 times and checking the deviation. The multi-meter has been cross checked by measuring the same samples with a different multi-meter. The DO was cross examined in-situ by taking measurements with both the Greisinger G1610 and the Horiba LAQUA DO220. The EC and pH values were cross examined with a Horiba U-50 multi parameter water quality checker by taking one sample to the laboratory every week.

The quality of the measurements themselves was assessed by taking 20 samples from the same point at the same time and examining these samples for every parameter that can be checked in-situ. The nitrate/nitrite strips were tested by testing the same sample twice and comparing the results. Lastly, the quality of the BOD laboratory results were checked by using a double blind.

2.7.8. *Handling and Storing Data*

The data acquired during the fieldwork is non-sensitive. It has been shared with all stakeholders involved. To ensure that the data would not get lost it was stored both locally and in a cloud environment.

2.7.9. *Human and Financial Resources*

The costs of the fieldwork are listed in table H.4 in Appendix H. The surveying was carried out in a group of six to seven people contributing as volunteers.

2.7.10. *Rainfall Time-Series*

The weather conditions during the fieldwork and an overview of the rainfall during the monitoring period are provided in figure I.25 in Appendix I.

2.7.11. *Continuation of the Monitoring Plan*

As described in Appendix B.3, the area has a wet and dry season. It is worth noting that the data acquired for this thesis does not include the full picture as it only includes measurements executed in the dry season. In order to offer a full understanding of the temporal variability it is recommended, if not essential that the monitoring is continued in both wet and dry seasons. Additionally, in order to encompass not only seasonal, but also annual variability it is recommended to measure at all sites once every month in the coming years. The choice of a monthly interval is chosen because it balances capturing the full spectrum of seasonal changes with remaining cost-effective.

Moreover, in the continued plan, more attention should be given to the parameters that have been underrepresented in the plan as described above. BOD, ammonia and phosphate should be measured at every site to monitor the spatial variability of

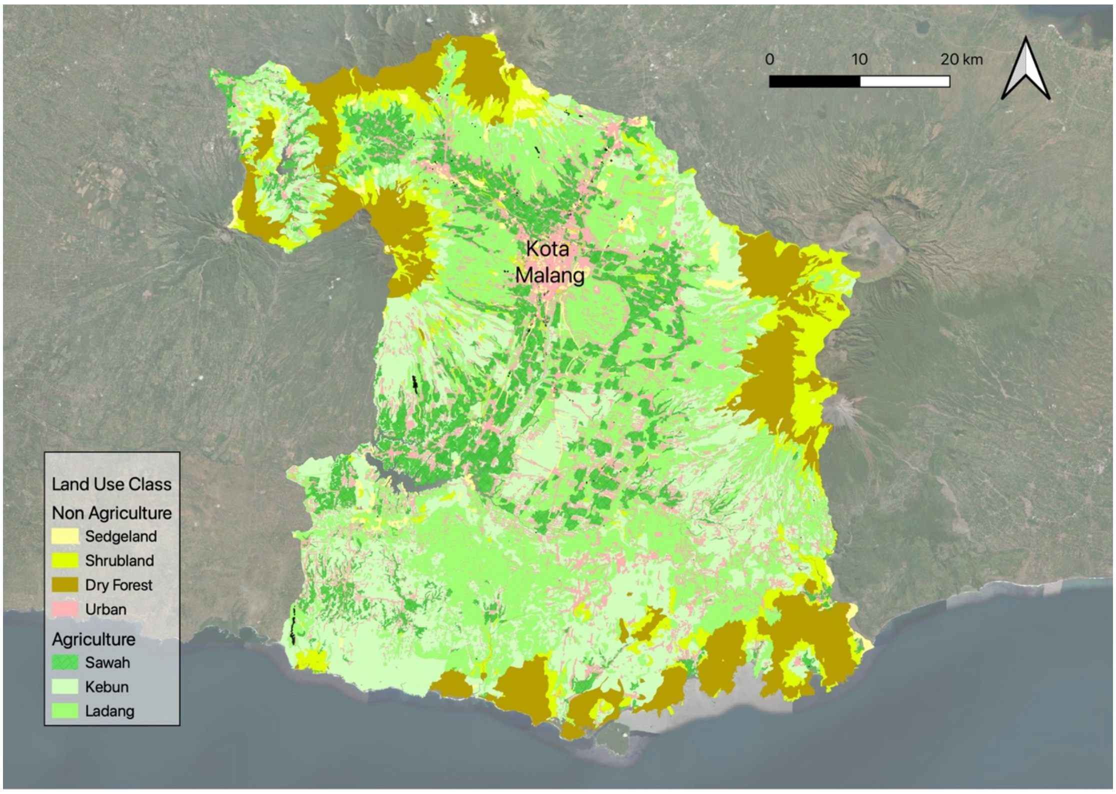


Figure 3: Land Use Map

these parameters. As the current methods to assess the concentrations of these three parameters do not offer a high level of accuracy, other assessment methods should be taken into consideration. Additionally, it would be valuable to start monitoring for additional parameters related to agriculture such as pesticides.

3. Results and Discussion

3.1. General Note on Dissolved Oxygen Measurements

The Greisinger DO meter did not deliver accurate results when compared to the Horiba DO meter and a third DO meter. As visualized in figure K.26 in Appendix K, there is no clear correlation between the measurements from the Greisinger and Horiba instruments. Because unlike the Greisinger device, the Horiba instrument seemed to be working well when compared to the Horiba U-50 in a laboratory, the results regarding the DO based on the measurements with the Greisinger device are deemed unreliable. However, they are still included in the results as they might offer an insight into the relative differences in DO levels. Because the Horiba device was only used later on, the resulting data-set is not large enough for it to be displayed in box-plots.

3.2. Note on How to Read the Plots Below

3.2.1. Upstream Area per Land Use Class

Below, scatter-plots with corresponding regressions are visible. The dots of the scatter-plots represent individual measurements. The x-axis represents the size of the areas for each land use class overlapping with the watershed for the sampling locations. In other words, if the watershed of a single sampling site consists for a 100 hectares of urban area, that is were the dot will be located on figure 4g, the EC versus Urban Area subplot with respect to the x-axis. The y-axis, represents the water quality parameters of the water sample taken at the sampling location. Considering the plot mentioned above, if a sample has an EC value of 400 µS/cm, that is were its corresponding dot will be located with respect to the y-axis. The line represents the regression through the data, about which more can be found in subsection 2.1.

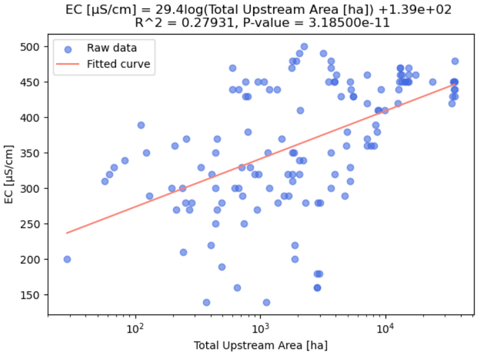
3.2.2. Upstream Area Fractions per Land Use Class

The scatter-plots representing the upstream area fractions per land use class are similar in function to the plots representing the total area per land use class as described above. The difference is that the x-axis of the plots describing the upstream area fractions do not represent the absolute area per land use class but the fraction of area covered by this land use class. To put it another way, if the watershed of a single sampling site consists for a 100 hectares of urban area while its total area is 1000 hectares, the dot representing this sampling point will be located at 0.10 on the x-axis in figure 5f.

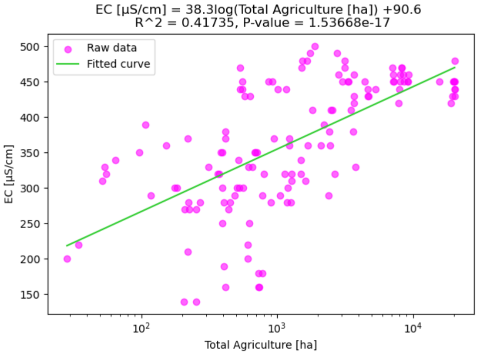
3.3. Electrical Conductivity

3.3.1. Upstream Area per Land Use Class

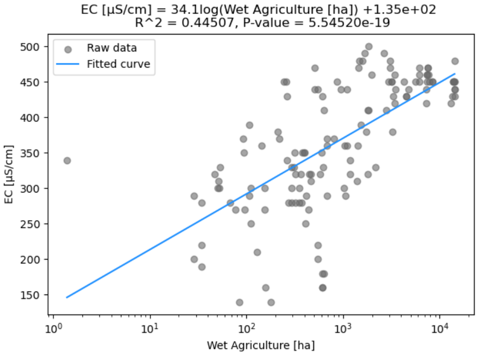
As visible in the figures below, the different land use classes have varying correlations with the sampled EC values. The land use classes ranged from stronger to weaker correlation to EC according to their respective R^2 values are urban area (with an R^2 of 0.48), wet agriculture area, total agriculture area, sawah are, ladang area, total upstream area and kebun area (with an R^2 of 0.09) respectively. For all figures, the direction of the curve is upwards. The steepest and gentlest curve are those of the relationship between EC and total upstream agricultural area (38.3) and upstream kebun area (12.1) respectively. The P-values of the regressions are all below 0.05, with the highest and lowest values belonging to the plots representing urban and kebun area respectively.



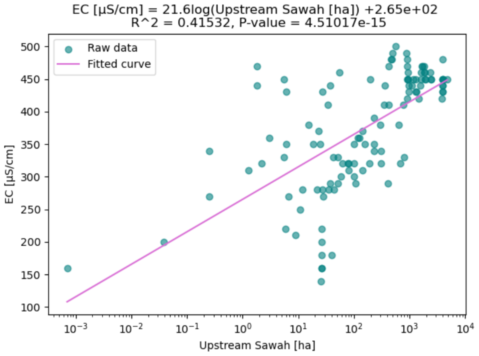
(a) EC versus Total Upstream Area



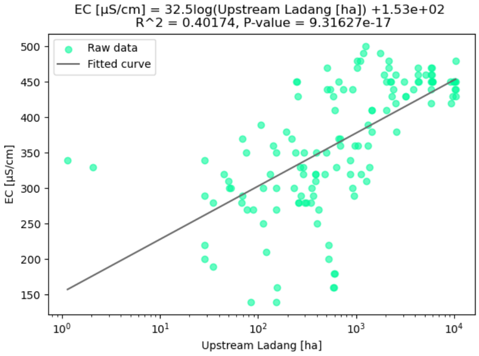
(b) EC versus Total Upstream Agriculture



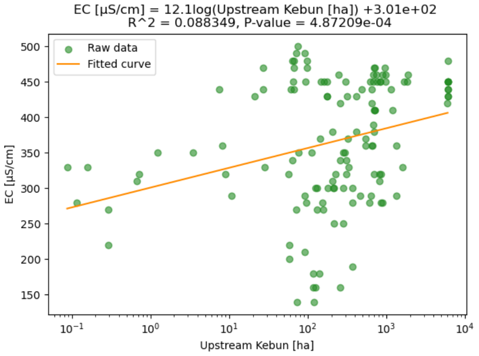
(c) EC versus Upstream Wet Agriculture



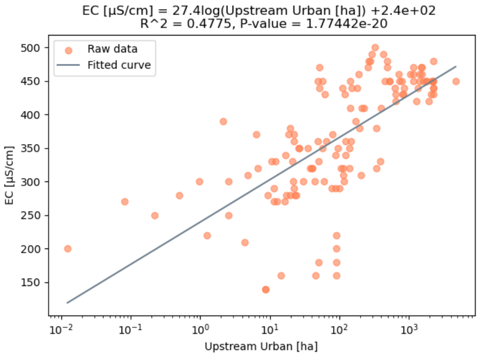
(d) EC versus Sawah Area



(e) EC versus Ladang Area



(f) EC versus Kebun Area

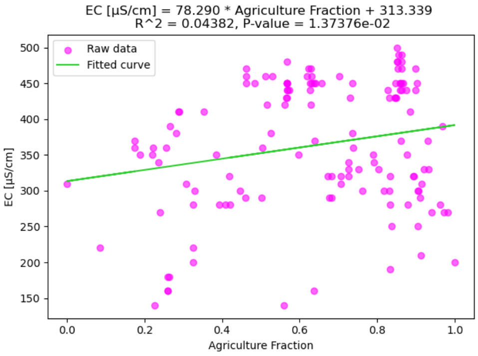


(g) EC versus Urban Area

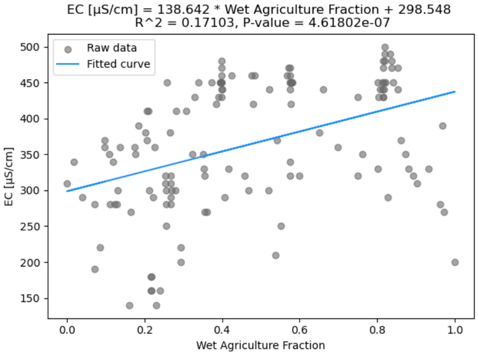
Figure 4: EC versus Upstream Area per Land Class

3.3.2. *Upstream Area Fractions per Land Use Class*

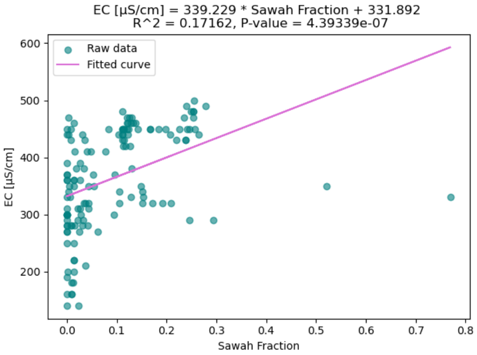
Below the relationship between the fractions of the land use classes and the EC values of the measurements are shown. All land use class fractions seem to have a positive correlation with the EC measurements with the exception of the kebun area fraction. The slopes are steep compared to the plots of other parameters. The steepest curve belongs to the urban area fraction and has a slope of 941. The gentlest slope is the one depicting the regression of the total agriculture area fraction with a value of 78.3. As mentioned before, the curve belonging to the kebun Area fraction is directed downwards, with a slope of 136.4. The R^2 values range from 0.082 for the ladang area fraction to 0.31 for the urban area fraction. The P-values of the regressions are all below 0.05.



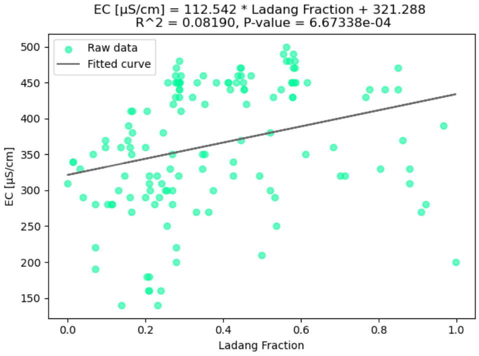
(a) EC versus Upstream Agriculture Fraction



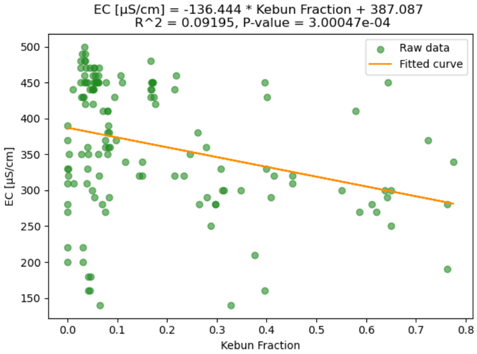
(b) EC versus Upstream Wet Agriculture Fraction



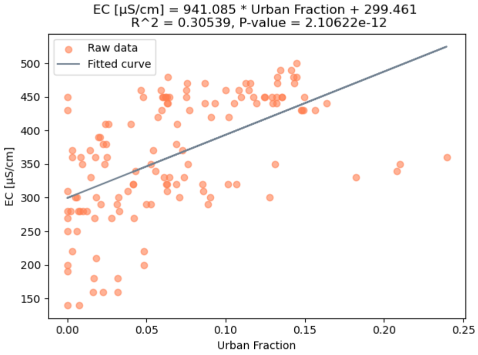
(c) EC versus Sawah Area Fraction



(d) EC versus Ladang Area Fraction



(e) EC versus Kebun Area Fraction



(f) EC versus Urban Area Fraction

Figure 5: EC versus Upstream Area Fractions per Land Class

Because all curves describing the total area are directed upwards, including the curve displaying the total combined upstream area it seems that the larger the upstream area, the larger the EC values are. However, all land uses excluding kebun area feature a more defined relationship with EC values compared to the total combined upstream area according to the R^2 values of the regressions. Additionally, the curves representing the total agriculture, wet agriculture and ladang areas are steeper than the curve representing the total combined upstream area. From statistical analyses by Li et al. (2012), it was concluded that EC values were influenced by agricultural land use and according to

Bostanmaneshrad et al. (2018), agricultural lands caused an increase in EC. This research also suggests this based on the interpretation above, but how significant and strong this relationship is depends on the land use class. As the steepest curve belongs to the relationship between EC and total upstream agricultural land use, agricultural land use seems to have the strongest influence on EC values, while kebun area, featuring the gentlest curve and a low R^2 value, seems to have the least defined effect on the EC values of the water samples. When looking at the area fractions, the theory that kebun area has the least detrimental effect on EC values is underlined, as it is the only curve featuring a negative relationship, while wet agriculture has the steepest upward sloping curve. However, because there is a hardly any correlation according to the R^2 value of the regression, no strong conclusions can be drawn.

3.4. Nitrate

Although correlations are hardly visible, when looking at the scatter-plots on the next page, most trends regarding total area seem to be sloping upwards. This would make sense, as a larger area would mean more nitrate loading, but it does not necessarily mean that specific land uses have certain effects on nitrate concentrations. The upward trend can also be observed in the plots representing the area fractions, with the exception of kebun area, where the general trend seems to be sloping downwards. This would mean that larger fractions of urban land use and all agricultural land uses, with the exception of kebun area, would result in higher nitrate concentrations. However, as correlations are hardly observable, no strong conclusions should be drawn and it is likely that other factors play a role.

Li et al. (2012) found that that nitrate concentrations were influenced by agricultural land use, which is supported by Zhang et al. (2012), who concluded that nitrate concentrations in multiple rivers, namely the Yang Ding River, Chaobai River, Beiyun River, Jiyun River, and Daqing River were dependent on chemical fertilizer discharge. More specifically, Berka et al. (2001) found that nitrate contaminated groundwater contributed to high nitrate concentrations in a major tributary during the summer. With these studies in mind, it was expected that increasing amounts as well as increasing fractions of agricultural land uses would feature significant positive relationships with nitrate concentrations. Because in this research no clear relationships with the various land uses are found, it could be that there are other, more important sources of nitrate contributing to the total load, for example, poorly treated sewage.

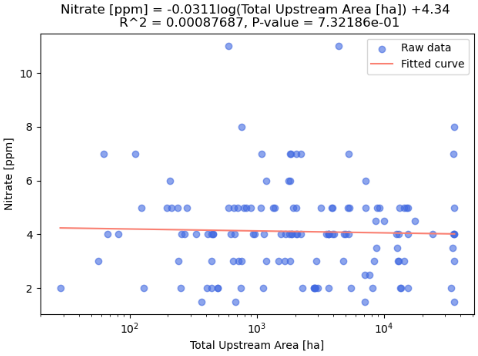
In comparison, in research conducted by Harmel et al. (2008), in which over 1677 watersheds were considered over multiple years with various agricultural land uses, it was found that on average, annual runoff loads were 14.2 kg per ha for total N and 2.2 kg per ha for total P. These losses represented 10 to 25% of applied nitrogen and 4 to 9% of applied phosphorus Harmel et al. (2008). Similar results were found in research conducted by Choi et al. (2012). In their study, runoff loads of total nitrogen and total phosphorus were calculated to be 15.7 kg/ha and 0.4 kg/ha, respectively, which they found to be rather low compared to the loads of total nitrogen and total phosphorus from paddy fields presented by other studies, most likely as a result of rainfall as well as hydrological conditions, irrigation water, fertilizer application, rice straw and plowing (Choi et al., 2012). The observed nitrate concentrations in this study range from approximately 1 to 11 ppm, while most samples had concentrations of around 4 ppm which is equal 4 mg/L. This is in line with a study by Choi et al. (2012) in which the range of total nitrate concentrations was measured to be 2.28 mg/L to 11.75 mg/L.

When comparing these values to the runoff loads observed by Harmel et al. (2008) and Choi et al. (2012), the following calculation can be made. Assuming that an average stream from which the samples are taken has a velocity of 1 m/s, a width of 2 metres and a depth of 1 metre, the discharge of this stream would be 2 m^3/s. The annual loads of nitrate discharged through this average river assuming an average concentration of 4 mg/L of nitrate as observed as approximate average in this research, would then total 252,288 kg. Assuming that 80% of the total nitrogen is present in the form of nitrate, this would result in annual total nitrogen load of 315,360 kg. The upstream areas consisting of combined agriculture range from close to 0 to 11,000 hectares. A large cluster can be found around 1,000 hectares. When taking this cluster as an average area, the annual runoff loads would total 315 kg/ha. The result from this calculation is significantly higher than calculated in the case of the studies by Harmel et al. (2008) and Choi et al. (2012), which underlines that other sources might contribute to the nitrate load observed in the surface water.

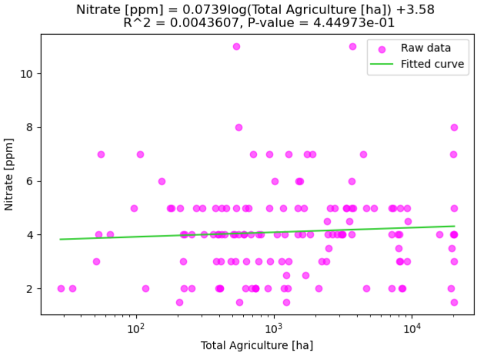
What has to be considered in addition, is that the taken nitrate measurements were not very precise. This can be observed in the data by noting that the nitrate measurements are all clustered at single values. However, the measurements seem reasonably accurate based on the fact that measurements taken from a single sample resulted in the same result.

3.4.1. Upstream Area per Land Use Class

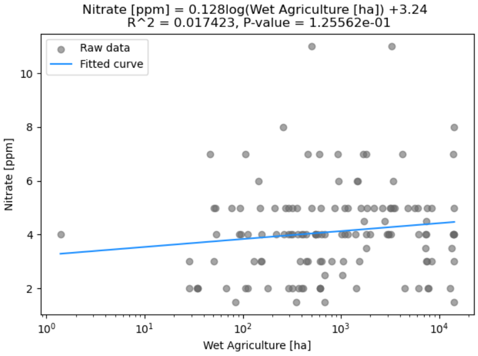
In the figures below the relationship between nitrate concentrations and the land use classes are shown. As visible, there is very little to no correlation between the land use classes and this parameter. The land use classes wet agriculture, ladang and urban area seem to show a slight positive correlation. The R^2 values range from 0.00087 for total upstream area to 0.031 for urban area. The P-values of the regressions are all below 0.05.



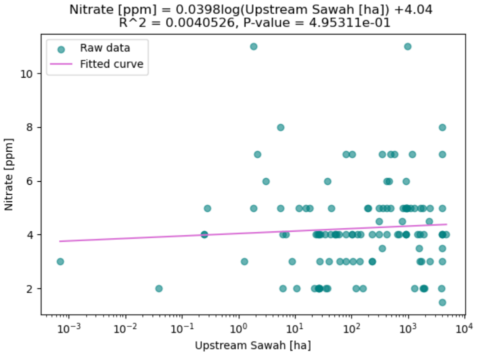
(a) Nitrate versus Total Upstream Area



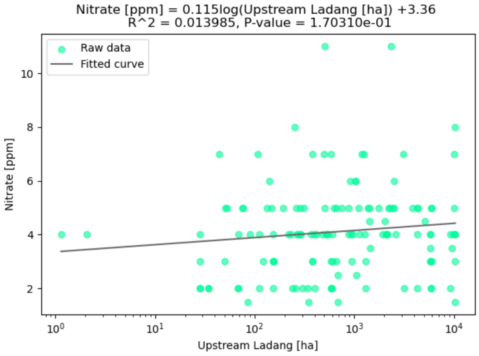
(b) Nitrate versus Total Upstream Agriculture



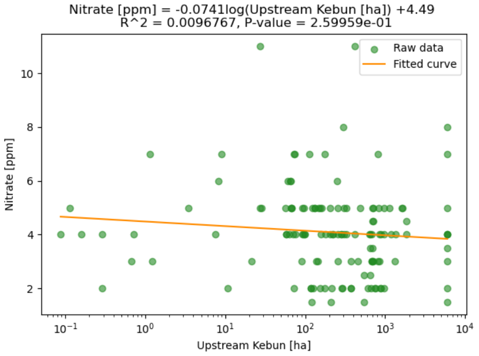
(c) Nitrate versus Upstream Wet Agriculture



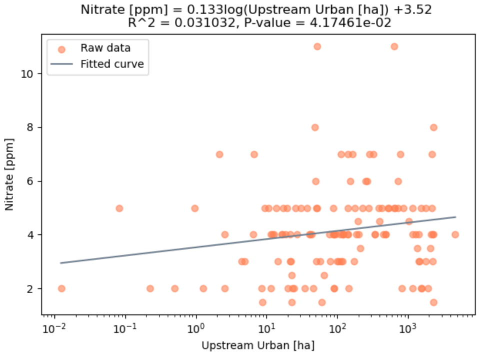
(d) Nitrate versus Sawah Area



(e) Nitrate versus Ladang Area



(f) Nitrate versus Kebun Area

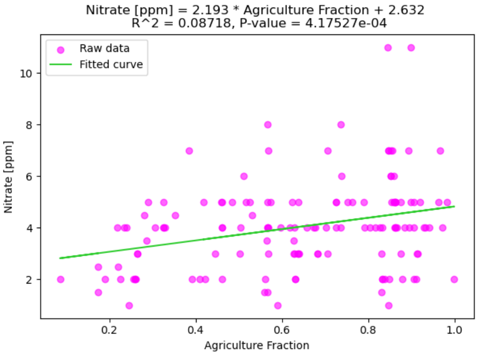


(g) Nitrate versus Urban Area

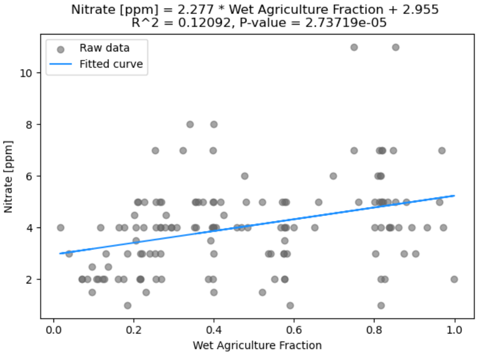
Figure 6: Nitrate versus Upstream Area per Land Class

3.4.2. *Upstream Area Fractions per Land Use Class*

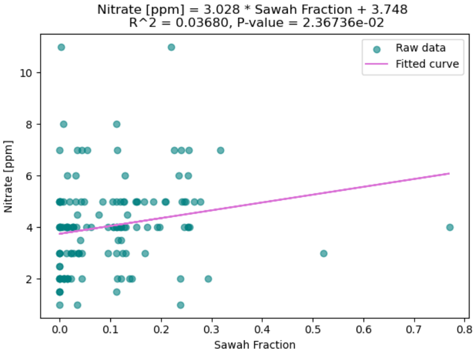
Below the plots of the nitrate concentrations against the land use class fractions are shown. For the plots showing the land use class fractions of total agriculture, wet agriculture, and ladang area, a slight positive correlation can be observed. The plots of the sawah, kebun and the urban area fraction do not seem to show any correlation with the nitrate concentration. The highest R^2 value belongs to the plot displaying the wet agricultural area fraction which has a value of 0.12. The P-values are all below 0.05, apart from the regression belonging to the sub-plot of the kebun area fraction, which is 0.16.



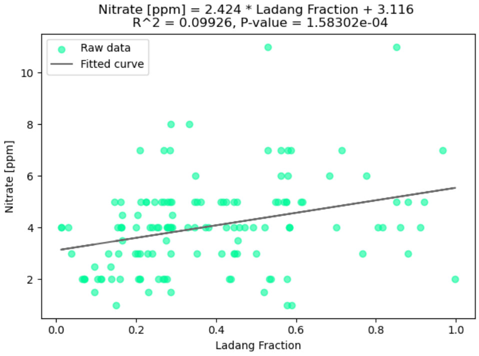
(a) Nitrate versus Upstream Agriculture Fraction



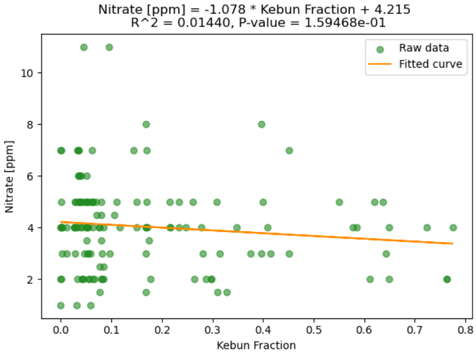
(b) Nitrate versus Upstream Wet Agriculture Fraction



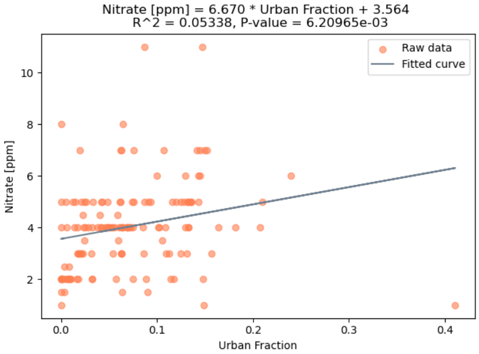
(c) Nitrate versus Sawah Area Fraction



(d) Nitrate versus Ladang Area Fraction



(e) Nitrate versus Kebun Area Fraction



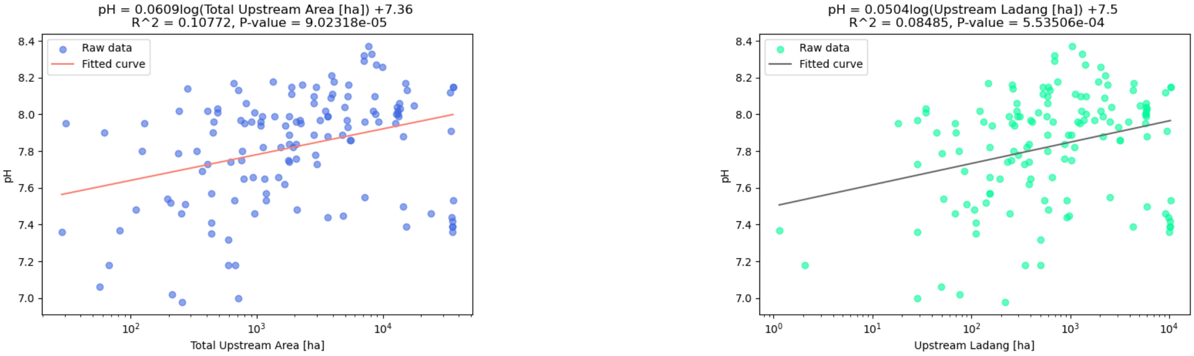
(f) Nitrate versus Urban Area Fraction

Figure 7: Nitrate versus Upstream Area Fractions per Land Class

3.5. *pH*

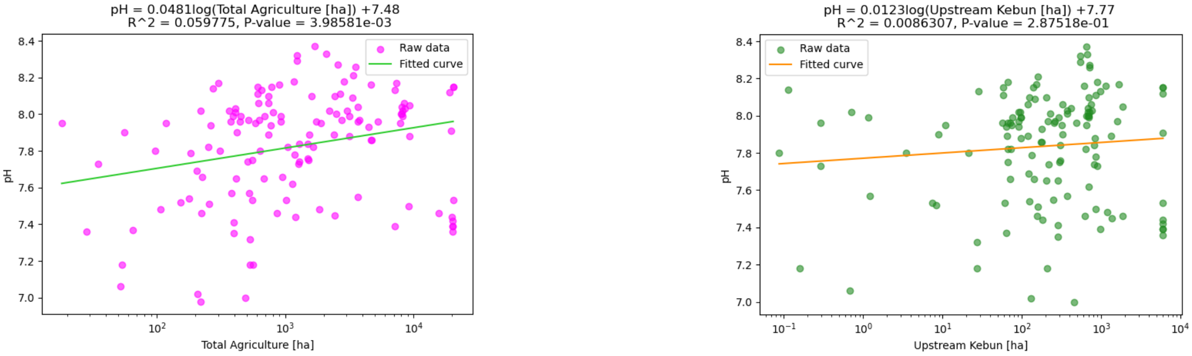
3.5.1. *Upstream Area per Land Use Class*

The plots below show the areas of the upstream land classes against the pH levels of the measurements. All figures show a slight positive correlation with slopes ranging from 0.012 for kebun area, to 0.061 for total upstream area. The R^2 values range from 0.0086 for kebun area to 0.11 for total upstream area. The P-values are below 0.05, apart from the P-value belonging to the kebun area regression.



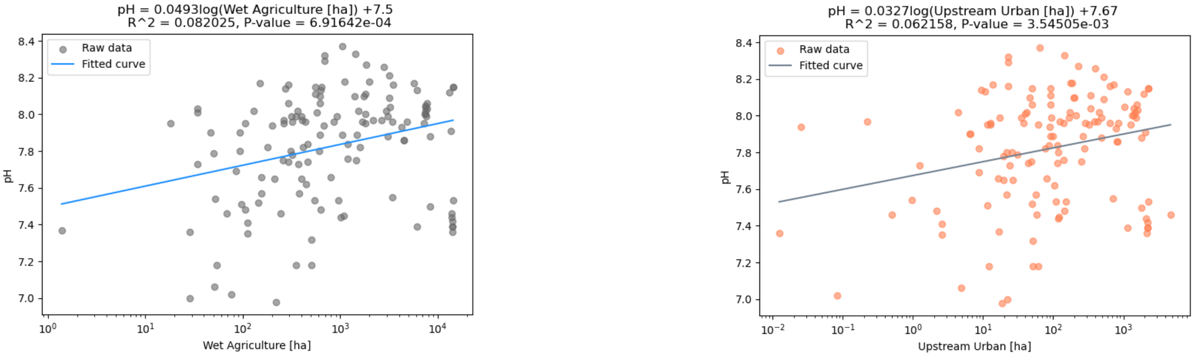
(a) pH versus Total Upstream Area

(e) pH versus Ladang Area



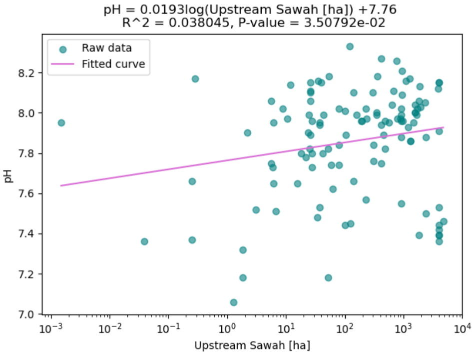
(b) pH versus Total Upstream Agriculture

(f) pH versus Kebun Area



(c) pH versus Upstream Wet Agriculture

(g) pH versus Urban Area

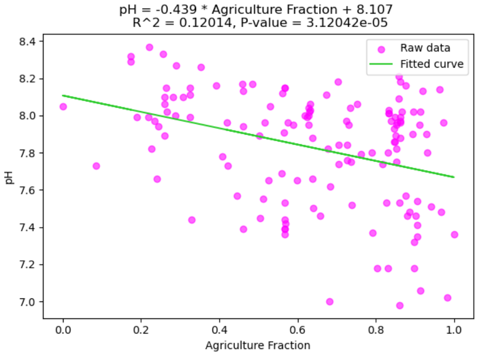


(d) pH versus Sawah Area

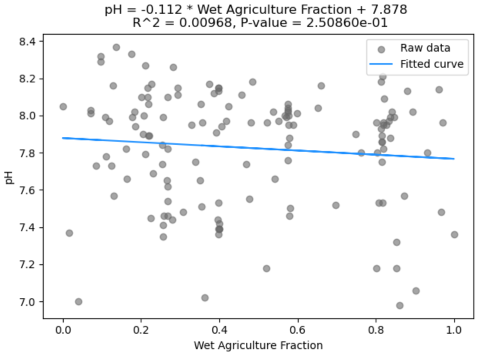
Figure 8: pH versus Upstream Area per Land Class

3.5.2. Upstream Area Fractions per Land Use Class

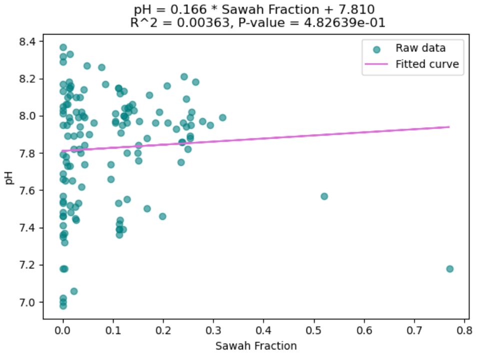
Below scatter-plots and subsequent regressions are shown of the land use class fractions and the pH values of the measurements. As visible, the regressions are sloping downwards, with the exception of the plot belonging to the sawah area fraction. However, clear correlations are not distinguishable with the exception of the plot displaying the agricultural area fraction and the kebun area fraction which seems to be slightly negatively correlated. The R^2 values of the regressions are all below 0.12. The P-values of the plots displaying the wet agriculture area fraction, the sawah area fraction, the ladang area fraction and urban area fraction are all above 0.05.



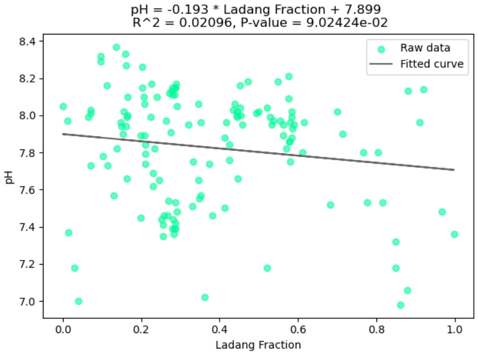
(a) pH versus Upstream Agriculture Fraction



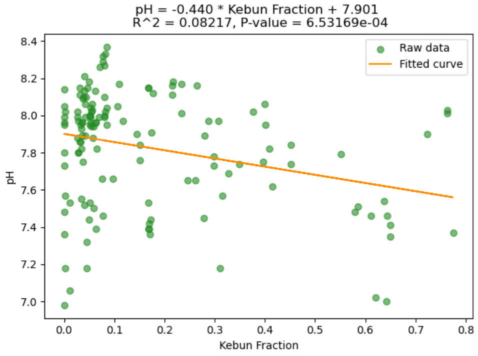
(b) pH versus Upstream Wet Agriculture Fraction



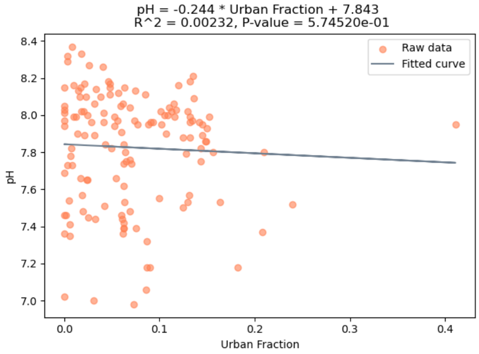
(c) pH versus Sawah Area Fraction



(d) pH versus Ladang Area Fraction



(e) pH versus Kebun Area Fraction



(f) pH versus Urban Area Fraction

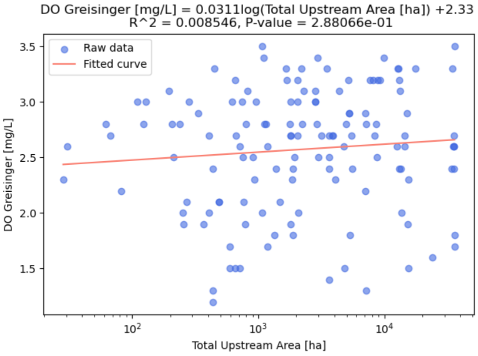
Figure 9: pH versus Upstream Area Fractions per Land Class

It is important to consider that the pH of surface water should remain in a safe range, which is according to local standards between 6 and 9. All of the measured values are within these limits. Notably, the pH seems to increase with larger amounts of any land use class, which could be caused by the mineralogy of the soils. When looking at the area fractions, the pH decreases for increasing fractions of agricultural area as well as for kebun area. This conclusion is supported by Bostanmaneshrad et al. (2018), who found that urban land use reduced pH. For the other land use area fractions, no direct correlations with pH are found.

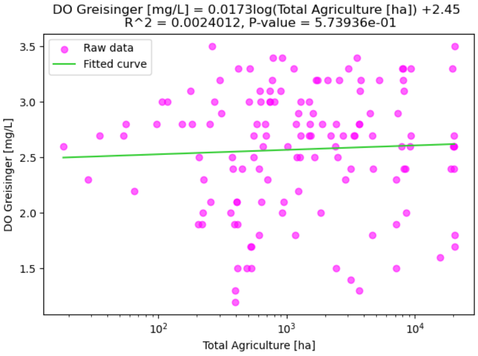
3.6. Dissolved Oxygen (Greisinger)

3.6.1. Upstream Area per Land Use Class

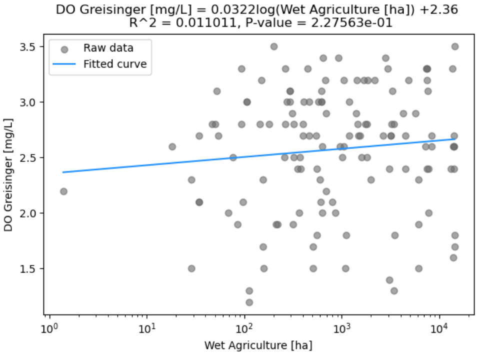
The figures show the scatter-plots and subsequent regressions with the land use classes on the x-axis and the DO concentrations, measured with the Greisinger device on the y-axis. The figures seem to show no obvious correlation and the values for the R^2 of the fitted curves are all below 0.011, while the P-values are all above 0.05.



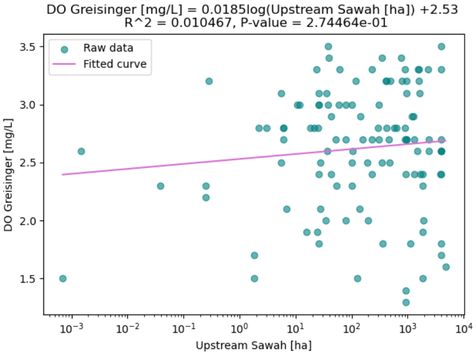
(a) DO (Greisinger) versus Total Upstream Area



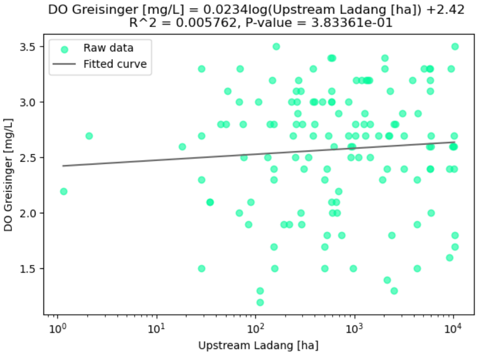
(b) DO (Greisinger) versus Total Upstream Agriculture



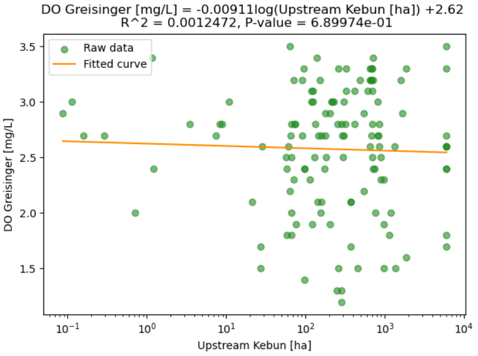
(c) DO (Greisinger) versus Upstream Wet Agriculture



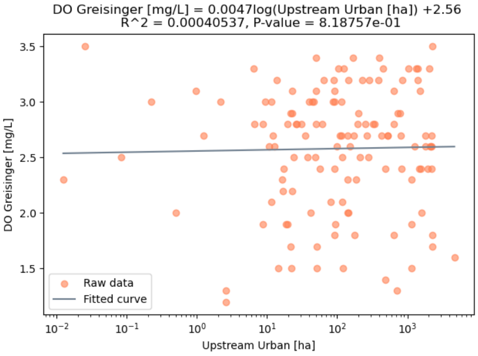
(d) DO (Greisinger) versus Sawah Area



(e) DO (Greisinger) versus Ladang Area



(f) DO (Greisinger) versus Kebun Area

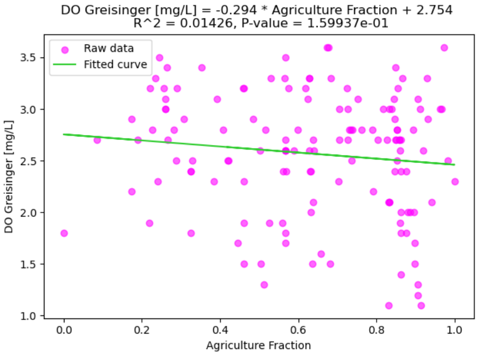


(g) DO (Greisinger) versus Urban Area

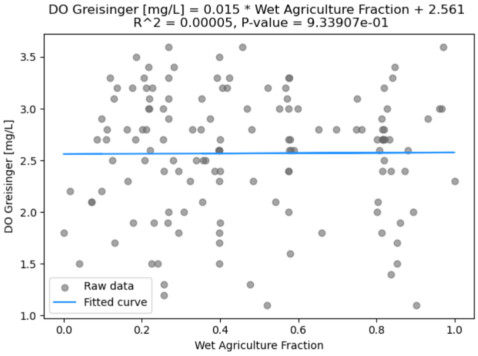
Figure 10: DO (Greisinger) versus Upstream Area per Land Class

3.6.2. Upstream Area Fractions per Land Use Class

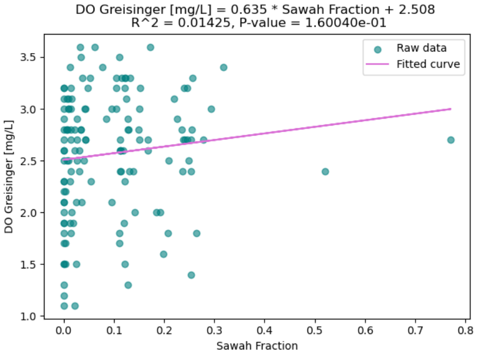
The plots below are displaying the scatter-plots of the land use classes against the DO values measured with the Greisinger instrument. The data seems to be random. The R^2 values of the regressions are all below 0.024 and the P-values above 0.05.



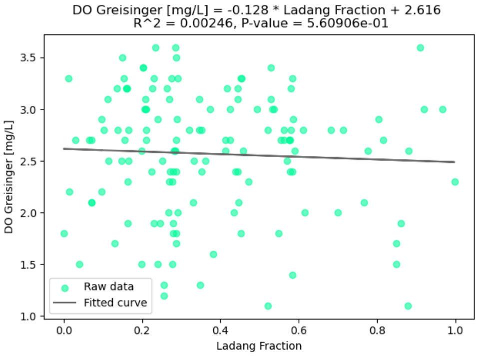
(a) DO (Greisinger) versus Upstream Agriculture Fraction



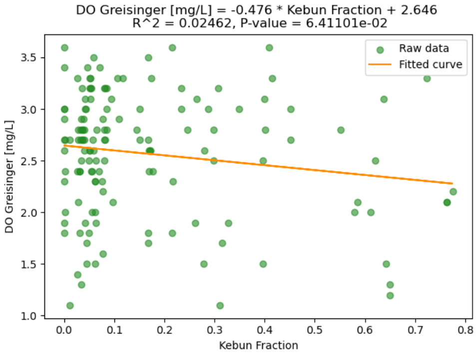
(b) DO (Greisinger) versus Upstream Wet Agriculture Fraction



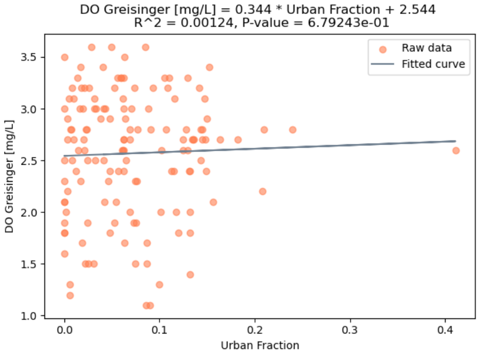
(c) DO (Greisinger) versus Sawah Area Fraction



(d) DO (Greisinger) versus Ladang Area Fraction



(e) DO (Greisinger) versus Kebun Area Fraction



(f) DO (Greisinger) versus Urban Area Fraction

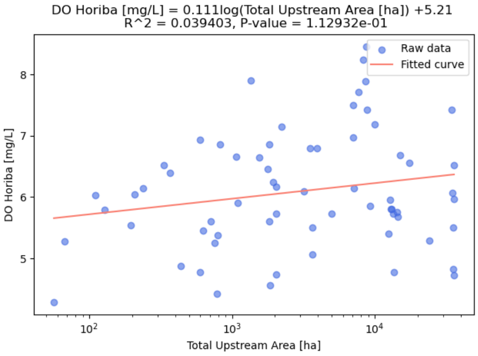
Figure 11: DO (Greisinger) versus Upstream Area Fractions per Land Class

As mentioned in the beginning of this chapter, the Greisinger DO meter was not working properly, which could be the reason the observed DO concentrations seem independent of increasing land use area and increasing land use fractions. The scatterplots representing the absolute upstream areas based on the data produced with the Horiba device seem to be more or less random as well. When looking at the plots with the Horiba data featuring the land use fractions, a downward trend could be observed for some plots, in particular those of the total agriculture, wet agriculture ladang and urban fractions. This could indicate that an increasing fraction of these types of land uses decreases the DO. This theory is supported by Bostanmaneshrad et al. (2018), who found that agricultural lands caused a decrease in the DO of surface waters. Notably, this relationship is not visible in the plot representing the sawah and kebun area fraction.

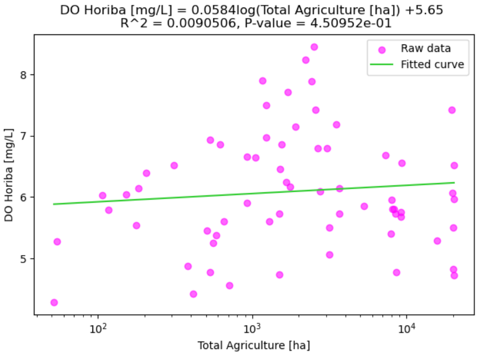
3.7. Dissolved Oxygen (Horiba)

3.7.1. Upstream Area per Land Use Classs

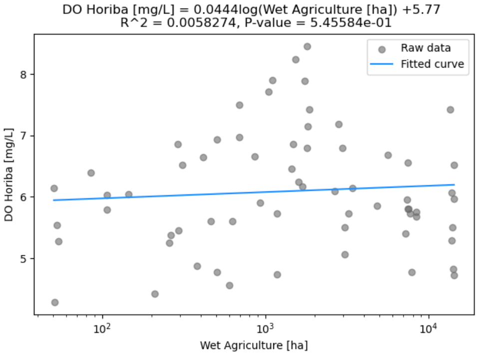
Like in the figures above, the plots show the land use classes plotted against the DO concentrations with on the x-axis the absolute areas. The plots seem to show slight positive correlations. The R^2 values are at 0.03 or below and the P-values are above 0.05. The measurements in these figures are executed with the Horiba device.



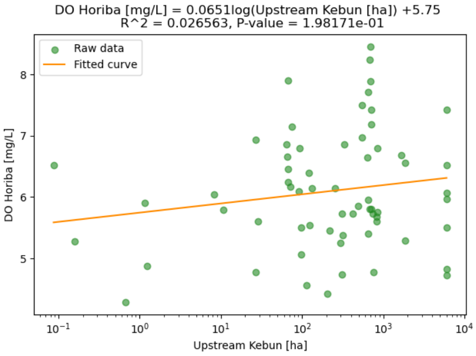
(a) DO (Horiba) versus Total Upstream Area



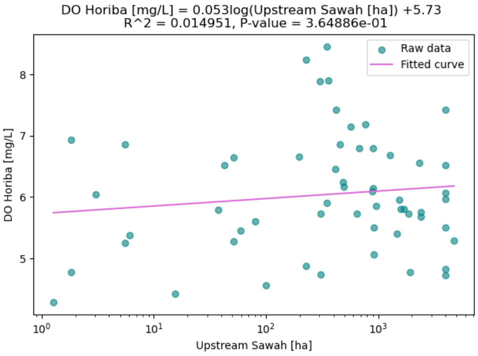
(b) DO (Horiba) versus Total Upstream Agriculture



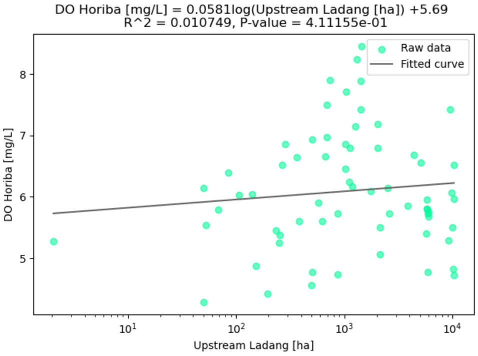
(c) DO (Horiba) versus Upstream Wet Agriculture



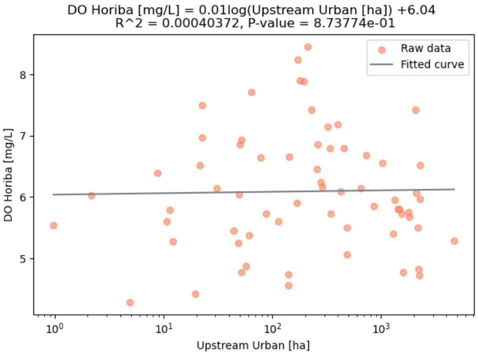
(f) DO (Horiba) versus Kebun Area



(d) DO (Horiba) versus Sawah Area



(e) DO (Horiba) versus Ladang Area

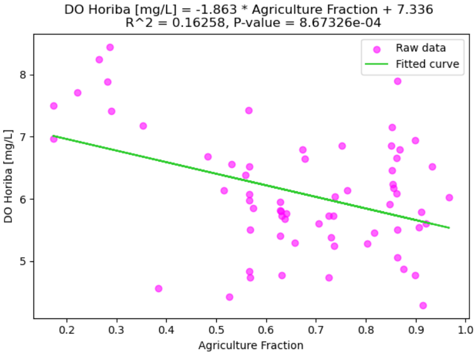


(g) DO (Horiba) versus Urban Area

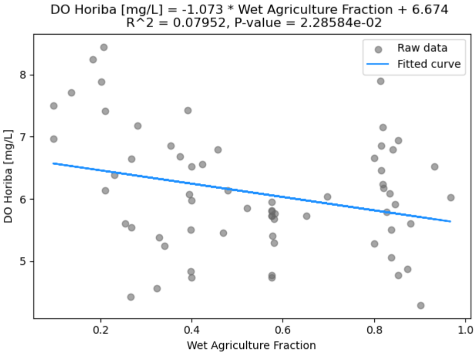
Figure 12: DO (Horiba) versus Upstream Area per Land Class

3.7.2. Upstream Area Fraction per Land Use Class

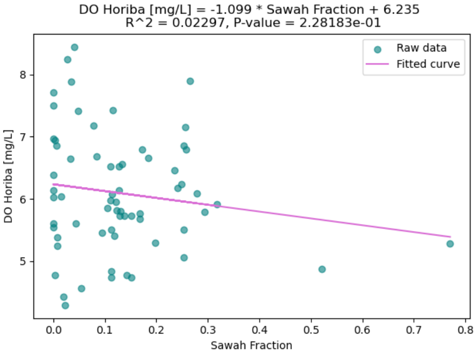
These plots show the land use class fractions against the DO values, measured with the Horiba device. The slopes of the regressions are facing downwards and range from -0.60 for the kebun area fraction to -3.8 for the urban area fraction. The plots of the agricultural and wet agricultural area fraction seem negatively correlated, but they also have the highest R^2 values, of 0.16 and 0.08 respectively. For the other plots a clear correlation cannot be easily observed and the r^2 values of the regressions are 0.06 and below. The P-values of the agriculture fraction and the wet agriculture fraction are above 0.05, but those of the sawah area fraction, the ladang area fraction, the kebun area fraction and the urban area fraction are not.



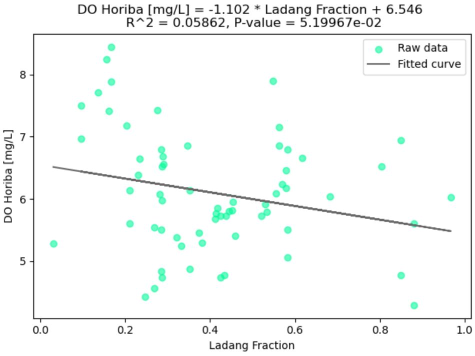
(a) DO (Horiba) versus Upstream Agriculture Fraction



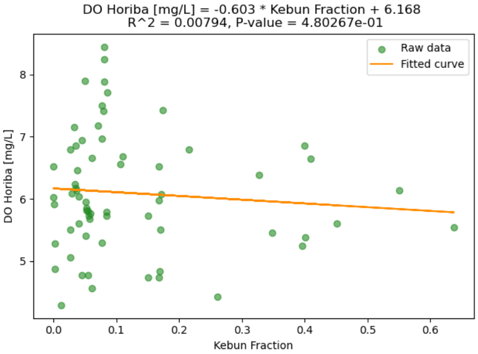
(b) DO (Horiba) versus Upstream Wet Agriculture Fraction



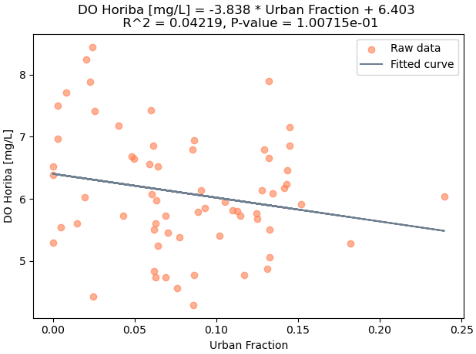
(c) DO (Horiba) versus Sawah Area Fraction



(d) DO (Horiba) versus Ladang Area Fraction



(e) DO (Horiba) versus Kebun Area Fraction



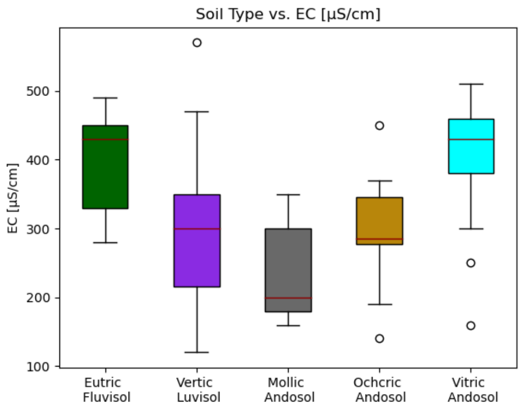
(f) DO (Horiba) versus Urban Area Fraction

Figure 13: DO (Horiba) versus Upstream Area Fractions per Land Class

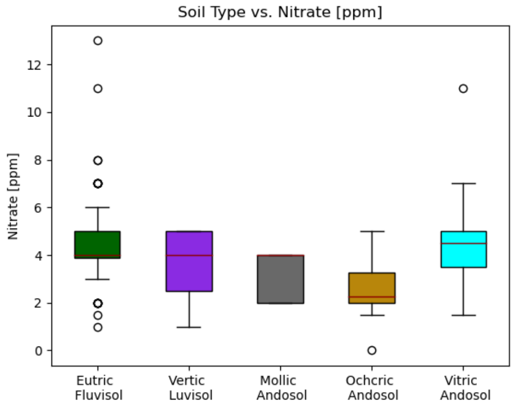
Although previous reports have identified agricultural non-point source pollution as the leading source of water quality impacts to rivers and lakes (Bhumbla, 2012), most plots in this section do not show a significant or clear correlation between land use and water quality. The subsequently low R^2 values of the regressions underline this, the only exceptions being the plots with the EC values. There are various reasons which could explain these low correlations. Firstly, there could be too little hydrological connectivity between the complete areas of the sub-catchments of each sampling site and the streams in which the water quality is measured. Alternatively, the low correlation which is observed might be due to a more significant impact of other factors, for example, waste disposal, cattle or chicken excrement. The latter explanation is supported by a study by Antunes and Rodrigues (2011), in which it was found that the most eutrophic aquatic systems are in basins where the surrounding land is exploited by the livestock industry. A multitude of the observed potential point-sources of local factors influencing the data is given in Appendix P. The findings that specific land uses such as urban areas and intensive agriculture do not necessarily result in very significant or severe water quality degradation is supported by Reimann et al. (2009), who found that even a city of the size of Oslo, which is a major diffuse source of contaminants in southern Norway as well as intense agriculture have a limited influence on inorganic stream water quality. In their study, low lying agricultural areas as well as the Oslo area are generally characterised by only modestly elevated concentrations (2–20 mg/L). What has to be additionally considered regarding urban area in this study, is that the number or the concentration of inhabitants is not accounted for. In this analysis, solely the areas which are classified as urban are taken into account, but no information on the population density of these areas is taken into consideration. In summary, as water quality parameters are typically dependent (Bhatnagar and Devi, 2012), non-normally distributed (Helsel, 1987), as well as highly dimensional (Wang et al., 2006), it is likely that in the pursuit of using simple models to distinguish between the effects of varying land uses, the models failed to describe a more complex reality.

However, there are some patterns recognizable in the obtained results. There are signs pointing to kebun area as the land use class which has the most favorable or in most cases, the least pronounced influence on the water quality parameters when looking at general trends in the scatter-plots and regression curves. This holds for both the absolute area and the area fraction results. However, because the R^2 values of the regressions are low and the confidence with which one can determine trends, further research needs to be conducted before this conclusion can be drawn with any certainty. In contrast, other types of agricultural land uses as well as urban area seem to have adverse effects on the water quality. This could be explained by intensive fertilization in the case of farmland and the deposition of untreated sewage and waste in the surface water in and around urban areas. But again, the confidence with which this conclusion is drawn based on the given data is low and future research is necessary to offer more certainty.

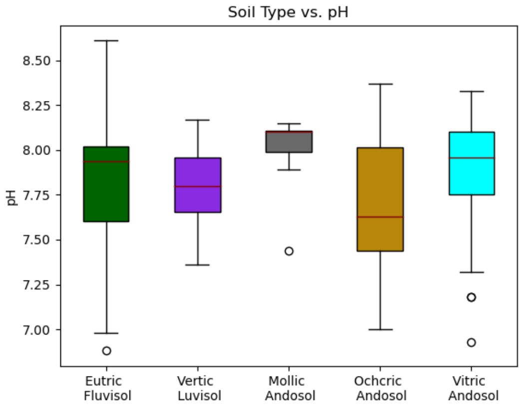
3.8. *Water Quality and Geology*



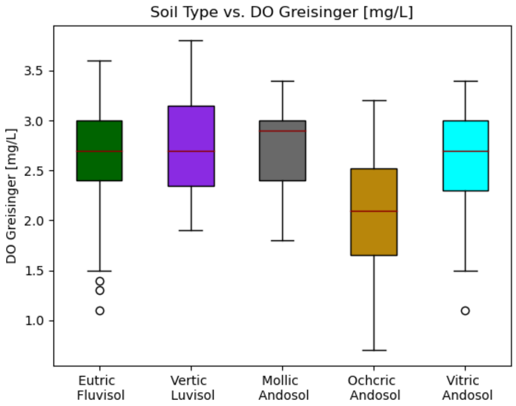
(a) EC per Soil Type



(b) Nitrate Concentrations per Soil Type



(c) pH per Soil Type



(d) DO concentrations (Greisinger) per Soil Type

Figure 14: Water Quality Parameters per Soil Type

On the previous page, box-plots are shown, displaying the EC, nitrate, pH and DO measurements per soil type. The EC values are highest for measurements taken on vitric andosol, closely followed by eutric fluvial soils, then vertic luvisols, ochcric andosol and lastly mollic andosol.

Nitrate concentrations do not differ much per soil type, but are highest on average for vitric andosols, which also features the largest spread of nitrate values. The second highest concentration is measured on eutric fluvisol, then vertic fluvisol, followed by mollic andosol and lastly, ochcric andosol.

Soils from East Java have been found to be weakly to moderately acidic (Hartono et al., 2015). This does not show in the water samples, as almost all measurements indicated a a pH above 7. Vitric andosol displays the highest median pH with the widest range, indicating a broad variability in pH for this soil type. Ochric andosol also showcases significant variability with a broad pH range. Eutric fluvisol and mollic andosol have similar median pH values, however, eutric fluvisol presents a slightly broader range compared to mollic andosol. Lastly, vertic luvisol stands out as the soil type with the least variability, having the narrowest pH range among the displayed soil types.

The box-plots visualizing the distribution of the DO values, indicates that eutric fluvisol has a lower median DO value as well as some outliers on the lower end. Vertic luvisol and Mollic andosol display similar distributions, with mollic andosol's median being slightly lower. Ochric andosol has a median DO value higher than the soils previously mentioned and exhibits a broad range, indicating considerable variability. Lastly, vitric andosol shows the highest median DO value among the area's soil types, with a compact range and an outlier towards the lower end.

The contents and chemistry of surface water are often dominated by naturally occurring element sources and processes such as differing rock formations and soil types (Reimann et al., 2009). These can influence the characteristics of an area's surface waters. For example, limestone and other calcareous rocks, contributing to alkaline soils, can buffer acidic runoff and increase the pH levels. Soils with high organic matter content, which can decompose, can lead to the consumption of DO in surface water. Another example is that soils with a high permeability and porosity can increase the rate at which pollutants can seep into groundwater, all affecting water quality.

Different soil types have varying effects on EC values (Olson and Hawkins, 2012), which are be influenced by factors like mineral content, moisture retention, and soil composition. The minerals in vitric andosols or eutric fluvisols might have properties that make them more conductive. Another probable explanation could be that as the plots have not been corrected for upsteam area, the EC content increases from upstream to downstream. This would explain why the samples taken on mollic andosols have the lowest EC values and the samples taken on eutric fluvisols and vitric andosols the highest. Finally, the differences could be explained given that eutric fluvisols and vitric andsosols are suitable and therefore intensively used for agricultural purposes, hence their high EC values. This would however not explain the low EC values for mollic andosols, as this soil too offers excellent characteristics for agriculture.

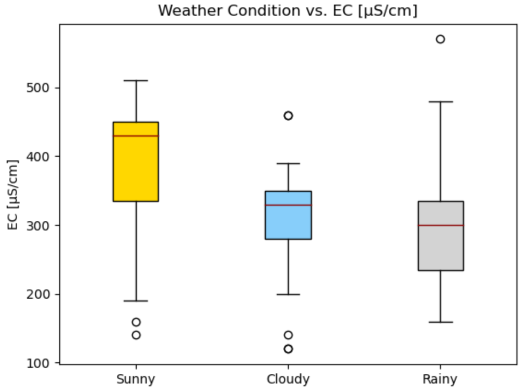
Though the variations in nitrate concentrations between soil types are low, the comparison between nitrate concentration per soil type follows a similar pattern as with the EC values. These results therefore support the theories above, that the nitrate concentrations increase upstream to downstream, or they are elevated on eutric fluvisols and vitric andosols because of their beneficial characteristics for farming. As opposed to the plots showing the EC values, ochcric andosols, which are less suitable for farming feature the lowest nitrate concentrations.

The plots showing the pH of the samples taken on different soils show an inverse trend compared to the plots featuring the EC values and nitrate concentrations. Because the plots on pH show that the pH increases when the upstream area becomes larger, this can not be explained as a trend from upstream to downstream. From observed water quality data in the Mount Ida region, it was concluded that waters originating from highly altered and jointed volcanic rocks created low pH and high element contents (Baba and Gündüz, 2017). This does however not explain the trend nor pH values from this research. A possible explanation could be that soils with a lower pH value feature a higher fraction of minerals acting as base when in solution.

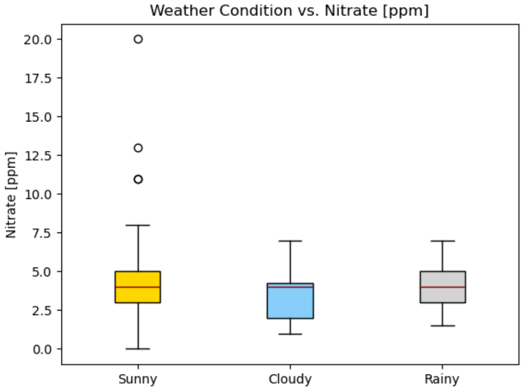
The ranges in DO value per soil type are relatively close to one another. Nonetheless, the DO concentrations seem to follow a trend from upstream to downstream. Samples taken on vitric and mollic andosols, which are situated upstream in the catchment have relatively high concentrations, while ochcitric andosols and eutric fluvisols, which are located downstream feature the lowest concentrations. Thus, the DO concentrations decrease from upstream to downstream, which could be explained by the inflow of nutrients. In order to explain the results regarding the geology and soils in a more substantiated way, it is recommended that data on the mineralogy is obtained and considered in further research. More information on the areas geology and soils can be found in Appendix B.1 and a soil map is provided in figure B.18.

Food productivity depends on soil quality and the health of a soil determines the capacity of a soil to continuously sustain plant growth (Bünemann et al., 2018; de Paul Obade, 2019). The quality of a soil depends on many factors such as depth, nutrient cycling dynamics and soil leaching (Jobbágy and Jackson, 2004; de Paul Obade, 2019). Agriculture and on soil type are therefore highly interconnected and it is therefore hard to consider these parameters separately. In order for further studies to assess the dynamics of agriculture and water quality objectively, it is recommended that soil type is also taken in consideration by means of a multivariate model.

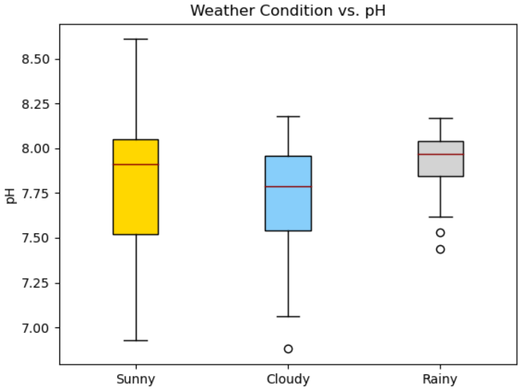
3.9. Water Quality per Weather Condition



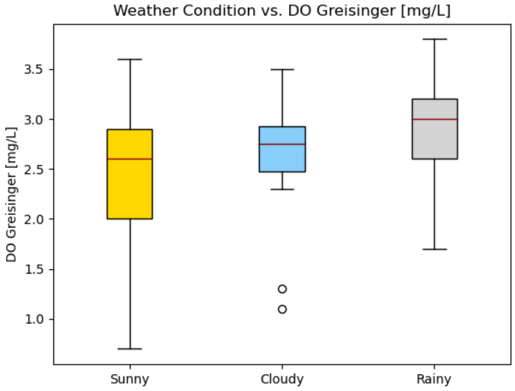
(a) EC per Weather Condition



(b) Nitrate Concentrations per Weather Condition



(c) pH per Weather Condition



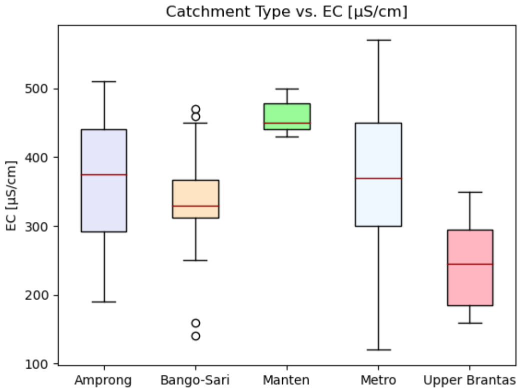
(d) DO concentrations (Greisinger) per Weather Condition

Figure 15: Water Quality Parameter per Weather Condition

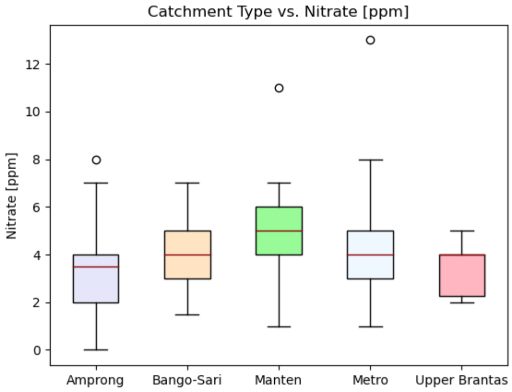
Above, box-plots are shown of the EC, Nitrate, pH and DO measurements for each weather condition. EC values are highest during sunny conditions, followed by cloudy, and are lowest during rainy conditions. Nitrate concentrations are highest during sunny conditions, followed by rainy and cloudy conditions respectively. The pH is highest for the measurements in rainy conditions, then sunny conditions and lowest in cloudy conditions. DO is highest during rainy conditions, followed by cloudy, and then sunny conditions.

Weather conditions might have influenced the water quality, which could be concluded from the EC values and the nitrate concentrations being the highest during sunny conditions. It is probable that less runoff during sunny conditions, which consequently means smaller water volumes, leading in turn to an increased concentration of minerals, finally results in higher EC and nitrate values. Conversely, during rains, the influx of fresh water can dilute the solute concentration, lowering the EC values and nitrate concentrations. This is in line with what Nakasone (2003) found, namely that both the EC values and nitrate concentrations declined during rainfall. However, the nitrate concentration became higher in the non-irrigation period, or the wet season and low in the irrigation period, or the dry season (Nakasone, 2003). This could mean that when longer periods of rain occur, nitrate concentrations will rise. Nonetheless, this would suggest high connectivity between the streams and the watersheds, which the low correlations between water quality parameters and upstream land use do not indicate in this research. For all parameters, the spread was largest during sunny conditions, which can be explained by the fact that most measurements were taken during sunny conditions, leading to a larger and more varied data-set, which finally results in a larger range of values. An overview of the daily rainfall during the fieldwork period and the specific fieldwork days can be found in figure I.25 in Appendix I. In this figure it can be observed that there were no substantial periods with a large amount of daily rainfall. This indicates that the conclusions drawn above are not very much substantiated as this would require data from prolonged wet and dry periods.

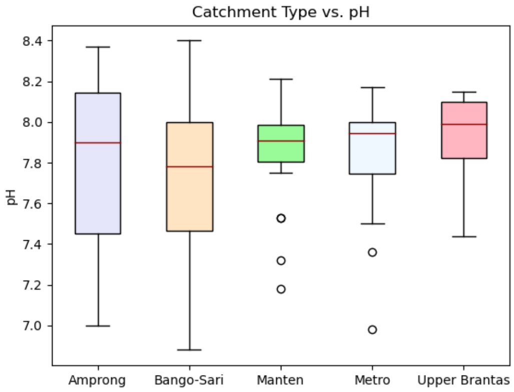
3.10. Water Quality per Sub-Catchment



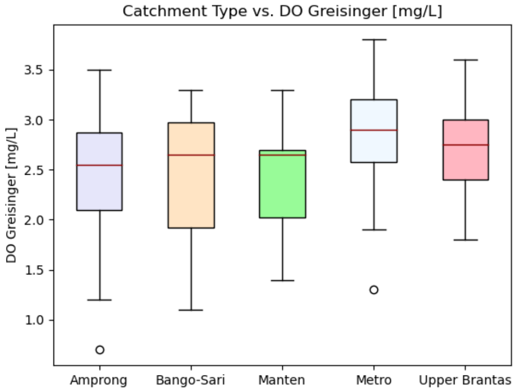
(a) EC per Catchment



(b) Nitrate Concentrations per Catchment



(c) pH per Catchment



(d) DO concentrations (Greisinger) per Catchment

Figure 16: Water Quality Parameters per Sub-Catchment

In the box-plots above, the results per catchment can be viewed. The samples from the Manten sub-catchment had the highest EC values, followed by the Metro, Amprong, Bango-Sari, and Upper Brantas sub-catchments, respectively. The nitrate concentrations per sub-catchment in order from high to low are Manten, Bango-Sari, Metro, Upper Brantas and lastly Amprong. pH levels of the measured samples do not vary significantly. Amprong and Bango-Sari have a large range of values compared to the other three sub-catchments. The DO levels of the samples from the Metro catchment are highest followed by the Upper Brantas, the Bango-Sari, the Amprong and lastly the Manten sub-catchment.

Factors such as the size of the catchment, land use within, and its topography could all play a role. What is important to consider when analysing these results is the differences between the sub-catchments. The Upper-Brantas catchment features the most urban area as the city of Batu is located here. The city of Malang plays less of a role because all measurements are taken upstream from this city. The Bango-Sari catchment also features relatively large urban areas. The share of agricultural area is more or less equally divided and therefore it is hard to base the analysis of the results on this parameter. The large urban areas in the Upper-Brantas and Bango-Sari sub-catchments seem to be of little influence on the water quality as they feature low EC values, relatively low nitrate concentrations and average pH and DO values. The Manten catchment scores the worst on all water quality parameters. It is however not directly clear why this is the case as many factors could play a role, for example intensive fertilization, the disposal of untreated sewage or waste in the river. It is therefore recommended that more research is conducted into the specific characteristics of each catchment. Further studies could look into the distribution of land use in the three sub-catchments, to obtain a better understanding of their distinctive characteristics.

3.11. Biological Oxygen Demand

The BOD measurements are displayed in the map in figure F.22 and the boxplot in figure 17 below. The values ranged from 6.22 to 6.87 mg/L.

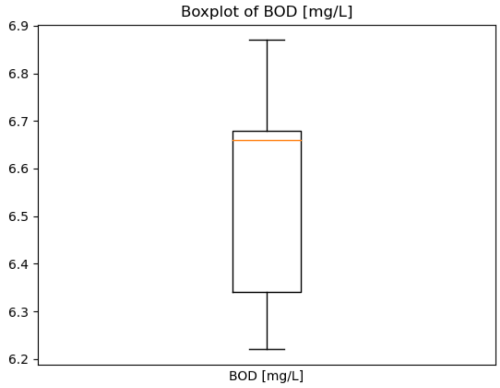


Figure 17: BOD Measurements Results

The reliability of the BOD lab tests appears to be questionable, given that the results of a double-blind, or in other words two samples from the exactly same time and the same location gave two varying outcomes which differed significantly from one another when compared to the range of values from all samples. For an overview of the BOD lab test results, including the double blind see Appendix L. That being stated, all samples tested for this parameter, featured a high BOD concentration. This means that, if the approximate values of the lab tests are accurate, BOD concentrations are a reason for concern in the catchment. Even so, due to the limited amount of samples tested for BOD concentration, their values all being close to each other, the questionable reliability of the results and the limited spatial variability in the tested samples, it is not possible to give an explanation about which factors are most important in influencing the BOD levels in the catchment without further research. It is recommended that further sampling is done over a more spread out area in the future. This is not properly done in this research is due to logistical issues.

3.12. Nitrite, Phosphate and Ammonia

The occurrence of nitrite in surface waters is closely connected to the nitrogen cycle and the main nitrite source is the oxidation of ammonia and organic nitrogen (Minero et al., 2007). It was therefore no surprise that at places where nitrite was present in the water, upstream plots that could have been fertilized recently or in some cases cattle and chicken farms were identified upstream. This explains the elevated nitrite levels. But importantly, in 82.4% of all measurements nitrite concentrations were zero. In the remaining 17.6% of measurements, nitrite concentrations of up to 3 ppm have been observed. This is is a good sign, given that an excessive intake of nitrites can impair the oxygen transport capacity of the blood of humans and animals and cause serious cancers and even death (Cao et al., 2016; Santharaman et al., 2017; Wang et al., 2022).

The results of the phosphate measurements are illustrated in figure F.23. Out of the six measurements two samples had a concentration of 0.25 mg/L and 4 samples concentrations of 1.0 mg/L. In figure F.24, the ammonia levels of the taken samples are visualized. Five out of the six samples did not have a ammonia concentration above the threshold that could be observed with the used method. One sample had a concentration of 0.25 mg/L ammonia. While a few samples still showed phosphate and ammonia presence, the concentrations were within the acceptable limits. What this could indicate, is that urban pollution does not necessarily have an overhand in the total pollutant load as higher ammonia/nitrate rates usually signal the presence of urban wastewater effluent.

A study on surface water pollution as a result of agricultural activity by Berka et al. (2001) found in the winter season which is characterized by elevated precipitation ammonia, phosphate and coliform-levels were relatively high. Possibly, the pollutants resulting from agricultural land use in the basin wherein this study is conducted were not able to travel to the surface water. Possibly as a result of too little groundwater or overland flow connecting the edges of the sub-catchments and the streams. However, this could become a more significant issue throughout the wet season, which underlines the importance of continued monitoring. What also has to be noted is that the phosphate and ammonia measurements were taken with the very basic methods at hand, namely with fish-store test kits. Therefore, the ammonia and phosphate results are not very precise and offer merely an indication.

3.13. Republic of Indonesia National Water Quality Standards

In table C.2, the parameters EC, pH, and nitrate concentrations in the acquired data are compared against the standards set by the Indonesian Government. These are taken over from Djaman (2021) of which the full list can be found in Appendix J.

Table 1: Percentage of Data Meeting the Classes as Defined by the Republic of Indonesia in Djaman (2021)
*Only based on the parameters EC, pH, and Nitrate

Class	Amount of Data Meeting the Criteria*
I	95.07%
II	95.07%
III	97.18%
IV	99.30%

Regarding the parameters that were not systematically measured, the results of the comparison between the data and the Indonesian water quality classes are described below. The nine samples for which the BOD was measured, of which the results can be viewed on the map in figure F.22 all fall in class IV (<12 mg/L). In the case of phosphate (figure F.23), these samples meet the criteria for class I in two out of six cases (<0.2 mg/L as P or <0.065 mg/L of PO_4^{3-}). The remaining four samples fall under class III (<1.0 mg/L as P or <0.33 mg/L of PO_4^{3-}). Regarding ammonia of which the results can be viewed in figure F.24, one out of the six samples falls under class III (<0.5 mg/L as N, or <0.61 mg/L of NH_3). In the other five samples no ammonia was perceived, which means they fall under class I (<0.2 mg/L as N, or <0.24 mg/L as NH_3). Based on the above, it can be said that regarding the systematically measured parameters, the water quality is overall quite good according to the Republic of Indonesia's Water Quality Standards. For the other parameters, this is not always the case. This means that more data should be acquired. The varying results between systematically measured samples and others underline the importance of consistent data acquisition methodologies.

3.14. World Health Organization Guidelines

In case of the guidelines set by the WHO, 99.30% of the data, meets the requirements on the maximum nitrate and nitrite concentrations. For the other parameters, the WHO does not give health related guidelines.

3.15. Water Quality Monitoring Plan

When designing the monitoring plan, certain decisions have been made which should be reflected upon. First of all, there is an imbalance between the parameters that have been extensively measured and the parameters which are problematic in the catchment. The values of the parameters EC, DO, pH, nitrate and nitrite for which the water quality was analyzed at every site, are mostly within acceptable limits, while in the case of BOD, phosphate and ammonia, for which the concentrations were only tested at a few sites, the values were more problematic according to the Indonesian standards. This is because a large data-set consisting of cos-effective and quickly measurable parameters was favored over a smaller data-set with parameters requiring more time-consuming and expensive measurement techniques. The rationale behind this was that a large data-set would lead to a better insight in the differences between land use classes. But as the sparsely acquired data on BOD, ammonia and phosphate indicates, more attention should be paid to other parameters in order to locate areas with a problematic water quality. Other parameters, like heavy metals, pathogens, pesticides or micro-plastics have not been measured at all because of time and financial restraints. Testing for these parameters should also be considered in the future when the monitoring plan is continued.

The currently used measuring sites were selected based on reachability. They mostly include bridges from which a sample could be taken with a bucket on a rope. When expanding the monitoring plan it should be considered that most streams are hard to reach and that it is therefore not possible to select any spot.

4. Conclusion

Compared to the local water quality standards, the EC values, and nitrate concentrations in the area's surface water were low, the pH was within reasonable limits and the DO concentrations were relatively high. However, when looking at the more sparsely measured parameters such as BOD, phosphate and ammonia, there is some reason for concern.

The data does not indicate high correlations between land use classes and water quality parameters. The bulk of the water quality parameters seemed to depend only little on the land use of the watersheds upstream, except for EC values. This suggests that other external factors might overshadow the influence of the land use of the complete upstream areas. Alternatively, the used methodology does not properly incorporate the influence of the various and land use classes. Non-point source pollutants at a far distance from the measuring sites might not reach the small streams, but might instead be infiltrating the groundwater.

Some cautious conclusions can however still be drawn. Firstly, kebun area seems to be the land use class that has the most favorable influence, or at least the least distinctive influence on the water quality parameters. Other land use classes seem to have more detrimental effects on water quality compared to combined upstream area.

The different trends regarding soil type and water quality parameters potentially offer interesting insights in correlation or causation between geology and water quality. However, more research, especially on the mineralogy of the soils is necessary to draw definitive conclusions. Patterns were observed in how weather conditions influenced the EC values. But considering the field work period did not cover extensive periods of drought or rain, more research is necessary before conclusions can be drawn on the influence of weather on the area's water quality.

Sustainable water management depends on a good understanding of water quality dynamics. While this study provides a starting point regarding the influence of agricultural land uses on water quality, there is a need for further investigation. Integrating technical theories, ensuring consistency in data acquisition, and continuous monitoring can shed more light on how land use and other factors affect water quality. A broad approach, including refined methodologies, continuous monitoring, factoring in additional variables, and using multi-parameter approaches are necessary to build a more definitive understanding of water quality dynamics in the region.

5. Recommendations

While this study offers some valuable insights into the current state of water quality in the region, it also points to areas where further research with refined methodologies is necessary. As starting point, the monitoring plan could be continued throughout the wet season. In parallel, smaller scale experiments could be set up to investigate in which way pollutants from agriculture mostly enter surface water during various weather conditions and the monitoring plan could be adjusted accordingly. Regarding the analysis, it is recommended that multivariate statistical techniques, such as cluster analysis, principal component analysis, factor analysis or discriminate analysis are used in the future, to avoid biases in the data of for example weather and geology and properly reflect on the results caused by specific pollution sources only. Additionally, more water quality parameters should be taken into account, especially those indicative of certain kinds of pollution such as pathogens and pesticides. To properly estimate the pollution load from urban sources, population density can be considered where this data is available.

The high BOD concentrations raise concern and it is therefore recommended that more samples are tested for this parameter, over a larger time and spatial scale. Additionally, research should be conducted to investigate where BOD loads are coming from and how BOD loading can be reduced. To a lesser extent, this also holds for ammonia and phosphate concentrations.

The results tend to point to Kebun agriculture as the land use with the least adverse, effects on water quality, while Ladang and Sawah types of agriculture could have a more detrimental effect. However, from this research alone, this conclusion can not yet be drawn with any certainty. Therefore it is recommended that this is looked into in further research so that if this is indeed true, it can be taken into account in land management planning.

In order to avoid biases in the regressions, further studies could correct for other influences such as geology and weather conditions as mentioned below.

As the goal of this monitoring plan was connecting land use to the measured water quality parameters, there was a preference for the quantity of monitoring sites over the amount of measured parameters. Since no strong correlation was found linking the measured parameters to specific land uses, and the structurally measured parameters are within acceptable limits, a shift in the monitoring plan is recommended. It is suggested to transition from monitoring a large number of sites for a few easily measurable parameters to focusing on more detrimental parameters and a more limited number of carefully selected sites. These parameters should include BOD, ammonia and phosphate as their concentrations were proven to be elevated. The list can be extended to include chemical oxygen demand, pesticides, turbidity, micro-plastics and heavy metals because not much data on these parameters is available, while they can potentially have detrimental effects. The spots, should be selected such that they cover upstream areas featuring distinctive land uses, ideally one single land use. It is recommended that monitoring takes place each month over the coming years. This interval allows for a good insight into seasonal variability, while still being cost effective.

Acknowledgements

Conducting this research would not have been possible without the help of Leandro Alexander Michael Sipahutar, Rifqy Akmal Fadhil, Ageng Rizky Hutama, Faza Haekal Yahya, Muhammad Ridho Abdillah, Halim Cahya Putra, Natalia Deassy Arianti, Mr. Pras, Rizky Almarendra Wirawan Putra and Muchammad Ja'far Shiddik who accompanied me on the fieldtrips resulting in the data this research is based on. Not only did they help me in gathering the data, they also made sure my time in Indonesia was unforgettably pleasant. Furthermore, I would like to thank my supervisors Maurits Ertsen, Mr. Didit, Boris van Breukelen, Gerrit Schoups and Schuyler Houser as well as Reza Pramana who have been of great help on both the scientific and the logistical aspect. Finally, I would like to express my gratitude to friends and family who supported me throughout the process.

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Appendix A. Abbreviations

*List of Abbreviations

WQI	Water Quality Index
EC	Electrical Conductivity
WQMP	Water Quality Monitoring Plan
DO	Dissolved Oxygen
COD	Chemical Oxygen Demand
EC	Electric Conductivity
BOD	Biological Oxygen Demand
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
POP	Persistant Organic Pollutants
EDC	endocrine-disrupting chemical
BPA	Bisphenol A
GEMS	Global Environment Monitoring System
WHO	World Health Organization
NSF	National Sanitation Foundation
SDGs	Sustainable Development Goals
WHO	World Health Organization
FAO	Food and Agriculture Organization

Appendix B. Area Description

Appendix B.1. Geology and Soils

The area has a diverse geology. Tectonically, East Java is part of the larger Sunda Arc, which marks the convergent boundary between the Eurasian Plate and the Australian-Indian Plate. The subduction of the Australian-Indian Plate beneath the Eurasian Plate has resulted in the formation of the Java Trench offshore and volcanic activity on land. The territory is renowned for its volcanic landscapes. The province is home to several active and dormant volcanoes, including Mount Bromo, Mount Semeru, the islands highest peak, Mount Ijen, and Mount Kelud. These volcanoes are part of the volcanic arc known as the ”Ring of Fire.” Volcanic activity has led to the formation of various volcanic landforms, such as calderas, lava domes, and pyroclastic cones. For example, the Tengger Caldera, which contains Mount Bromo and Mount Semeru, is a major tourist attraction known for its unique landscapes. The areas soil consists of litosols, tuff, volcanic compounds, reddish lithosol complexes, and grey alluvial clay sediments (Putra et al., 2021). Soils from East Java have been found to be weakly to moderately acidic (Hartono et al., 2015).

Along the rivers in East Java, particularly the Brantas River, there are extensive alluvial plains. These fertile plains are vital for the areas agriculture and therefore play an important role in supporting the economy of the region. Alluvial soils are generally rich in organic matter, minerals, and nutrients. The continuous deposition of sediment replenishes the soil, making it productive for cultivation. The alluvial soils along the

Brantas River exhibit some variation depending on the location and depth. The soils closer to the riverbanks tend to be siltier and more fertile due to recent deposition, while those farther away may have a higher sand content. While the alluvial soils are highly productive, they are also prone to erosion. Uncontrolled soil erosion can lead to land degradation and reduced agricultural productivity. Thus, soil conservation practices such as terracing and contour plowing are implemented to minimize erosion and maintain soil health.

In figure B.18 a map of the soil types in the study area is provided. The soils within the study area reflect the complex geological history and varying topography of the region. Towards the volcanoes on the East and West of Kota Malang, there are two distinct soil types, namely mollic andosols (in dark grey) and ochric andosols (in brown). Mollic andosols are found higher up, closer to the volcanic peaks. The mollic horizon is a well structured, dark coloured surface hoizon with a high base saturation and a moderate to high content in organic matter (Deckers and Nachtergaele, 1998). Their characteristic rich, dark organic matter content, makes them ideal for agriculture and plant growth. However, mollic andosols become dry a few days after a rainfall event due to their high infiltration rates (Satognon et al., 2021).

The ochric horizon lacks fine stratification and has a lighter colour and a lower organic matter content (Deckers and Nachtergaele, 1998). Ochcric andosols, which are situated slightly lower in our study area, are less suitable for agriculture compared to mollic andosols due to their less developed horizon, yet they still offer favorable conditions for cultivation.

Moving further downhill, the present dominant soil type are vitric andosols (in light blue) and vertic luvisols (in purple). Vitric andosols are volcanic soils with a high volcanic glass content (Herre et al., 2007). The vitric horizon is a surface horizon dominated by volcanic glass and other primary minerals derived from volcanic projectiles (Deckers and Nachtergaele, 1998). The glassy volcanic ash that these soils consist of, contributes to their excellent moisture and nutrient retention capabilities.

Meanwhile, luvisols are soils in which high activity clay has migrated from the upper part of the profile, generally grayish in color, (Driessen et al., 2000). They are characterized by distinct vertical horizons that result from leaching processes. Both of these soil types are valuable for a range of agricultural practices. The vertic horizon is clayey subsurface horizon which as a result of shrinking and swelling consists of structured aggregates (Deckers and Nachtergaele, 1998).

In the lower-lying areas of the study site, eutric fluvisols are prevalent. Fluvisols are young soils in alluvial deposits (Mantel et al., 2023). Eutric refers to a high base saturation Driessen et al. (2000). These fertile soils have developed in alluvial deposits, offering excellent nutrient content and moisture retention. Their suitability for agriculture and plant growth is highly regarded.

Finally, at the southern coast of the study area, lithosols become prevalent. Lithosols, also known as leptosols are thin soils with many coarse fragments (Schad, 2016). These shallow, stony soils are challenging soils for agricultural purposes due to their limited depth and high rock content. However, they play an essential role in the coastal ecosystem, influencing plant and animal biodiversity in this unique environment.
Geological features, such as rock formations and soil types, can influence the mineral content of water. For instance, water flowing over limestone regions can lead to higher calcium content and higher pH values. Furthermore, the permeability and porosity of the geology determine how quickly pollutants can seep into groundwater, affecting its quality. Because of these characteristics, the diverse soils in the study area offer a multiple opportunities and challenges for agriculture, land use planning, and ecological conservation. These distinct soil types offer a wide range of characteristics. They all come with different challenges or benefits when it comes to sustainable land management and resource utilization within the region.

Appendix B.2. Climate

The area features a tropical monsoon climate with an average annual rainfall of 2220 mm (Jennerjahn et al., 2004) and an average temperature of 26°C. The warmest and coldest months are October and June respectively. March and August are respectively the wettest and driest months. Unlike the province of West Java, East Java only features one wet season over the months of November to April, which is also the period of peak river discharge (Jennerjahn et al., 2004). In the months June, July and August covering the field trip, the rainfall will be approximately 80, 40 and 20 mm respectively (Weather & Climate, 2023).

Appendix B.3. Farming Practices

Appendix B.3.1. Rice Growing Season

In 2007, the International Rice Research Institute reported that Indonesia is the third largest rice producer, and consumer in the world as 133 kilogram of rice is being consumed per person, every year (Handono et al., 2012). Rice cultivation in Malang regency consists of one, two or three rotations per year depending on water availability. Rice crops are planted at the beginning of the wet season, which is from November to March and the growing season ends as the dry season progresses and water is less readily available.

Farmers around Malang interviewed by Yatmo and Almekinders (2019) told the authors that there are generally three moments where rice is harvested, namely in January, May and the third harvesting moment can be as late as in August or September. Though overall, the subsequent dry season, which is from April to October is characterized by little rice planting (Naylor et al., 2007).

Besides rice cultivation, this research will take into account the impact of cattle farming, which is also common in the area around Malang. The province of East-Java is responsible for 54% of the countries milk production (Sutawi et al., 2021; Kemantan, 2018). The majority, or 80% of the countries dairy farms are small scale, 17% is of medium scale and only 3% is categorized as large scale (Mandaka and Hutagaol, 2005; Kemantan, 2018).

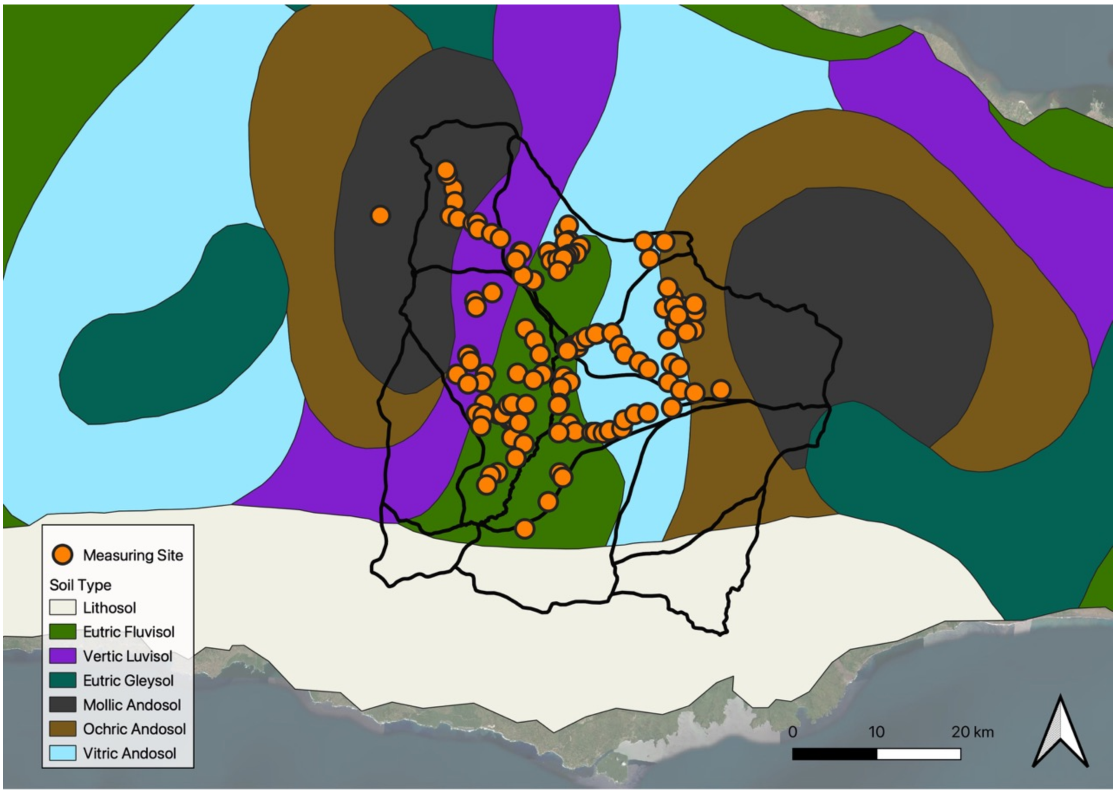

Figure B.18: Soil Types Map, Based on Data From FAO (2003)

Appendix B.3.2. Fertilizers

In the study area, both organic and inorganic fertilizer is commonly used. Organic fertilizer, generally consists of cow dung or plant residues while inorganic fertilizer is manufactured artificially. Nitrogen, phosphorous, and potassium are the three major macro-nutrients important for plant growth (Shaji et al., 2021). Inorganic fertilizer contains a high amount of soluble nitrogen, which is easily soluble in water, while the majority of organic fertilizers contain balanced amount of raw nitrogen which is released in a slower manner (Shaji et al., 2021). Because of the quick release of its nitrogen, inorganic fertilizers pose a higher risk of water contamination.

Organic fertilizer is commonly used before or during land preparation to increase the nutrient content of the soil as well as its fertility. Used types of organic fertilizer in the area include farmyard manure, compost, green manure and crop residues. Some farmers may opt to apply organic fertilizers as a top dressing during the crop's growth stages as well to further increase nutrient availability. The cost of organic fertilizer amounts to about 2% and the cost of the used organic variant is about 1% to 8% of the total costs of rice cultivation (Handono et al., 2012). The inorganic types are commonly applied at each growth stage of the crop to accommodate specific nutrient needs. Commonly, farmers apply a basal dose of fertilizer during land preparation and follow it up with one or two additional applications during the vegetative and reproductive stages of the rice crop. Farmers typically spend about 9% to 20% of the total costs on inorganic fertilizer (Handono et al., 2012). The use of chemical or organic fertilizer differs however from farmer to farmer. While conducting interviews, Yatmo and Almekinders (2019) found that some farmers opt to only use organic fertilizers, while others exclusively use the chemical variant.

Appendix B.3.3. Irrigation

The plains along the Brantas River have an extensive network of irrigation channels and infrastructure. Water from the river is channeled to the fields through canals and irrigation systems, ensuring a controlled water supply for crop cultivation. The irrigation fee is approximately 6% of the total cost of rice cultivation (Handono et al., 2012). The farmers around Malang use less water in first and last stages of the rice cultivation process or as one farmer from Malang explained in an interview "I use less water for the nursery and transplanting stages.. I then keep my field flooded for the next growth stages.. Then, I use less water before harvesting" (Yatmo and Almekinders, 2019).

Appendix C. Theory on Water Quality Monitoring

Water quality monitoring is an essential aspect of environmental management, ensuring the sustainability and safety of water resources. Traditionally, the primary goal of monitoring water quality has been to confirm whether the observed water quality meets the necessary requirements for its intended uses (Bartram and Ballance, 1996). Over time, the objectives of water quality assessments have expanded. They now include not only verifying compliance but also describing spatial and temporal patterns in water quality and identifying the various factors and processes that influence these conditions (Council et al., 1994; Mueller et al., 1997; Smith et al., 1997). Today, the reliable assessment of water quality through monitoring plays a crucial role in helping decision-makers better understand, interpret, and utilize this information to develop strategies aimed at protecting our precious freshwater resources (Behmel et al., 2016).

Water quality monitoring involves collecting physical, chemical, and biological data on water quality. The collected data is used to assess the current water quality status, detect potential sources of pollution, and develop mitigation strategies. In this chapter, an overview is provided on water quality monitoring, describing physical, chemical, and biological parameters, the utilization of models and indices, and on global initiatives, local regulations, and stakeholder engagement.

Appendix C.1. Description of Water Quality Parameters

Standard water quality monitoring involves the measurement of a wide array of parameters, each of which provides important insights into the condition of a water body. The parameters commonly measured in water quality monitoring include temperature, turbidity, DO, pH, Total Dissolved Solids (TDS), BOD, Chemical Oxygen Demand (COD), nutrients, metals and bacteria. Additional parameters which are less commonly measured, but are still of great importance to human and animal health are micro-plastics, pesticides and hormones.

Appendix C.1.1. Temperature

Water temperature can have a significant impact on water quality, affecting various physical, chemical, and biological characteristics of water bodies. This parameter affects most other parameters described below. The water temperature for example directly affects the DO levels in the water as well as biological activity, chemical reactions and nutrient cycling. Monitoring water temperature is therefore necessary in order to assess the state of aquatic ecosystems.

Appendix C.1.2. Turbidity

Turbidity is a measure of the cloudiness or the optical clarity of water. The presence of suspended particles, organic matter content and temperature can all affect the turbidity of a body of water (Kitchener et al., 2017).

Appendix C.1.3. Nutrients

Nutrients, primarily nitrogen and phosphorus, are fundamental components of living organisms and are key to global food production. However, excessive nutrient levels which can be caused by the production and use of inorganic fertilizers, animal manure, and discharge of human wastewater have dramatically altered and continue to shape aquatic environments (Richardson and Jørgensen, 1996; Pellerin et al., 2016). Monitoring nitrogen and phosphorus levels is therefore necessary to assess the risk nutrients impose as high concentrations can lead to eutrophication, algal blooms, and oxygen depletion in aquatic ecosystems. Examples of parameters which can be used to measure nitrogen and phosphorus content are nitrate (NO_3^-), nitrite (NO_2^-) ,ammonia (NH_3) and phosphate (PO_4^{3-}) concentrations.

Appendix C.1.4. Heavy Metals

Heavy metals include copper, cadmium, zinc, lead, mercury, arsenic, silver, chromium, iron and platinum group elements. These toxic elements can be released into the water from various natural and anthropogenic sources and because they are not biodegradable, they tend to accumulate in organisms (Zamora-Ledezma et al., 2021). Therefore it is important that they are monitored due to their harmful effects on both aquatic life and human health.

Appendix C.1.5. Pesticides

Pesticides are, by their very nature, designed to kill living things and therefore it is easy to imagine that they impose risks (Ward et al., 1993). As they leach to into the water they can have a significant impact on water quality and disturb flora and fauna (Chaudhry and Malik, 2017). For similar reasons as with heavy metals, it is therefore important that pesticide concentrations are monitored.

Appendix C.1.6. Dissolved Oxygen

Low oxygen levels in water, also known as oxygen depletion, can create favorable conditions for some organisms while causing harm to others. DO is required for respiration by most aquatic animals (Araoye et al., 2009). Low oxygen levels can stress or suffocate them while other organisms, including certain algae and bacteria, can take advantage of reduced competition and low-oxygen conditions and form harmful algal blooms. This can lead to reduced biodiversity. Additionally, the presence of DO determines if important elements such as carbon, sulphur, nitrogen and phosphorous form into toxins or into essential compounds for aquatic life like carbonate, sulphate, nitrate and phosphate (Araoye et al., 2009).

Appendix C.1.7. pH

pH is another important parameter that affects water quality. pH plays a critical role in the health and survival of aquatic organisms. Different species of fish, invertebrates, and plants have specific preferred pH ranges in which they survive. Significant deviations from those pH ranges can stress or harm these organisms. pH also affects the solubility and behavior of various chemicals and ions in water. Additionally, the pH affects the availability of essential nutrients, particularly phosphorus and nitrogen. In some extreme cases, low pH levels can limit the availability of these nutrients, potentially affecting the growth of aquatic plants and algae.

Appendix C.1.8. Total Dissolved Solids

The concentration of TDS provides information about the concentration of dissolved salts in water. An increase in TDS beyond acceptable levels can have a significant impact on municipal, industrial, and agricultural use of water (Sherrard et al., 1987). TDS is a measure of the inorganic and organic constituents dissolved in water. Inorganic ions found in natural waters may include carbonate, calcium, sulfate, chloride, sodium, and other, often minor, constituents such as iron, copper, bromide, or manganese (Wilson et al., 2014). The concentration of

TDS can affect water quality in several ways. Some dissolved solids may include potentially harmful substances like heavy metals, nitrates, or sulfate. High TDS levels can also affect aquatic ecosystems. For example, sensitive aquatic organisms may be adversely affected by elevated TDS concentrations. Increased TDS can also alter the osmotic balance in aquatic organisms, affecting their ability to regulate salt and water uptake. Moreover, TDS levels in irrigation water can impact soil quality and crop growth. High TDS levels in irrigation water can contribute to soil salinity, which can negatively affect crop yields.

Appendix C.1.9. Biological Oxygen Demand

BOD is a measure of the dissolved oxygen consumed by microorganisms during the oxidation of reduced substances in water. Typical sources of BOD include readily biodegradable organic carbon and ammonia. These compounds are common constituents or metabolic byproducts of plant and animal wastes and human activities (Penn et al., 2009). High BOD levels indicate nutrient pollution in the form of organic pollutants, such as sewage, agricultural runoff, or industrial effluents, into a water body. As microorganisms break down these organic substances, they consume DO, leading to decreased oxygen levels in the water. As described before, this in turn can cause water quality problems such as severe dissolved oxygen depletion and dying fish in receiving water bodies (Penn et al., 2009).

Appendix C.1.10. Chemical Oxygen Demand

Similarly to BOD, COD is a parameter used to measure the oxygen demand of substances in water. However, they differ in several ways. Firstly, while BOD measures the amount of oxygen consumed by microorganisms during the biological degradation of organic matter in water (this process takes place over a specific incubation period, typically 5 days, and is expressed as BOD5), COD on the other hand, measures the total amount of oxygen required to chemically oxidize both organic and inorganic substances in water. The COD test provides results more quickly than the BOD test, typically within a few hours.

Appendix C.1.11. Micro-plastics

Micro-plastics are tiny plastic particles (less than 5mm in size) that form when larger plastic items break down. When they are present in surface water bodies, aquatic organisms can ingest micro-plastics, potentially leading to negative health effects.

Micro-plastics also pollute the environment by leaching chemicals like plasticizers. Plasticizers are chemicals added to plastics to increase their flexibility and durability. An example of a plasticizer is Bisphenol A (BPA), a chemical with the characteristics of an endocrine-disrupting chemical (EDC). This will be described further below.

Appendix C.1.12. Hormones

Natural and synthetic hormones, like those used in agriculture and veterinary medicine, can contaminate water bodies and affect water quality. Examples are BPAs and E2 (17beta-estradiol) which classify as EDCs of which BPA is a synthetic hormone which can leach from plastic as described above and E2 is a natural hormone found in humans and animals. As the name of this hormone group gives away, these hormones can lead to endocrine disruption in aquatic organisms, affecting their reproduction and development. Elevated E2 levels have been linked to the feminization of male fish (Gimeno et al., 1998; Fenlon et al., 2010; Norazmi-Lokman et al., 2021), affecting fish populations and biodiversity.

Appendix C.1.13. Bacteria

Monitoring for bacteria like fecal coliforms and E. coli is vital for assessing the safety of water for human consumption, irrigation, fish cultivation and recreational activities.

Appendix C.2. Models and Indices

Water quality monitoring goes beyond measuring individual parameters. It employs advanced models and indices to synthesize data and provide a comprehensive understanding of water quality. Given the differences in regulatory requirements, water quality standards, geographical and geological differences, land-use variations, and other site specificities, a one-in-all solution is not possible (Behmel et al., 2016). It is also helpful, if not necessary, to tap into local knowledge and to identify the knowledge needs of all the stakeholders through participative approaches based on geographical information systems and adaptive survey-based questionnaires (Behmel et al., 2016). Some notable models and methods are described below.

A Water Quality Index (WQI) combines multiple water quality parameters into a single numerical value, offering a holistic view of water quality and facilitating data interpretation. Which water quality criteria are suitable for a certain study depends on the prevailing conditions, the type of use and it can vary from time to time and region to region (Poonam et al., 2013).

Appendix C.2.1. The Republic of Indonesia National Water Quality Standards

A water quality index and its thresholds can be defined by local authorities. In this study, the criteria as described by the authorities of the Republic of Indonesia in Djaman (2021) will be used as they are designed specifically for this basin and this system is used by the stakeholders involved.

For the Brantas basin, the authorities differentiate between 4 classes as described in Djaman (2021).

(i) The first class being water whose designation can be used for raw drinking water, and/or other uses that require the same quality of water as that use;

(ii) the second class is water that can be used for infrastructure/facilities. water recreation, freshwater fish cultivation, animal husbandry, water for irrigating plantations, and/or other uses that require the same quality of water as that use;

(iii) the third class is water that can be used for freshwater fish farming, animal husbandry, water for irrigating plants, and/or other designations that require the same quality of water as those uses;

(iv) the fourth class is water whose designation can be used to irrigate plantations and/or other uses that require the same quality of water as that use. Relevant for this study is class two, as the assessed water quality is used for these purposes.

The requirements regarding the parameters that will be taken into account in this research can be found in table C.2 below. For the full list of the parameters and water quality classes as determined by Djaman (2021) see Appendix J.

Table C.2: Water Quality Classes Djaman (2021)

Class	**I**	**II**	**III**	**IV**
Nitrate (mg/L as N)	10	10	20	20
TDS (ppm)	1000	1000	1000	2000
DO (mg/L)	6	4	3	1
pH	6 - 9	6 - 9	6 - 9	6 - 9
BOD (mg/L)	2	3	6	12
Ammonia (mg/L as N)	0.1	0.2	0.5	-
Phosphate (mg/L as P)	0.2	0.2	1.0	-

Appendix C.2.2. National Sanitation Foundation's Water Quality Index

According to a study by Marselina et al. (2022), the most suitable WQI assessment method for determining Indonesian surface water quality is the National Sanitation Foundation Water Quality Index (NSF WQI), which will be described in more detail below. The benefit of this method, according to Marselina et al. (2022) paper is namely that it is able to distinguish between different water quality states in this river between seasons and years. Another asset is its relative simplicity, as it takes into account a limited number of easy to determine parameters (Marselina et al., 2022). As mentioned in subsection Appendix C.1.10, a notable example of a WQI is the index made by the National Sanitation Foundation (NSF). As described by Noori et al. (2019) the NSF WQI is considered a comprehensive and generally applicable index for classification of surface water resources based on their water quality. This index consists of nine parameters including DO, pH, Total Solids, BOD, turbidity, total phosphate, nitrate, temperature change, and fecal coliform. Each of these parameters has an individual weight proportional to their impact and importance in the development of the NSF WQI model (Brown et al., 1970; Noori et al., 2019). It is widely used and adaptable, making it suitable for assessing water quality in various regions and water bodies.

Appendix C.3. Global Initiatives

The Global Environment Monitoring System (GEMS) is a collective effort of the world community to acquire, through monitoring, the data needed for the rational management of the environment (Gwynne, 1982). The program is established by the United Nations Environment Program and its main objectives include the collaboration with member states in order to establish new water monitoring systems and to strengthen the existing systems, improving the validity and comparability of data on water quality within member states and assessing the long term incidence and trends of water pollution by hazardous substances (Gwynne, 1982).

Other global initiatives include the United Nations Sustainable Development Goals (SDGs) or the guidelines by the WHO, which will be described in more detail in subsection Appendix C.3.1. These initiatives also benefit the public awareness of the state of surface waters (Yisa and Tijani, 2010; Tyagi et al., 2013; Marselina et al., 2022), as they underline the significance of clean and safe water for human well-being and environmental sustainability.

Appendix C.3.1. World Health Orgainzation Guidelines for Drinking-Water Quality

The WHO has health based guidelines for a substantial amount of parameters, all described in (Organization et al., 2022). However, the only parameters measured for this research with health based guidelines from the WHO are nitrate and nitrite concentrations. Other parameters, for example Ammonia and TDS do have WHO guidelines with respect to taste and odour, but these will not be taken into account for this research. The advice regarding Nitrate reads ”Nitrate: 50 mg/l as nitrate ion, to be protective against methaemoglobi-naemia and thyroid effects in the most sensitive subpopulation, bottle-fed infants, and, consequently, other population subgroups” and for nitrite, ”Nitrite: 3 mg/l as nitrite ion, to be protective against methaemoglobinaemia induced by nitrite from both endogenous and exogenous sources in bottle-fed infants, the most sensitive subpopulation, and, consequently, the general population” (Organization et al., 2022).

Appendix C.4. Temporal Variability and Stakeholder Engagement

Water quality around the world is characterized by temporal variability due to factors like seasonal changes, agricultural practices, and industrial activities. As mentioned in Appendix C.2, local authorities therefore often define their own water quality standards and monitoring criteria tailored to specific environmental conditions and water usage within their regions. These regulations are essential for effective water quality management and public health protection. Effective water quality management often requires collaboration with various stakeholders, including local communities, industries, and government agencies. Engaging stakeholders in monitoring programs improves data accuracy, and helps to raise public awareness, and promotes informed decision-making. In summary, water quality monitoring includes a diverse range of parameters, modeling techniques, and global and local initiatives. Its importance lies in safeguarding water resources, preserving ecosystems, and ensuring the well-being of stakeholders that depend on clean and safe water. The choice of parameters, models, and standards should be designed based on the objectives of each monitoring program.

Appendix D. Expected Pollution

This section consists of an overview of what types of pollution as described in Appendix C.1 are expected to be found in the Brantas catchment as a result of agricultural activity. Agricultural water pollution primarily originates from runoff containing fertilizers, pesticides, and animal waste. This pollution is characterized by agricultural runoff, which often has high levels of nutrients, particularly nitrogen and phosphorus, from fertilizers. These nutrients can lead to eutrophication in water bodies, a process where nutrient overloads cause excessive growth of algae and subsequent depletion of oxygen, harming aquatic life. Additionally, presence of specific pesticides used in agricultural practices can be a suitable indicator. These chemicals may be found in water bodies near agricultural fields. Agricultural pollution often has a seasonal pattern, typically peaking during certain times of the year, like planting or harvesting seasons. Additionally, the closer water bodies are to agricultural lands the higher levels of pollutants associated with farming activities they are likely to show. Agriculture is a significant contributor to water pollution in the Brantas River, mainly through the use of fertilizers and pesticides. In a study by Roosmini et al. (2018) it was concluded that the parameters which were exceeding the maximum concentration in the Brantas river include Total Suspended Solids (TSS), TDS, DO and pH.

Appendix D.1. Nutrients

The nutrient pollution as result of the over-application of fertilizer results in elevated nutrient levels in runoff and groundwater, which in turn affects surface waters. Lusiana et al. (2023) found that as a result of fertilizer use, TSS, TDS, DO, BOD, nitrate, and nitrite are among the most influential variables in the water quality dynamics. The concentration of TSS is known to closely follow concentration patterns in phosphorus (Caruso et al., 2013), which makes it a suitable parameter to help determine pollution as a result of fertilizer use.

Appendix D.2. Pesticides

Apart from nutrients, runoff from paddy fields can also include concentrations of pesticide residues during the season of the appearance of planting and rice grains. In contrast to nutrients, pesticides are less easily degraded. The residue of pesticides from the upper stream may be carried all the way downstream (Gustinasari et al., 2019).

Appendix D.3. Other Chemical Compounds

Finally, as a result of both rapid development and agricultural activities, there has been large scale production of EDC, Persistant Organic Pollutants (POP), synthetic dyes, microplastics, and heavy metals Hadibarata et al. (2012); Kristanti et al. (2012); Sathishkumar et al. (2013); Poonkuzhali et al. (2014); Hamsawahini et al. (2015); Misni et al. (2015); Adnan et al. (2017); Hadibarata et al. (2021); Hii (2021); Ishak et al. (2022); Lai (2021); Sathishkumar et al. (2021); Tang et al. (2021); Sivamani et al. (2022); Ismanto et al. (2022). In a study by Ismanto et al. (2022) it was concluded that BPA was the most prevalent chemical in the Brantas River. Another source of EDC's are hormones used in livestock and aquaculture as well as pesticides and herbicides, which are widely used in agriculture (Ismanto et al., 2022).

Appendix D.4. Conceptual Pollutants Model

The interaction between agricultural activity, most relevant pollutants and the ecosystem has been summarized in a conceptual model, visualized in figure D.19.

Appendix D.5. Comparison to Pollution from Poorly Treated Sewage and Urban Waste

In order to assess the impact of agriculture on water quality, the pollution footprint of agricultural activity should be compared to the impact of other potential sources of pollution such as untreated sewage and urban waste from the upstream towns and villages. Like agricultural pollution, poorly treated or non-treated sewage can be high in nutrients. However the nutrient profile might be different. Agricultural runoff typically contains high levels of nitrogen and phosphorus which come primarily in mineral form from synthetic fertilizers and animal manure used in farming practices. In agricultural runoff, nitrogen is often present in the form of nitrate and ammonia, while phosphorus is primarily in the form of phosphate. Sewage also generally contains nitrogen and phosphorus, but the ratio and form of occurrence might be different compared to agricultural runoff. The nutrients in sewage originate from human waste, food remnants, and household products. Therefore, nitrogen from sewage could be present in various forms, including nitrates, ammonia, and organic nitrogen compounds.

Nitrogen represents the most prevalent nutrient, found in larger concentrations in sewage effluents (Fonseca et al., 2007) and it occurs predominantly as ammonia (Adams, 1973; Fonseca et al., 2007; Huang and Lu, 2014; Dong et al., 2019). In a study by Hanson and Lee (1971), 60% of nitrogen present in investigated wastewater streams existed in the form of this molecule. Other frequently occurring forms include organic nitrogen molecules (Adams, 1973; Pehlivanoglu-Mantas and Sedlak, 2006) (Adams, 1973; Fonseca et al., 2007). Fonseca et al. (2007) found that 10%, (Hanson and Lee, 1971) 12% and (Pehlivanoglu-Mantas and Sedlak, 2006) found that up to 80% of all nitrogen present in wastewater was in organic form. However, nitrate, the most prevalent form of nitrogen in agricultural pollution (Almasri and Kaluarachchi, 2004; Huang and Lu, 2014) also occurs abundantly in urban wastewater (Adams, 1973; Fonseca et al., 2007). On the other hand, about 90% of the nitrogen in underground water and in river water is in the form of nitrate nitrogen (Nakasone, 2003). A large ratio of ammonia against other form of nitrogen such as nitrate are therefore indicative to pollution by urban sources.

Huang and Lu (2014) analyzed water samples, clustered in the groups land use classes head-water sites, agricultural non-point sources pollution sites, point-sources pollution sites and mixed-sources pollution sites. From this research, it was concluded that while the water quality in head-water sites was generally good, containing only a few nutrients from the woodland runoff and soil erosion, agricultural non-point sources pollution sites, contained elevated concentrations of dissolved phosphorus, and nitrate from farmland as main pollutants Huang and Lu (2014). Huang and Lu (2014) further showed that samples from point-sources pollution sites contained ammonium (NH_4^+),

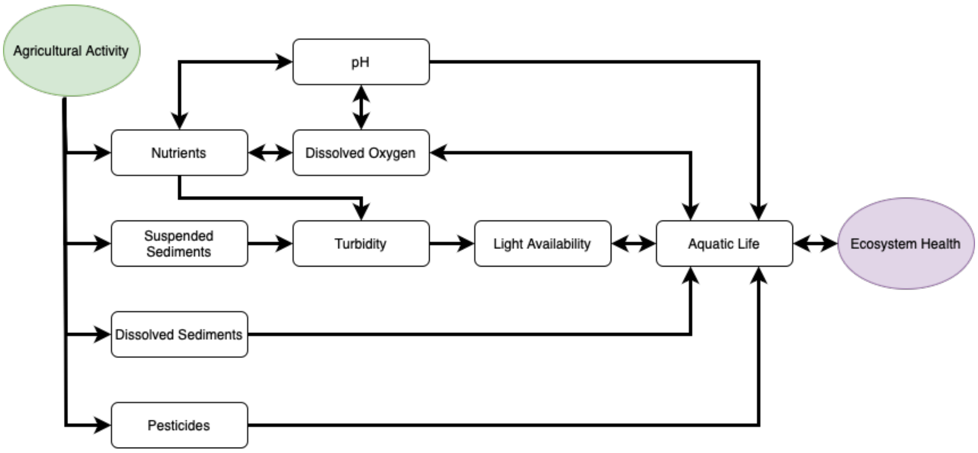

Figure D.19: Conceptual Model of Agricultural Pollution

which is the conjugate acid of ammonia, and organic pollutants originated from industrial and municipal sewage. In head-water sites and agricultural non-point sources pollution sites, nitrate was the main form of nitrogen, and a high ratio of nitrate-nitrogen/ammonium-nitrogen (NO_3^- -N/NH_4^+-N) was a distinctive characteristic, whereas ammonium was the main form of nitrogen in point-source pollution sites Huang and Lu (2014). The ratios of (NO_3^--N/NH_4^+-N) for waters in head-water sites and agricultural non-point source pollution sites were found to be near 10 and 8 times higher than that in the other groups, respectively. Analysis by Almasri and Kaluarachchi (2004) showed that areas with high nitrate concentrations were characterized by heavy agricultural activities and that a high ratio of (NO_3^- -N/NH_4^+-N) could be a characteristic for the nitrogen transport in forest and agricultural catchments. Conversely, a high ratio of (NH_4^+-N/NO_3^--N) could indicate pollution from urban sources (Almasri and Kaluarachchi, 2004). Shuquan et al. (2009) further showed that NH_4^+-N decreased with increased distance from cities, while NO_3^--N increased with an increase in farmland area in the catchments. A study on the Fuji River by Shrestha and Kazama (2007) had a similar result, wherein a high concentration of NH_4^+-N occurred in sampling sites characterized by an influence of domestic wastewater, wastewater treatment plants, and industrial effluents located at the upstream areas, while the highest average concentration of NO_3^--N is observed in sites mainly impacted by nitrogenous fertilizers in orchard and agricultural areas. In most natural water systems, both NH_4^+ and NH_3 coexist in a dynamic equilibrium, influenced by the water's pH and temperature. Therefore both forms of nitrogen can be used as an indication for pollution by urban wastewater.

The release of nutrients into water bodies as a result of farming, often corresponds to specific activities like fertilizing and ploughing, which typically follow yearly cycles. Conversely, nutrient levels in sewage tend to be more consistent, reflecting the continuous nature of human waste production. Therefore, unlike agricultural runoff, sewage-derived nutrient pollution does generally not have a strong seasonal pattern, unless there is a strong influence of other factors such as seasonal tourism. While sewage-derived nutrients contribute to oxygen depletion and eutrophication, the presence of pathogens in sewage can have additional adverse effects on water quality and aquatic ecosystems. Bacteria and viruses can indicate urban pollution and can be a great health hazard. The presence of fecal coliforms, like E. coli, is often used as an indicator of sewage contamination. Additionally, trace amounts of pharmaceuticals and personal care products can be used to indicate urban pollution, as these are not typically found in agricultural runoff. Another indicator can be that pollution from agriculture follows cropping patterns, while pollution from sewage tends to be more consistent and continuous, unlike it is influenced by for example a tourist season.

In conclusion, in order to distinguish between agricultural pollution and pollution from poorly treated sewage, water quality testing for specific contaminants like certain pesticides can indicate agricultural sources, whereas high levels of fecal coliforms or certain pharmaceutical compounds might point to sewage-related pollution. Additionally, a high ratio of (NO_3^--N/NH_4^+-N) could indicate agricultural pollution while conversely, a high ratio of (NH_4^+N/NO_3^--N) could indicate pollution from urban sources. If data is available on nutrient concentrations in a water body throughout the year, one could look into the temporal variability of the nutrient loads. If these follow a yearly cycle corresponding to farming activities, agriculture is likely to be the source, while more constant levels could indicate that the pollutants are derived from urban sources. Finally as distinguishing between these sources can be a challenge, it is important to take geographic and temporal factors such as upstream land use and population density into account.

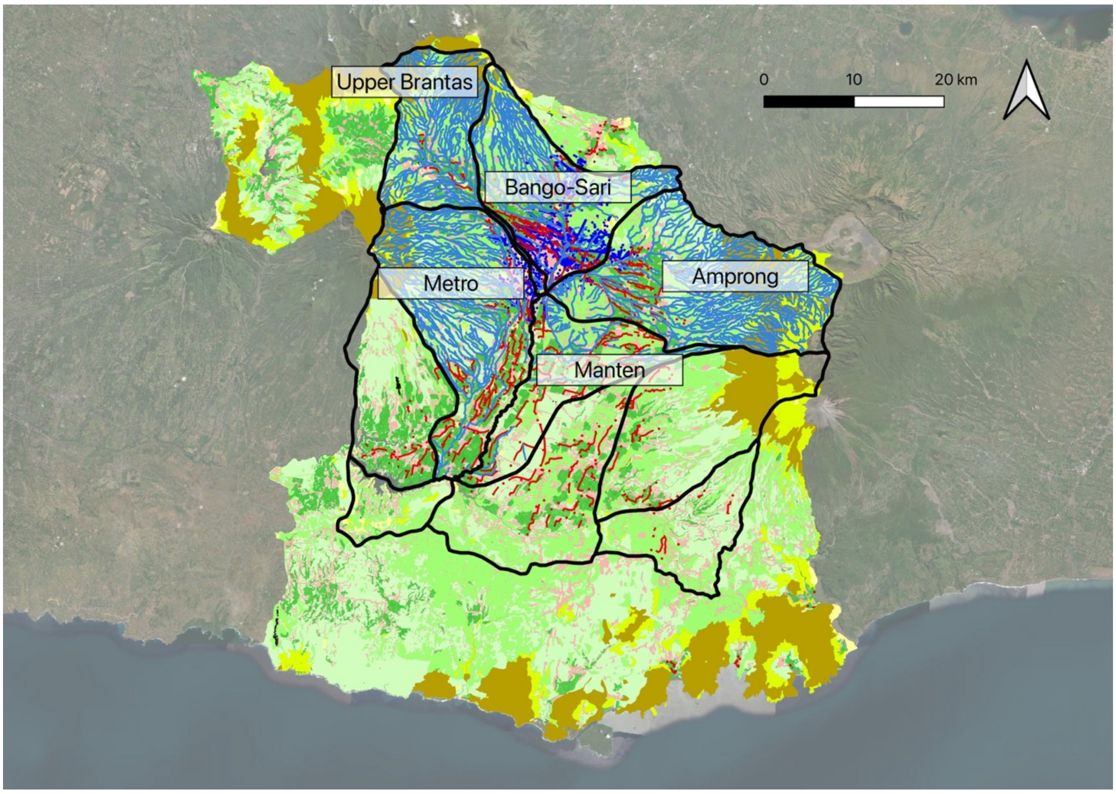

Figure E.20: Sub-Catchments

Appendix E. Maps Supporting the Methodology

Appendix E.1. Sub-Catchments

Appendix E.2. Watershed Delineations

Appendix F. Maps Supporting the Results

Appendix F.1. Map of the BOD Results

Appendix F.2. Map of the Phosphate Results

Appendix F.3. Map of the Ammonia Results

Appendix G. Instrument Accuracy

G.3.

Appendix H. Costs

Appendix I. Fieldwork Weather Conditions

Appendix J. Water Quality Standards of the Republic of Indonesia

Appendix K. Horiba versus Greisinger Dissolved Oxygen Measurements

Appendix L. Biological Oxygen Demand Results

Appendix M. Example Images of Land Use Classifications

Appendix M.1. Examples of Sawah Area

Appendix M.2. Examples of Ladang Areas

Appendix M.3. Examples of Kebun Areas

Appendix M.4. Examples of Urban Areas

Appendix N. Examples of the Sampling Method

Appendix O. Example of Agricultural Water Pollution Pathway

Appendix P. Examples of Observed Point Source Pollution

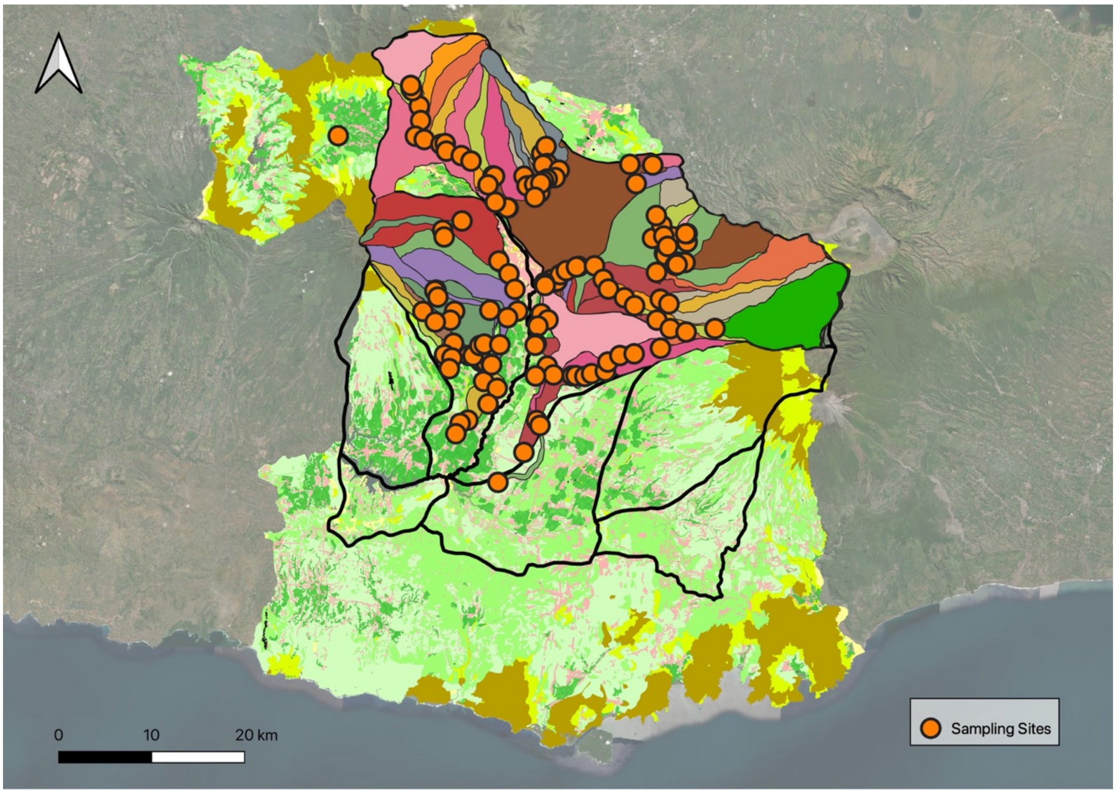

Figure E.21: Watershed Delineations

Table G.3: Accuracy of the Used Instruments

Instrument	**Accuracy (at 20 °C)**
Hanna Instruments HI991301 (pH)	± 0.01 pH
Hanna Instruments HI991301 (EC)	± 2%
Hanna Instruments HI991301 (Temperature)	± 0.5 °C
Greisinger G1610 (DO)	± 0.2 mg/L
Horiba LAQUA DO220 (DO)	± 0.1 mg/L
AquaChek 641426E Nitrate/Nitrite Test Strips	± one half of a color block
Salifert Phosphate Tests	± one half of a color block
Salifert Ammonia Tests	± one half of a color block
Horiba U-50 (DO)	0 to 20 mg/L: ± 0.2 mg/L and 20 to 50 mg/L: ± 0.5 mg/L
Horiba U-50 (EC)	±1% F.S. (Median of two-point calibration)

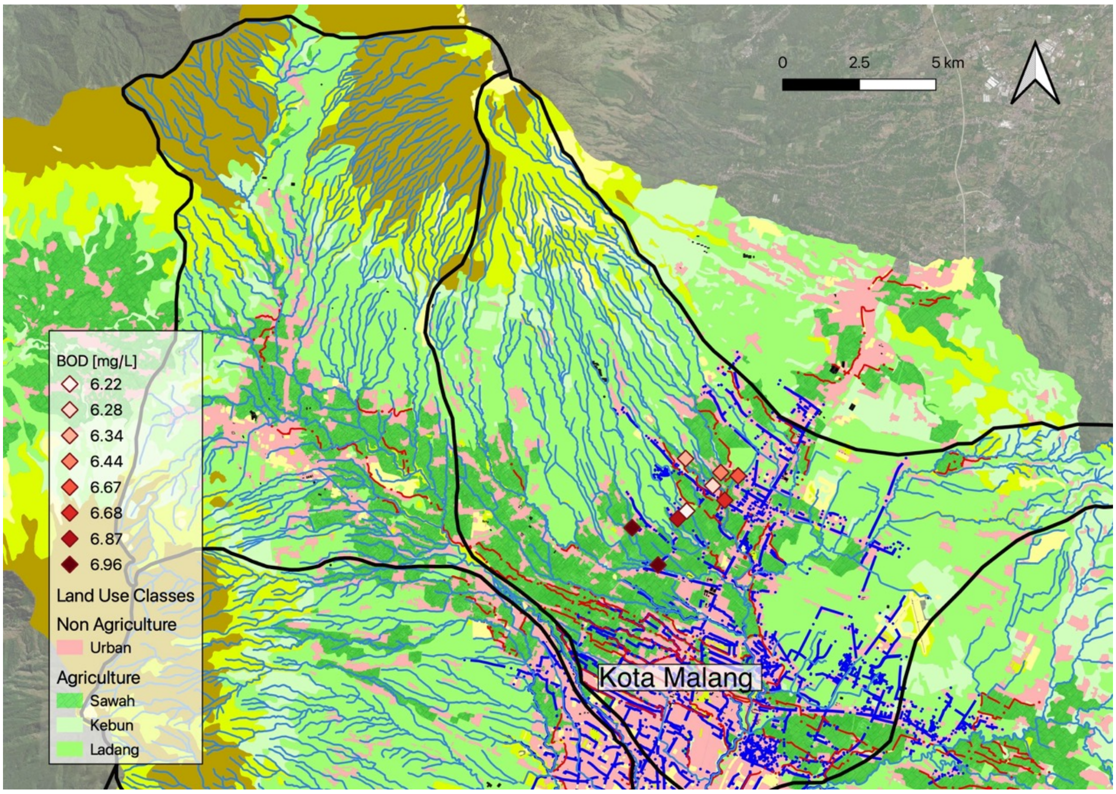

Figure F.22: BOD Measurements

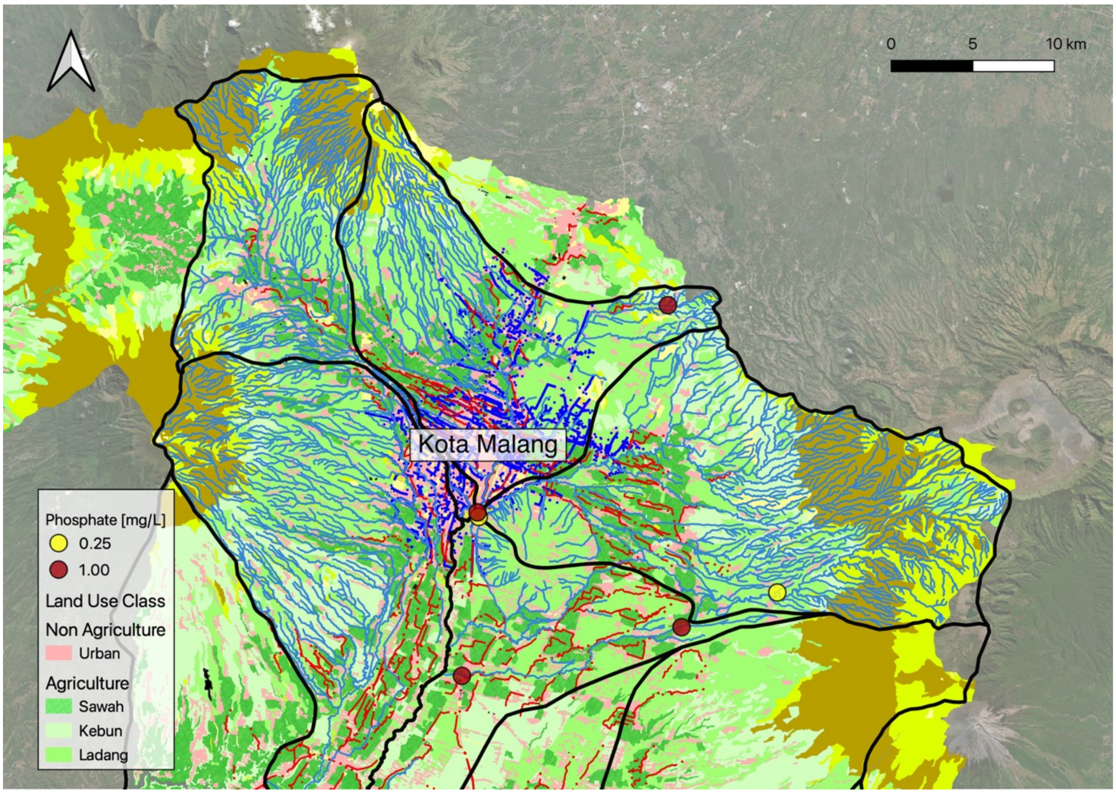

Figure F.23: Phosphate Measurements

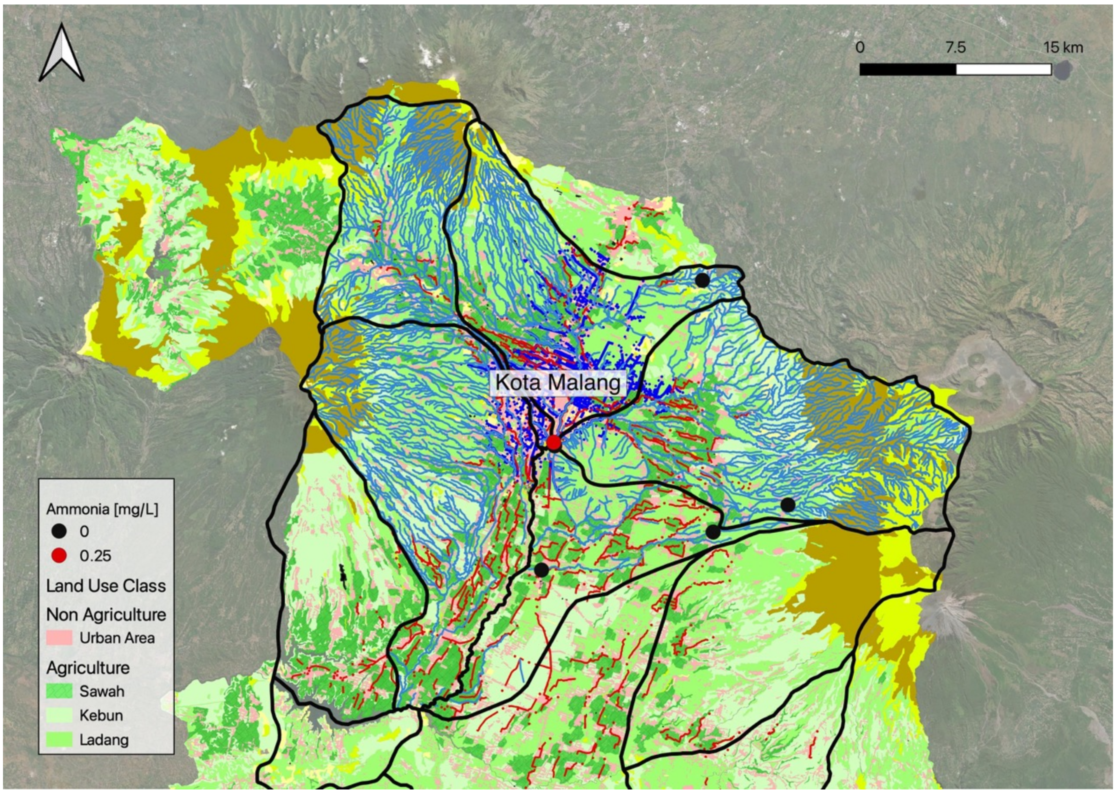

Figure F.24: Ammonia Measurements

Table H.4: fieldwork costs

Item	**Quantity**	**Price per unit (€)**	**Cost (€)**
Hanna Instruments HI991301 multi-meter depreciation cost	56 days	0.83	46.84
Greisinger G1610 DO meter borrowing cost	56 days	0	0.00
Horiba U-50 multi-meter meter borrowing cost	8 days	0	0.00
Horiba LAQUA DO220 DO meter borrowing cost	10 days	1.56*	15.60
Gasoline	33 litres	0.80*	26.40
BOD lab test	15 tests	3*	45.00
Nitrate lab test	1 test	2.75*	2.75
AquaChek 641426E Nitrate/nitrite test strips	10 x 25 strips	20.50	205.00
Salifert Nitrate Tests	50 tests	6.75*	0.81
Salifert Phosphate Tests	60 tests	6.75*	0.68
Total		*€1 = 16000 IDR	**344.08**

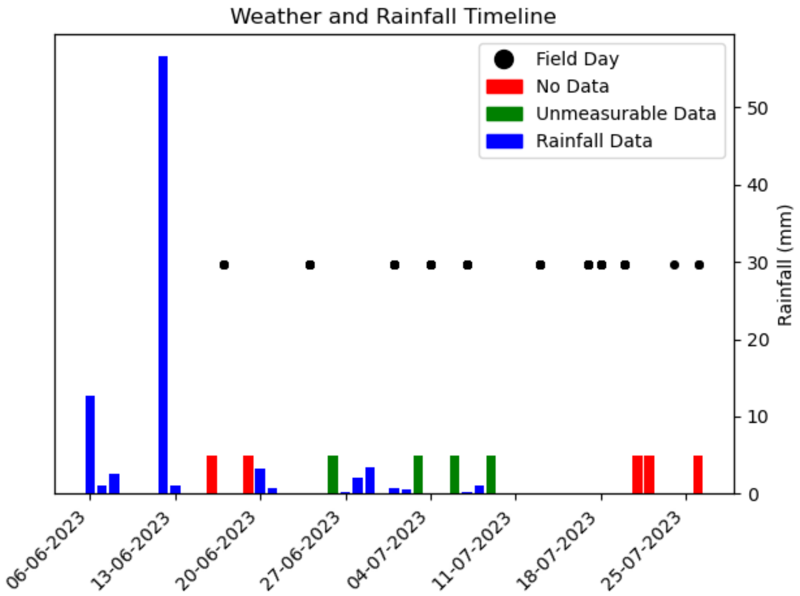

Figure I.25: Rainfall Time-series and Weather Timeline based on rainfall data from BMKG Stasion Klimatologi Jawa Timur

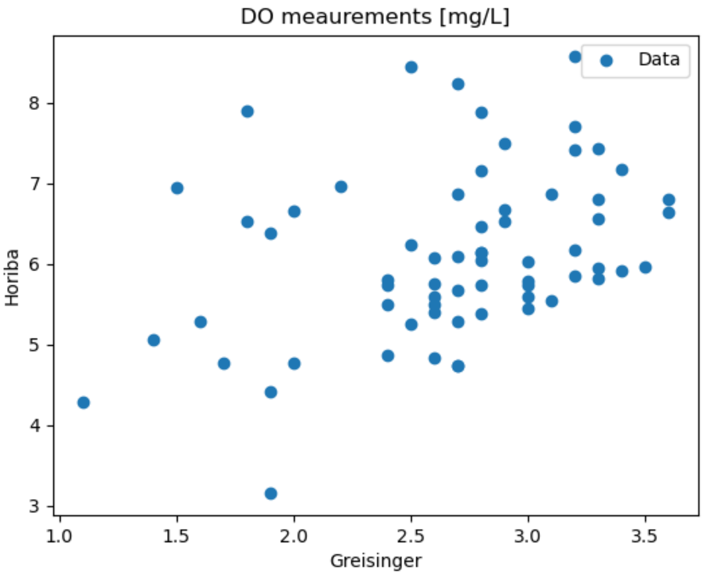

Figure K.26: Horiba vs Greisinger DO Measurements

Table J.5: Water Quality Standards (Djaman, 2021)

ID	Parameter	Unit	Class I	Class II	Class III	Class IV
1	Temperature	°C (deviation from air temperature)	Dev 3	Dev 3	Dev 3	Dev 3
2	TDS	mg/L	1000	1000	1000	2000
3	TSS	mg/L	40	50	100	400
4	Colour	Pt-Co Unit	15	50	100	-
5	pH		6-9	6-9	6-9	6-9
6	BOD	mg/L	2	3	6	12
7	COD	mg/L	10	25	40	80
8	DO	mg/L (minumum limit)	6	4	3	1
9	Sulfate	mg/L	300	300	300	400
10	Chloride	mg/L	300	300	300	600
11	Nitrate-N	mg/L	10	10	20	20
12	Nitrite-N	mg/L	0.06	0.06	0.06	-
13	Ammonia-N	mg/L	0.1	0.2	0.5	-
14	Total Nitrogen	mg/L	15	15	25	-
15	Total Phosphorus	mg/L	0.2	0.2	1.0	-
16	Fluoride	mg/L	1	1.5	1.5	-
17	Sulfur	mg/L	0.002	0.002	0.002	-
18	Cyanide	mg/L	0.02	0.02	0.02	-
19	Free Chlorine	mg/L	0.03	0.03	0.03	-
20	Barium	mg/L	1.0	-	-	-
21	Boron	mg/L	1.0	1.0	1.0	1.0
22	Mercury	mg/L	0.001	0.002	0.002	0.005
23	Arsenic	mg/L	0.05	0.05	0.05	0.10
24	Selenium	mg/L	0.01	0.05	0.05	0.05
25	Iron	mg/L	0.3	-	-	-
26	Cadmium	mg/L	0.01	0.01	0.01	0.01
27	Cobalt	mg/L	0.2	0.2	0.2	0.2
28	Manganese	mg/L	0.1	-	-	-
29	Nickel	mg/L	0.05	0.05	0.05	0.1
30	Zinc	mg/L	0.05	0.05	0.05	2
31	Copper	mg/L	0.02	0.02	0.02	0.2
32	Lead	mg/L	0.03	0.03	0.03	0.5
33	Chromium	mg/L	0.05	0.05	0.05	1
34	Oil and Fat	mg/L	1	1	1	10
35	Total Detergent	mg/L	0.2	0.2	0.2	-
36	Phenol	mg/L	0.002	0.005	0.01	0.02
37	Aldrin/Dieldrin	µg/L	17	-	-	-
38	BHC	µg/L	210	210	210	-
39	Chlordane	µg/L	3	-	-	-
40	DDT	µg/L	2	2	2	2
41	Endrin	µg/L	1	4	4	-
42	Heptachlor	µg/L	18	-	-	-
43	Lindane	µg/L	56	-	-	-
44	Methoxychlor	µg/L	35	-	-	-
45	Toxapan	µg/L	5	-	-	-
46	Fecal Coliform	MPN / 100 mL	100	1000	2000	2000
47	Total Coliform	MPN / 100 mL	1000	5000	10000	10000
49	Rubbish		0	0	0	0
50	Radio Activity Gross-A	Bq/L	0.1	0.1	0.1	0.1
51	Radio Activity Gross-B	Bq/L	1	1	1	1

(a) Workes Harvesting Rice

(b) Mature Sawah Plants

(c) Young Sawah Plants

(d) Inundated Young Sawah Plants

Figure M.27: Sawah Areas

(a) Soy Field (b) Burned Sugarcane Field

(c) Sugarcane Field (d) Harvested Sugarcane Field

Figure M.28: Ladang Areas

(a) Banana Trees (b) Various Trees in Kebun Type Plantation

(c) Banana Trees (d) Harvested Sugarcane Field

Figure M.29: Kebun Areas

(a) Large Village

(b) Small Village

(c) Irrigation Channel through Urban Area

(d) House next to Irrigation Channel

Figure M.30: Urban Areas

Table L.6: BOD Results

ID	BOD [mg/L]
1	6.67
2	6.34
3	6.44
4	6.28
5	6.73
6(1)	6.96
6(2)	6.36
7	6.87
8	6.22
9	6.68

(a) Taking a Sample with a Bucket on a Rope

(b) Taking a Sample with a Bucket on a Rope

(c) Measuring the EC and pH with the Multimeter

Figure N.31: Examples of how Samples were Taken

Figure O.32: Runoff from an Agricultural Field

(a) Chicken Farm

(b) Chicken Farm Effluent

(c) Trash in a Stream

(d) Trash on the side of a Stream

(e) Inhabitants Doing their Laundry in the River

(f) Someone Cleaning their Motorbike in the River

(g) Livestock

Figure P.33: Examples of Observed Point Source Pollution