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Variation in discharge due to changes in vegetation-cover characteristics in the Keduang catchment, Indonesia

Final version Bachelor Thesis

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Draft version Bachelor thesis

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Summary

The Indonesian environment has changed significantly in recent decades. Land use and land cover have changed dramatically, and this has caused floods and high discharges. Land use and land cover changes have been studied extensively, but vegetation-cover characteristics have been studied a little less. This study investigates the relationship between variation in discharges and changes in vegetation-cover characteristics in the Keduang catchment, Indonesia.

The years with useful discharges were analyzed first. After a check with a water balance, the years 1991, 1992, 2006, 2007, 2010, 2011, 2012 turned out to be useful. The most important vegetation-cover characteristics were studied next. For this research, the LAI, size of area with healthy vegetation, number of trees, diameter of trees and tree height were used. The LAI was measured by use of hemispherical pictures. The size of area with healthy vegetation was measured with spatial data. The number of trees was determined in the field. The diameter of trees was measured using a tape measure, and tree height was measured with a haga-meter.

The NDVI (normalized difference vegetation index) was extracted from the spatial data which was downloaded from www.glovis.usgs.gov. A linear relationship was found between the NDVI and the LAI of June 2015. However, the LAI and the discharge of the Keduang do not show a relationship, as the distribution of the LAI was the same during the years. The size of the area with healthy vegetation in the Keduang is related to the discharge: when the size of area with healthy vegetation increases, the discharge decreases.

Preface

After four years of studying for my Bachelor, I bring my study to completion with this thesis. In the past four years, I organized a study tour to Argentina and Uruguay with three other committee members. I enjoyed seeing how civil engineering works in another country during the study tour. Besides, I really enjoy other cultures and countries. So I decided to go to abroad for my Bachelor thesis as well. I chose to go to Indonesia. When I arrived in Surakarta, it was wonderful to see how people wanted to help me to make the most of my time here. I had an amazing time with all the people I met there.

I would like to thank a few people who helped me to finish my research. First, Martijn Booij, he gave me a lot of feedback and very good advice. My research happened in context of Andry Rustanto's PhD research. I also was to thank Prima Nugroho. He arranged my boarding house in Indonesia, accompanied me to the field for my field work and helped me get the necessary software. Finally, I want to thank my supervisors from the water board BPDAS Solo: Pak Sigit Haryadi and Mbak Kumala Nurhayati.

Henrike Maris
July 2015, Surakarta

Table of figures

List of abbreviations

DBH	Diameter at Breast Height
GLA	Gap Light Analyzer
LAI	Leaf Area Index
LULC	Land use land cover
NDVI	Normalized Difference Vegetation Index
NIR	Near Infra-Red reflectance
R	Red reflectance
VCC	Vegetation-cover characteristics
VI	Vegetation index

Table of Contents

1 Introduction

This chapter provides an introduction to this study. Background for this study will be presented in the first paragraph. In paragraph two, the research gap will be described. Paragraph three deals with the main goal of the study and lists the research questions. Finally, paragraph four presents an overview of the contents of this report.

1.1 Background

In recent decades, developments in Indonesia have occurred that have led to a significant and rapid change in the environment (Farid, Mano, and Udo, 2010). Due to the rapid development of these events and to the changed environment, land use and land cover (abbreviated as LULC) have dramatically changed. These changes of land use and land cover cause floods and high discharges; moreover, they play a significant role in the climate system (Mahmood et al., 2014).

Much research has been done to determine the relationship between alterations of vegetation cover and changes in water yield. Bosch and Hewlett (1982) reviewed 94 catchments experiments based on a paired-catchment methodology and time-trend studies. None of the experiments related reductions in water yield with reductions in cover or increases in water yield with increases in cover. Therefore, the direction of changed water yield can be predicted. Additional papers have been published about this topic since 1982. Brown et al. (2005) summarized 72 paired-catchment experiments based only on a paired-catchment methodology. This paper is focused on determining changes in water yield that result from changes in vegetation.

As mentioned above, Bosch and Hewlett reviewed experiments that use a paired-catchment methodology or a time-trend methodology. In the paired-catchment methodology, two adjacent located catchments with similar characteristics in terms of slope, aspect, soils, area, climate and vegetation are compared (Brown et al., 2005). In a time-trend analysis, differences in streamflow between differences in land use and land cover periods are estimated (Bosch and Hewlett, 1982a). An advantage of time-trend analysis is that it is applicable to a non-paired-catchment (Zhao, Zhang, Xu, and Scott, 2010). Another advantage is that it costs less than a paired-catchment study (Bosch and Hewlett, 1982a). These advantages makes it useful for large catchments.

A useful example of the relationship between changes in water yield and alterations in land cover can be found in a recent study of micro-catchments in southern Amazonia (Guzha et al., 2014). This study presents a link between land cover change and rainfall-runoff characteristics. It suggests that a conversion of forest to pasture may lead to changes in runoff (Guzha et al., 2014). Another example of this relationship is from a study in the Bai River catchment in Beijing, China. This study evaluated the impact of land use and land-cover change on runoff. Results indicate that LUCC increases run-off and that the response of the run-off to rainfall decreases (Zhan, Xu, Ye, and Su, 2011).

To determine the relationship between peak discharges and changes in vegetation cover, characteristics of vegetation cover can be used. Dutta (2014) reviewed different vegetation indices for vegetation monitoring. Different vegetation-cover characteristics are mentioned in a study of crop assessments (Wiegand, Richardson, Escobar, and Gerbermann, 1991). Both studies mention leaf-area index (LAI) as a vegetation-cover characteristic. Another study reports on the predictability of the LAI that is based on the variation of vegetation type, observation angle, and vegetation index. Different observation angles can be used to improve the estimation of LAI (Gu, Sanchez-Azofeifa, Feng, and Cao, 2015).

As mentioned above, a considerable amount of literature has been published on the impact of vegetation changes on water yield. However, this has not always been done based on vegetation-cover characteristics. Quantification of vegetation-cover characteristics will give a clearer understanding of effects of LULC on hydrological processes.

This study fits into the PhD research of Andry Rustanto. The title of his study is, *Effect of Land Use / Land Cover Changes on Hydrological Processes and Water Availability in the Upper Bengawan*

Solo Catchment: Parameter Assessment and Application in Hydrological Modelling (Twente, 2015). In tropical regions, there is a lack of information about the effects of LULC on hydrological processes. This study will contribute to a better understanding of the effects of LULC on hydrological processes; it will especially improve our understanding of the effects of vegetation cover on discharge.

1.2 Research gap

As mentioned in paragraph 1.1, land use and land-cover change have been studied by many researchers via the paired-catchment and time-trend methodology (Bosch and Hewlett, 1982b; Brown et al., 2005). Change in vegetation-cover characteristics is an important aspect of LULC change. Much research has been done into changes in LULC, but a little has been done into changes in vegetation-cover characteristics. On the basis of characteristics of vegetation cover, changes in land use and land cover can be determined.

However, very little is known about change in vegetation-cover characteristics and its effect on discharge in tropical regions. A better understanding of this relationship will improve our understanding of hydrological processes.

1.3 Objective and research questions

As mentioned in paragraph 1.2, much research has been done on land use and land-cover change and how these affect runoff. However, this relationship has not been studied for the Keduang sub-catchment of the upper-Bengawan Solo catchment. It has also not been done with some important vegetation-cover characteristics. Therefore, the aim of this study may be stated as follows:

"The main aim of this study is to investigate the relationship between variation in discharge and change in vegetation-cover characteristics in the Keduang sub-catchment of the Bengawan-Solo catchment by using remote sensing, station data and in-situ measurements."

To guide the research, several research questions have been specified:

1. What have the annual and average discharges in the Keduang sub-catchment been in the last few decades?
2. What vegetation-cover characteristics can be related to discharge in the Keduang sub-catchment?
3. How should vegetation-cover characteristics be measured, and how should this data be processed?
4. What is the relationship between peak-discharge variation and vegetation-cover characteristics in the Keduang sub-catchment?

1.4 Structure of the report

This paragraph presents an overview of what will follow in subsequent chapters. Chapter 2 presents an overview of the study area and the data of this research. Chapter 3 discusses the method used in this study; each paragraph is devoted to the method of one research question. Chapter 4 presents the results; each paragraph gives the results of one research question. Chapter 5 discusses the results from the fourth chapter. Finally, chapter 6 summarizes the conclusions and offers recommendations.

2 Study area and data

This chapter gives an overview of the study area and the available data. The first paragraph outlines information about the study area. The second paragraph describes the available data.

2.1 Study area

This study focuses on the Keduang sub-catchment, which is part of the Wonogiri district. The Keduang is located in the Bengawan Solo catchment, on the Island Java, Indonesia, between 110^{o}56'53'' - 111^{o}13'23'' East longitude and 7^{o}42'30'' - 7^{o}55'29'' South latitude. Figure 1 shows the location of the Bengawan Solo catchment included the Keduang sub-catchment. Balai Pengelolaan Daerah Aliran Sungai (BPDAS) Bengawan Solo, the water board that studies the Keduang sub-catchment, is located in Surakarta. The surface area of the Keduang sub-catchment is approximately 380 km^2. Java has a tropical climate that includes a rainy and a dry season. The rainy season starts in September and ends in March. In July and August, rainfall amounts are small. The dry season starts in April and ends in August. The average temperature during the year (1999-2005) is 29^{o}C, and it does not vary with different seasons. The average humidity in the dry season (1990-1996 and 2009-2013) is 72%, and the average humidity in the rainy season (1990-1996 and 2009-2013) is 80%. The average evapotranspiration during the year (1999-2005) is 5.3 mm per day.

Figure 1. Location Bengawan Solo catchment (Red part is Surakarta, blue part is Wonogiri, yellow part is Keduang sub-catchment)

Figure 2 shows the river system of the Keduang. Figure 3 presents the geology of the Keduang sub-catchment. There is not much variety in the geology. Most of the Keduang consists of old volcanic deposits. Some Miocene deposits appear. The soil of the Keduang sub-catchment is shown in Figure 4. There are four different soil types in the Keduang sub-catchment: andosol, latosol, litosol and mediteran. Figure 5 presents the land use and land cover in 2014 of the Keduang sub-catchment.

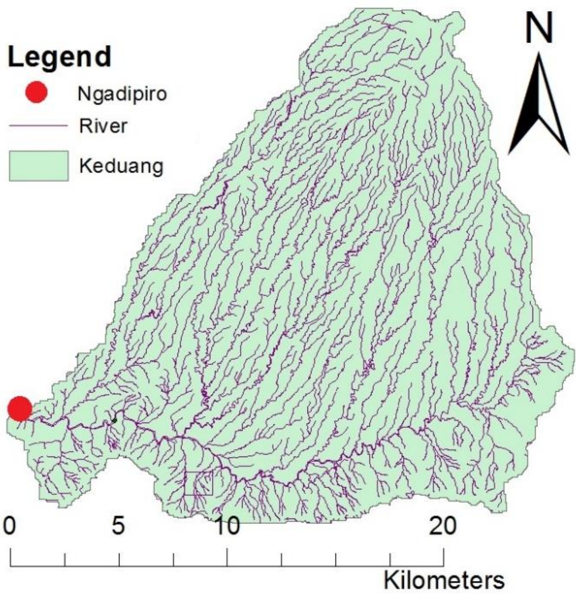


Figure 2. Rivers Keduang, Ngadipiro is the discharge station

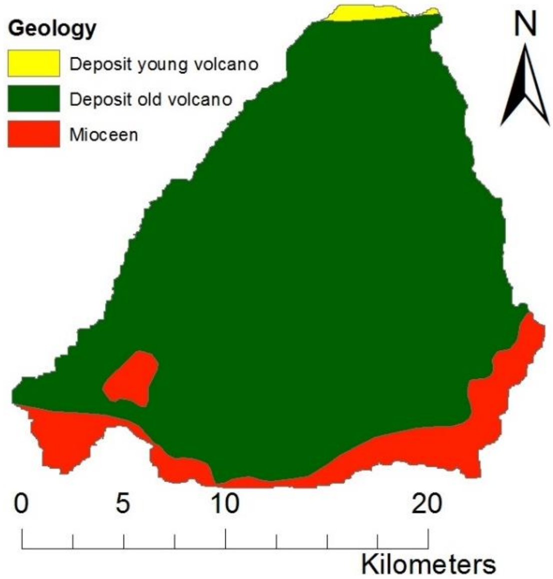


Figure 3. Geology Keduang

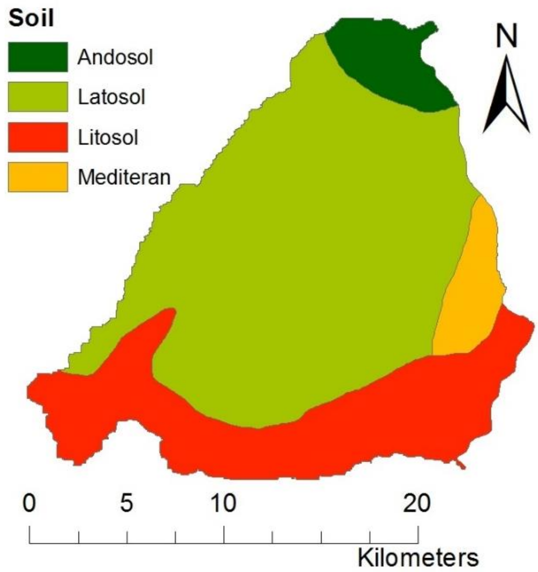


Figure 4. Soil Keduang

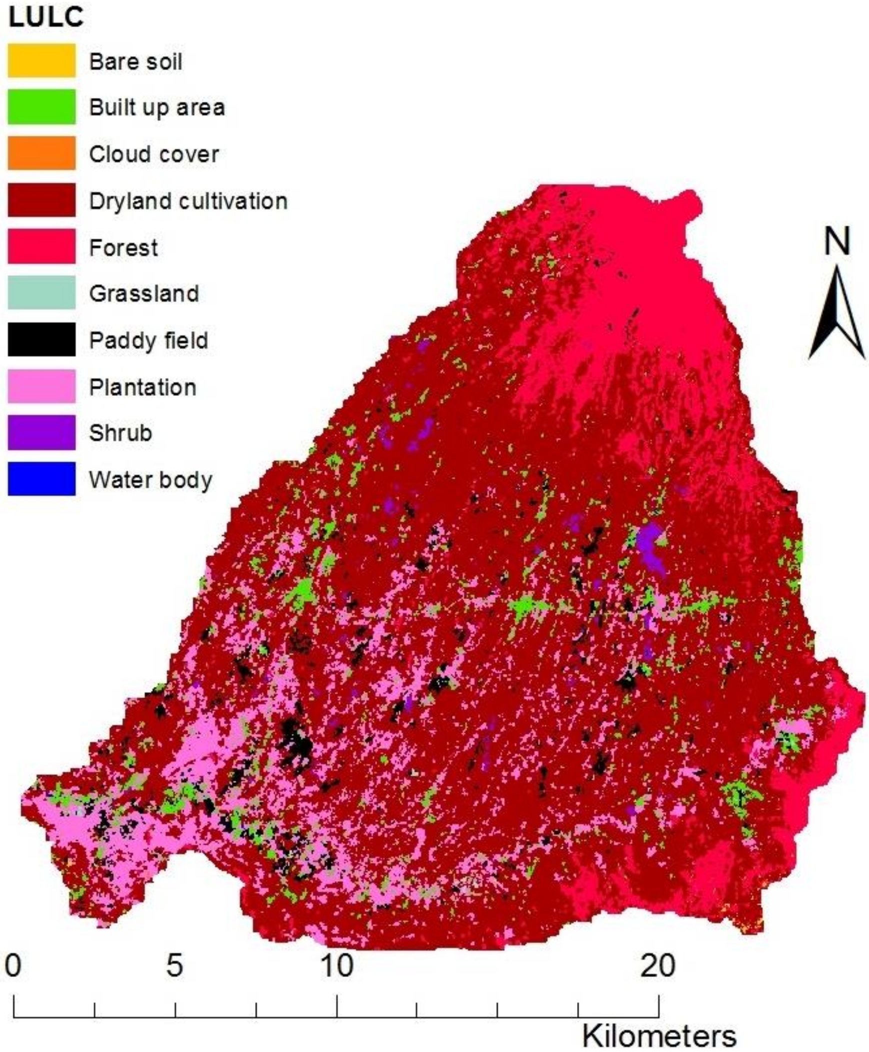


Figure 5. Land use Land cover Keduang 2014

2.2 Data

Data has been obtained from a variety of resources. Hydrological and climatological data are described in the first section; spatial data are described in the second section.

2.2.1 Hydrological and climatological data

Hydrological data and climatological data were obtained from the water board: BPDAS Bengawan Solo. This data consists of discharge and rainfall data from 1991 until 2013. The discharge data is from the Ngadipiro station, which is at the South-West of the Keduang catchment, see Figure 2 for the location. The discharge is measured by using the water-level height. Water-level height was converted to discharge by comparing it with a Q-h graph.

Rainfall data from many different stations in the Wonogiri district were provided by the water board BPDAS. Rainfall data is collected at four stations in the Keduang sub-catchment. Data values have been combined to get the final rainfall data of the Keduang sub-catchment. The data ranges from 1991 until 2013, but not all of the data from those years are available. There are some errors and missing data.

Climatological data were obtained from the water board BPDAS. It consists of data concerning temperature, humidity, wind velocity, air pressure and pan evaporation. Data were collected from 1990 until 2014, but not all data are available. For this study, the temperature, humidity and pan evaporation are used.

2.2.2 Spatial data

Spatial data were obtained from earthexplorer (earthexplorer.usgs.gov) and Glovis (glovis.usgs.gov). Datasets of Landsat 4-5 ETM (1994-2000), Landsat 7 ETM+ (2004-2012) and Landsat 8 ORS/OLI (2013-2014) (path 119/row 65 for all three) were used. Appendix A presents the Landsat images that were used during the study. Only the Keduang part of the images is used.

Some errors were found in the Landsat 7 images. After calculations were performed in ENVI (a program used to calculate NDVI with spatial data), many points exhibited a NDVI value of -1 (value for water). This is not possible, because they were scattered at the image and the pixels around have much higher values (0 and higher). Those values were therefore deleted. Figure 6 shows the peak at -1 of a Landsat 7 image which have been deleted. The Landsat 7 images also exhibit a very high number of pixels with values between -0.02 and 0. Figure 6 shows a high peak around 0, which is caused by error lines. The number of pixels for that point was re-calculated and the average of the number of pixels before and after that point was used. This recalculation was performed to correct the data. An image without errors (Landsat 5 or Landsat 8) is shown in Figure 7. Figure 8 shows the histogram of a Landsat 7 image after the incorrect data were deleted.

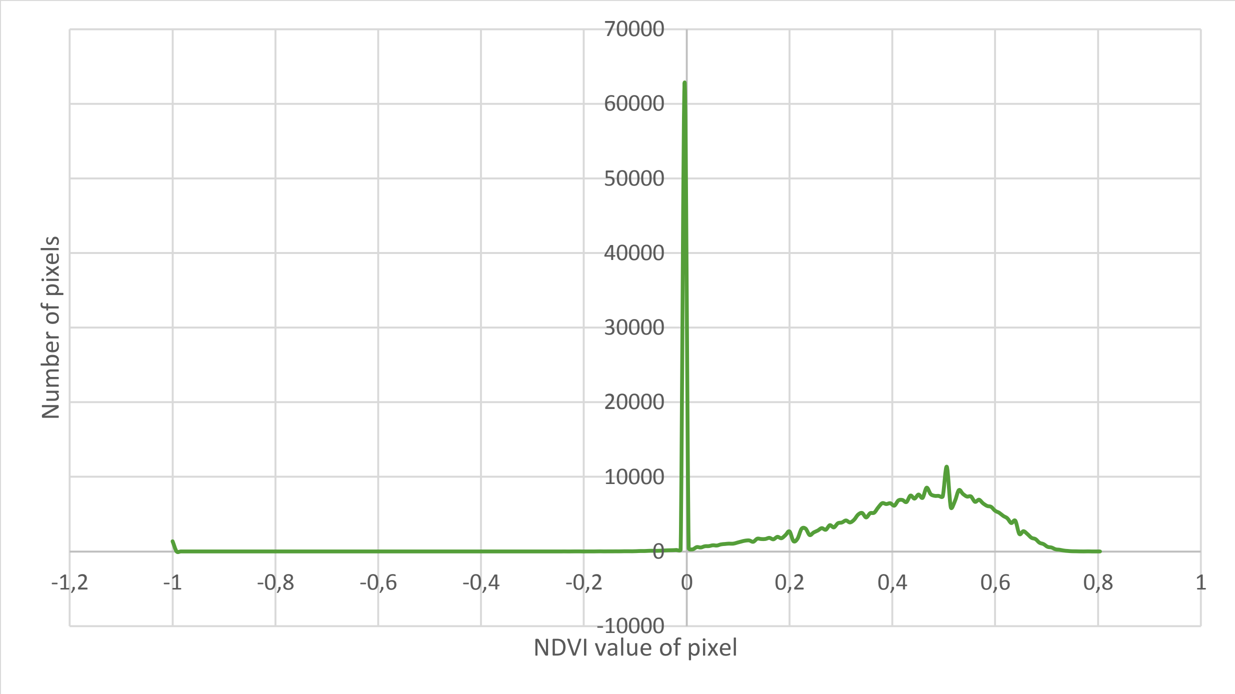


Figure 6. Distribution of pixels before deleting incorrect data L7 20-06-2011

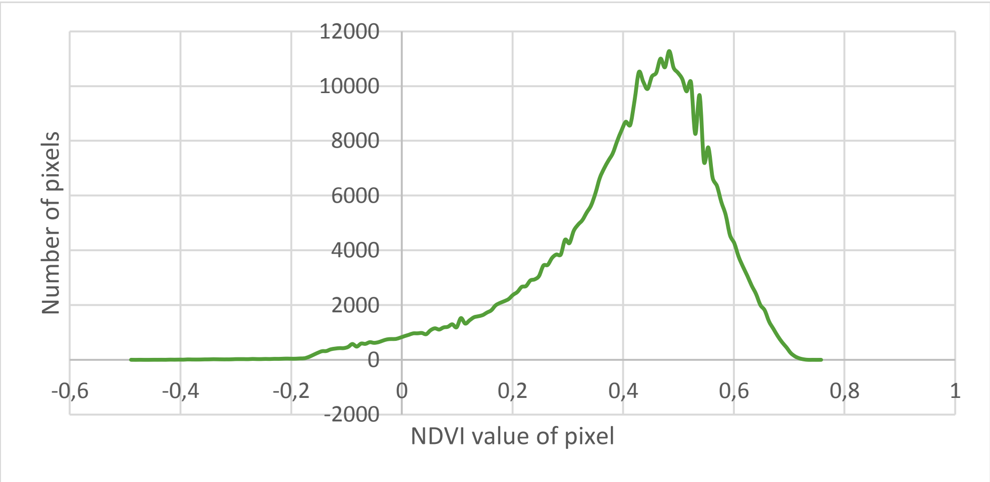


Figure 7. Distribution of pixels without incorrect data L5 09-03-1994

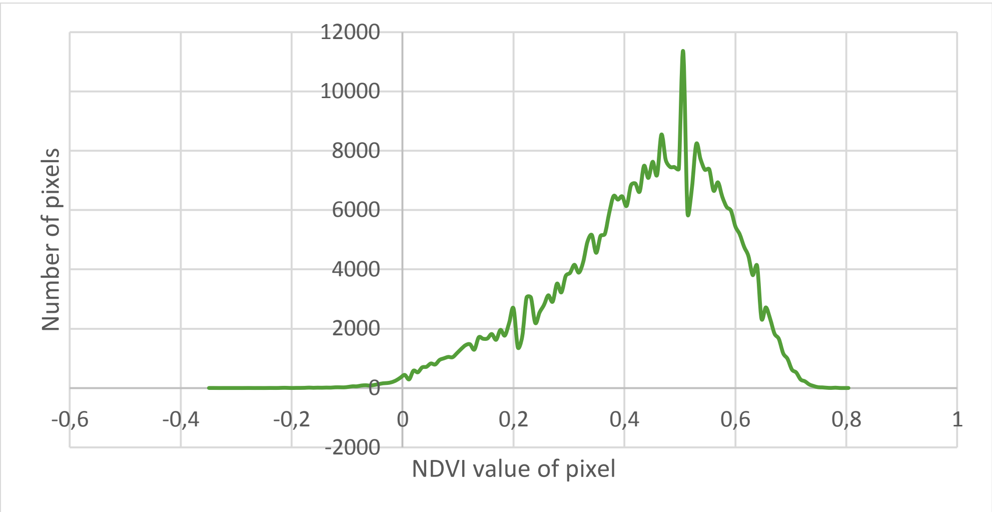


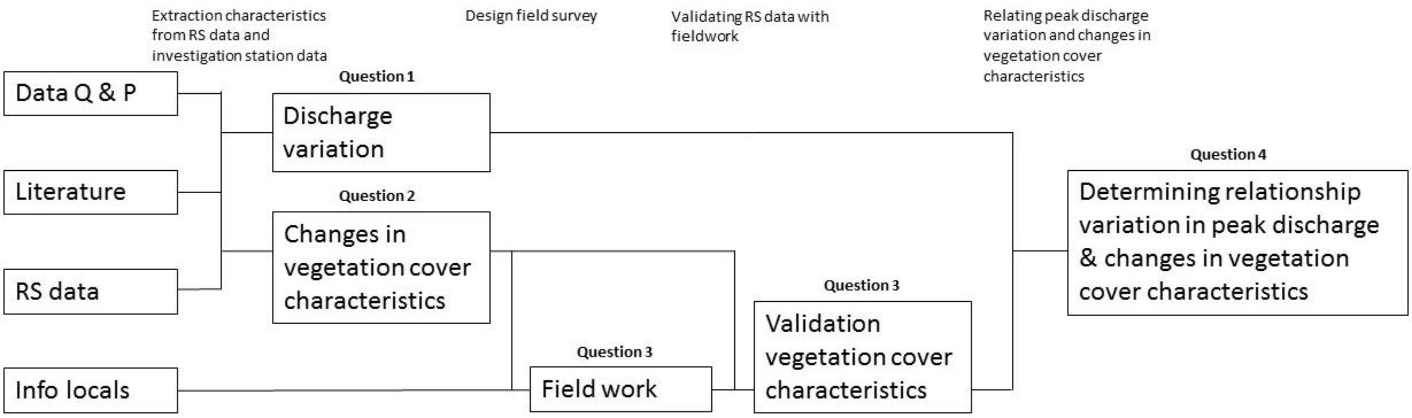
Figure 8. Distribution of pixels after deleting incorrect data L7 20-06-2011

3 Methodology

The purpose of this chapter is to present the methodology of this research. The first paragraph presents the research model. The first research question is described in the second paragraph. The third paragraph deals with the methodology of the investigation of the vegetation-cover characteristics. The design and execution of the field survey is described in paragraph four.

3.1 Research model

The research model of this study is shown in Figure 9. To identify the variation in discharge, hydrological-station data and literature were used. Vegetation-cover characteristics were subsequently analyzed using literature and remote-sensing data. Spatial data was used to determine changes in vegetation cover. To characterize vegetation-cover characteristics, in-situ measurements were performed in the Keduang catchments. The results of those in-situ measurements were related to the spatial data. Finally, the relationship between the discharge and vegetation-cover characteristics was investigated.



3.2 Investigation discharge

This paragraph deals with the first research question: What have the annual and average discharges been in the Keduang sub-catchment in the last few decades?. The first step was to carry out a quality analysis of the hydrological data. Using Excel, a graph of the discharge data was made. Using this graph, the data were checked to see if it is in line with the rainy and dry season. The discharge should be higher in the rainy season (September until March) than in the dry season (April until August). After this check, a graph of the rainfall was made. The rainfall data was first checked against the rainfall of the different stations in the Keduang sub-catchment. Using the data from the discharge and the rainfall, the actual evapotranspiration was calculated. The potential evaporation per year was also calculated. A graph was made from the actual evapotranspiration and the potential evaporation. For pan evaporation, the only available data is from 1999 to 2005. *Pan evaporation* is the maximal potential evaporation. Therefore, the decision was made to use the highest potential evaporation for the other years.

3.3 Investigation vegetation-cover characteristics

The method used for research question two is discussed in two sections. The first section deals with the determination of the most important vegetation-cover characteristics for the Keduang sub-catchment. The second section describes algorithms that can be used to extract the VCC and how the VCCs should be quantified.

3.3.1 Important vegetation-cover characteristics

To determine the important vegetation-cover characteristics for this study, six criteria were formulated. Criteria for selecting the vegetation-cover characteristics are as follows:

1. The VCC affects the infiltration;
2. The VCC affects the discharge;
3. The VCC must be present in the Keduang sub-catchment;
4. Remote-sensing data of the VCC must be available;
5. It must be possible to measure the VCC in situ;
6. It must be possible to validate the in situ data of the VCC with remote sensing data.

Prior to analysis of the vegetation-cover characteristics, a list of characteristics was made. Different vegetation-cover characteristics were found by searching the literature about vegetation. Those characteristics and criteria were put in Table 1. This table was used to determine the most important vegetation-cover characteristics for this study. The useful vegetation-cover characteristics for this study are the leaf-area index (LAI), vegetation height, understory, vegetation density, stand diameter and size of area with healthy vegetation. These vegetation-cover characteristics were studied because they fit the research aim.

Table 1. Vegetation-cover characteristics

Vegetation characteristic	Affects infiltration	Affects discharge	Present in Keduang	Remote sensing data	In-situ measurements	Validation
Crown coverage	Yes	Yes	No	No	Yes	No
Vegetation height	Yes	Yes	Yes	No	Yes (haga meter)	No
Vegetation type	Yes	Yes (some species need more water than others)	Yes	No	Yes	No
Vegetation layer depth	No	No	No	No	Yes	No
Vegetation age	No	No	No	No	Yes (indicated by diameter of stands (reference article))	No
Vegetation density	Yes	Yes (the more plants the more water they need)	Yes	Yes	Yes	Yes
Diameter of stands	Yes	Yes	Yes	No	Yes (tape measure)	No
Rooth depth	No (it is already infiltrated)	Yes (roots take water)	Yes	No	No	No
Understory	Yes (more understory, less infiltration)	Yes (more understory, less infiltration)	Yes	No	Yes (notitions)	No
Ground cover	Yes	Yes	Yes	No	Yes (notitions)	No
Kind of soil layer	Yes (some soils have a better infiltration than others)	Yes	Yes	Yes	Yes	Yes
Ground height	No	Depends on ground water level	Yes	Yes	Yes	Yes
Ground slope	No	Yes (higher slope, faster flow)	Yes	Yes	Yes	Yes

Human interventions	Yes	Yes	No	No	No	No
Leaf coverage (LAI)	Yes	Yes	Yes	Yes	Yes	Yes
Boundary of vegetation	No	No	Yes	Yes	No	No
Size of area with healthy vegetation	Yes	Yes	Yes	Yes	No	No

3.3.2 Algorithms to extract VCC from spatial data

As described in the previous section, the important vegetation-cover characteristics were compared with spatial data. Landsat images and vegetation indices were used to extract the vegetation-cover characteristics. Vegetation indices are conversions from reflectance measurements to mathematical ratios or linear combinations. The visible and near-infrared bands from spectral bands are used most. The vegetation indices can be used to gain information about surface characteristics (Payero, Neale, and Wright, 2004).

These vegetation indices (VI) can be divided into two groups: the slope-based VIs and the distance-based VIs. Slope-based VIs give an indication of the state and abundance of green vegetation cover (Silleos, Alexandridis, Gitas, and Perakis, 2006). The main objective of the distance-based VIs is to cancel the effect of soil brightness (Silleos et al., 2006). For this study, a slope-based VI was used, because the state and abundance of green vegetation are needed. The Normalized Difference Vegetation Index (NDVI) was used for this research. Because it can minimize topographic effects, this is the most commonly used vegetation index. Furthermore, it separates green vegetation from its background (Silleos et al., 2006). In this equation, *NIR* stands for near infrared reflectance and *R* stands for red reflectance.

$$NDVI = \frac{NIR - R}{NIR + R}$$

To extract the NDVI from the Landsat images, a software program called ENVI was used. ENVI is a software program for geospatial analysis and spectral-images processing (http://www.exelisvis.com/). The metadata files of the Landsat images were loaded in ENVI and radiometric calibration and NDVI calculations were performed. The data from ENVI were copied to Excel. Using Excel, boxplots were made of the NDVI values. A boxplot is used because it shows the distribution of the NDVI values. As mentioned in paragraph 2.2.2, Landsat 7 data contained some errors. The NDVI values of those errors have been deleted.

It is important to compare all the same dates of the different years, because different dates will have different data. To compare the same dates of all the years, a scaling method was used. Three Landsat pictures were downloaded for every year. All the steps mentioned above were taken. Using Excel, polynomial trend lines were calculated for the five values of a boxplot: minimum value, q1 value, mean value, q3 value and maximum value. With this trend line, the values for the same dates were calculated and compared. A more extensive explanation can be found in Appendix B Scaling method

3.4 Fieldwork and processing

This paragraph presents an overview of the method used for research question three. It is divided into three sections. The first section contains the method of the fieldwork. The second sections deals with the processing of the hemispherical images that resulted from the field work. The third section describes the relationship between the NDVI (research question two) and the LAI obtained from the hemispherical images. It is only possible to obtain the NDVI from spatial data and the LAI from hemispherical images. Therefore, those two values were compared.

3.4.1 Fieldwork

The most important vegetation-cover characteristics for research question two were measured during the fieldwork in the forest. The locations for the measurements were selected using different NDVI values of the Landsat images. The coordinates of those locations were taken from ArcMap. In the field, it was not possible to measure the exact coordinates, so the measured locations differ from the chosen coordinates. This, however, has no consequences for the results of the fieldwork.

Previous studies used hemispherical images to identify the LAI (Awal, Wan Ishak, and Bockari-Gevao, 2010; Van Gardingen, Jackson, Hernandez-Daumas, Russell, and Sharp, 1999; Zhang, Chen, and Miller, 2005). This study also used hemispherical images to calculate the LAI. The pictures of the understory and the crown coverage were taken with a Canon EOS DSLR 1000D Camera. A fish eye lens was attached: a 0.21X Digital King fish-eye lens optics Japan. The settings of the camera were as follows: (1) autofocus on, (2) Av mode, (3) F (aperture) set to 9.0. The pictures were taken in a square of five by five meters. At every corner, the coordinates were measured with a GPS (GPSmap 76CSxGarmin). Pictures were taken facing upward and downward. At every position, a series of pictures were taken facing upward and downward: one in underexposure (-1), one normal (0) and one in overexposure (1). The exposure value is the scale of brightness or darkness. These settings were to determine the picture where the sky appears the most white afterwards. With these settings, the most reliable results will be obtained.

After all the pictures at a square were taken, the other measurements were done. First, the trees were counted. Subsequently, the diameter of those trees was measured at breast height (DBH is diameter at breast height). The height of the trees was measured with a haga meter, see Figure 10.

3.4.2 Processing hemispherical images

Next, the fieldwork all the hemispherical images was processed. Using Gap-Light Analyzer software, (GLA) the LAI of the hemispherical images was determined (Frazer, 1999). Figure 11 shows a fish eye picture that was taken in the field. Those images were imported into the GLA. GLA software converted that picture into the picture used in Figure 12, of which the LAI was calculated. This process was repeated for every single point and picture.

First, the upward-facing pictures with the whitest sky were selected. The pictures facing downward with the most contrast between vegetation and ground were selected for the calculation of LAI. Finally, the LAI of the upward-facing pictures was added to the downward-facing pictures at the same coordinate.

Figure 11. Fish-eye picture taken in the field

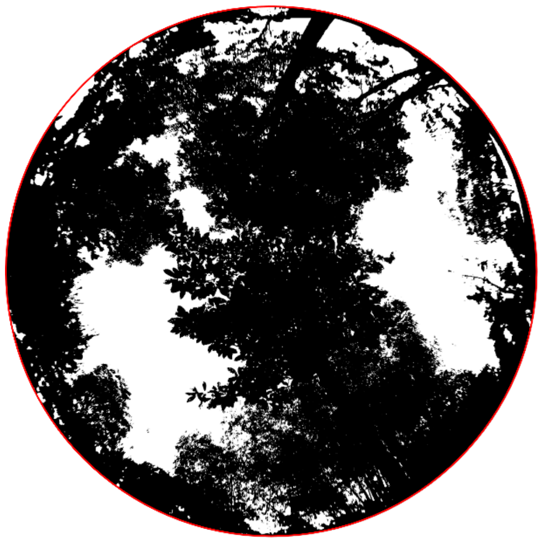


Figure 12. Working image in GLA software

3.4.3 Validating NDVI to LAI

Leaf-area index is defined as the one-sided green-leaf area per unit of ground surface. It is possible to determine LAI in different ways, but not on the basis of only spatial images. NDVI values can be determined from spatial data. To convert NDVI values to LAI values, a formula was used. This formula is formulated by comparing NDVI values with LAI values of the coordinates.

The NDVI was calculated from a Landsat image taken the 22nd of May, 2015 (Landsat 8). This was the best one with a cloud cover of 0% and an image quality of 9 out of 9 (i.e., without errors, a perfect scene). The hemispherical pictures were taken in the field on the 2nd of June. A scatter was made of the LAIs and NDVIs from the same coordinates. The polynomial trend line obtained was used as a formula to calculate LAIs of other years by using the NDVIs. In this study, the LAI was calculated for different years (1991, 1992, 2006, 2007, 2010, 2011, 2012).

For the other years, the LAI was calculated only for areas where the NDVI was 0.3 or higher, because these areas contains healthy vegetation. It is useful to calculate LAI for areas with healthy vegetation because only healthy leaf area will absorb water. The LAI says something about the green (healthy) leaf area and not about dead vegetation.

Landsat images were not available for every day of the year, so it was not possible to obtain the same days for every year. To get data for the same days, a scaling method was used (see Appendix B). The 9th of June was chosen to compare the different years, because it is in the beginning of the dry season.

4 Results

This part of the thesis describes the results that emerged from the research questions using the methods discussed in the previous chapter. This chapter is divided into four main paragraphs, each of which presents the results relating to one of the research questions. Paragraph 4.1 starts with the first research question about the discharge data. Paragraph 4.2 deals with the vegetation-cover characteristics. Paragraph 4.3 deals with the fieldwork and finally paragraph 4.4 deals with the relationship of the discharge and vegetation-cover characteristics.

4.1 Discharge data

This paragraph will provide an answer to the first research question: What have the annual and average discharges been in the Keduang sub-catchment in the last few decades? An answer will be given in two sections. Before proceeding to examine the annual and average discharges of the Keduang sub-catchment, it is necessary to check the data for correctness. This is done in the first section. The second section presents the annual and average discharges.

4.1.1 Correctness of data

To investigate the correctness of the discharge data, a few steps were taken. A graph of the discharge was made, as shown in Figure 13. A few years (1991, 1992, 1993, 2004-2007, 2009, 2010) follow the rainy and dry season, because those years have higher discharge in the rainy months (September to March). The other years exhibit steady discharge during the year, so they do not follow the discharge of the rainy and dry season.

Figure 14 shows the annual rainfall and discharge from 1991 until 2013. Using this data, the actual evapotranspiration was calculated and the water balance was checked. Figure 15 shows a graph of the actual and potential evaporation. This graph shows that, for only a few years (1991, 1992, 2006, 2007, 2010, 2011, 2012), the potential evaporation was higher than the actual evapotranspiration. It is not possible that the actual evapotranspiration is higher than the potential evaporation, so it suggests that the data of the other years may not be correct.

Two different scatter plots were made from the rainfall and discharge: one of all the data from 1991 until 2013, the other from only the years that are correct with the PET and AET (1991, 1992, 2006, 2007, 2010, 2011, 2012). A determination coefficient was used to check how well the data fits the trend line. The determination coefficient for all the years is 0.1346, and the determination coefficient for the years that are correct with PET and AET is 0.9537. The years that are correct with PET and AET are much better correlated than the data from all the years.

The results of this paragraph suggest that several years (1991, 1992, 2006, 2007, 2010, 2011, 2012) can be used for this research. These years are in line with the rainy and dry season, and they show a correlation between the discharge and rainfall ($R^2 = 0.9537$).

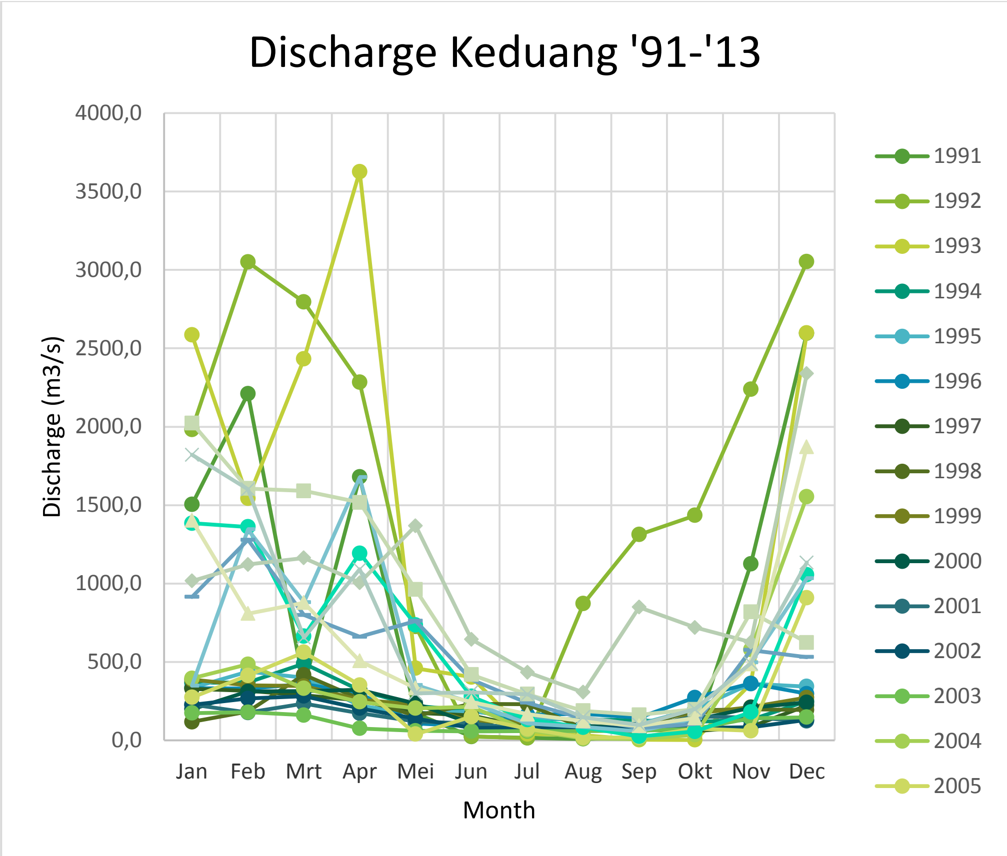


Figure 13. Discharge Keduang '91-'13

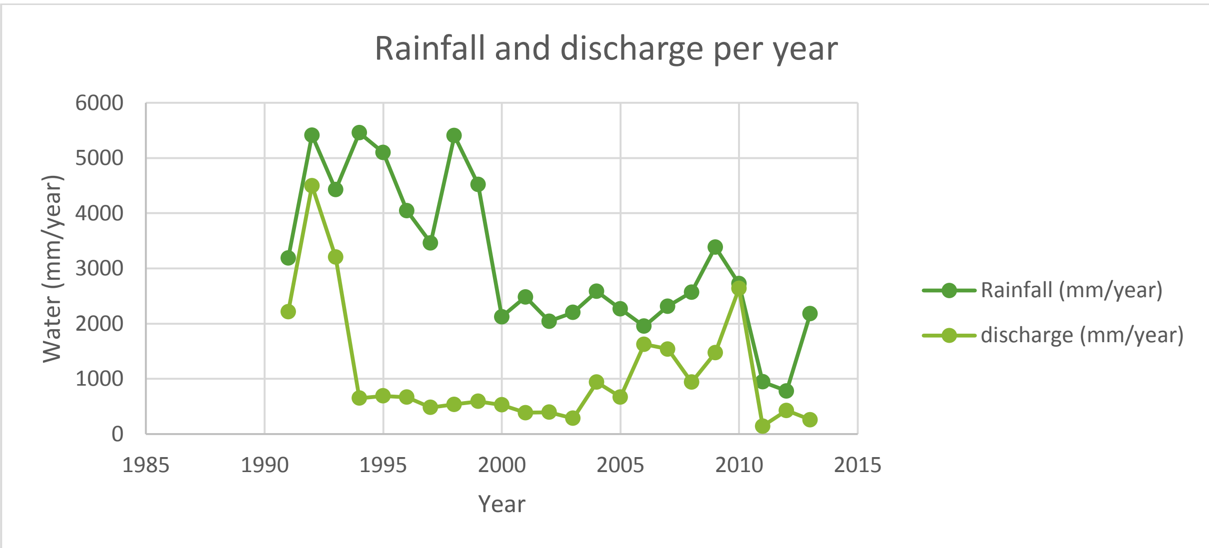


Figure 14. Rainfall and discharge per year

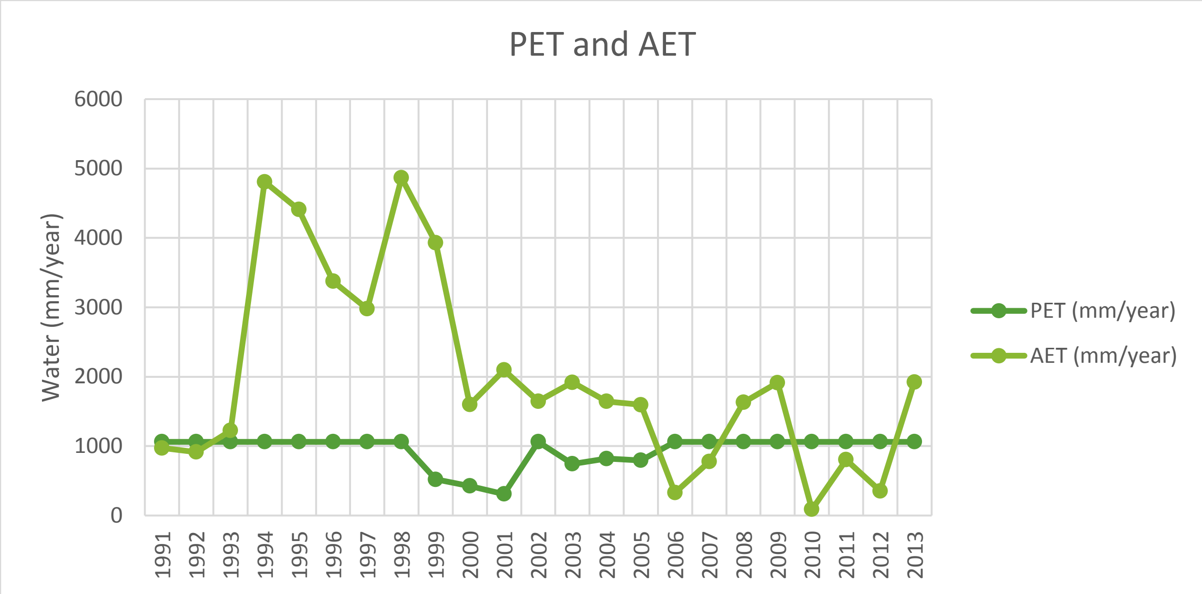


Figure 15. Potential evapotranspiration and actual evapotranspiration per year

4.1.2 Discharge variation

To determine discharge variation, the years 1991, 1992, 2006, 2007, 2010, 2011, 2012 were used. Figure 16 shows the rainfall and discharge of those years.

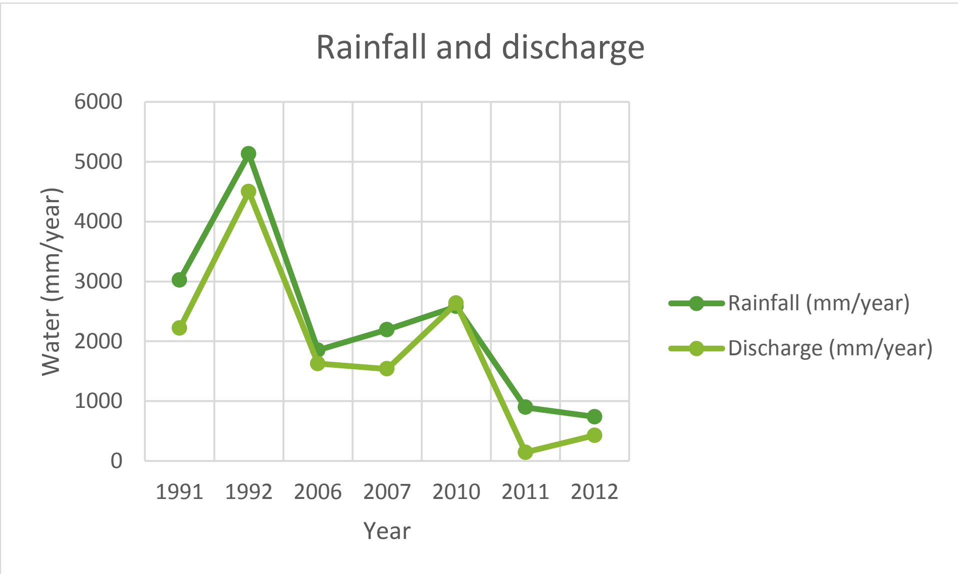


Figure 16. Rainfall and discharge

4.2 Vegetation-cover characteristics

This paragraph describes and discusses the results regarding to the second research question: Which vegetation-cover characteristics can be related to the discharge in the upper Bengawan Solo catchment? First, a definition of *vegetation* is given. *Vegetation* can be defined as an "assemblage of plant species and ground cover that are found in a particular area". This definition was used to determine some vegetation-cover characteristics. The first section of this paragraph deals with the important vegetation-cover characteristics used in this research. The second part describes the results of the NDVI from the Landsat images.

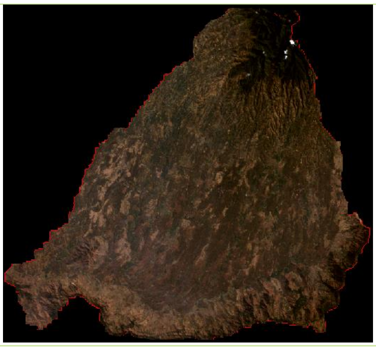
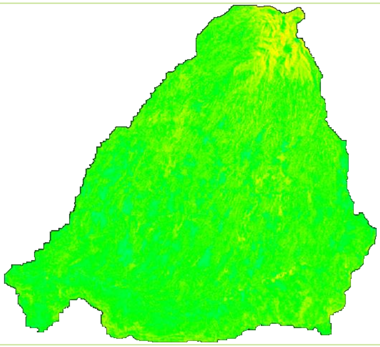
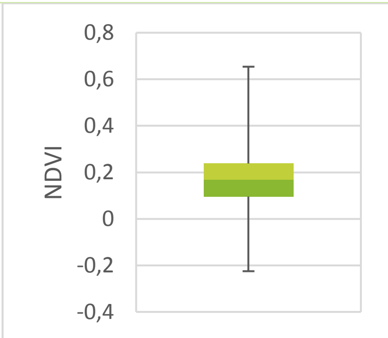
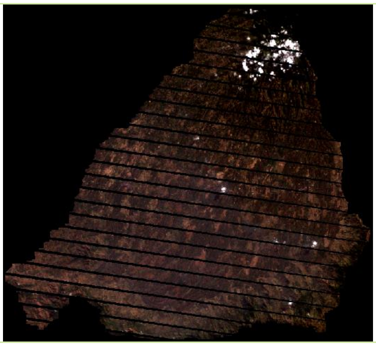
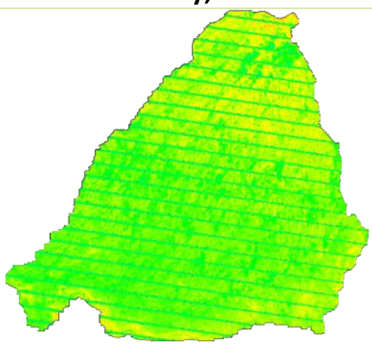
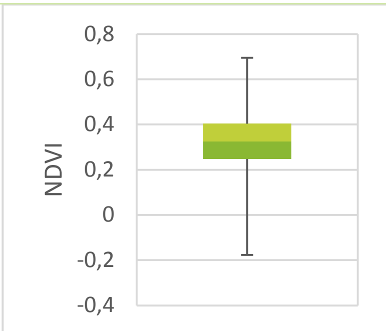
4.2.1 Important vegetation-cover characteristics

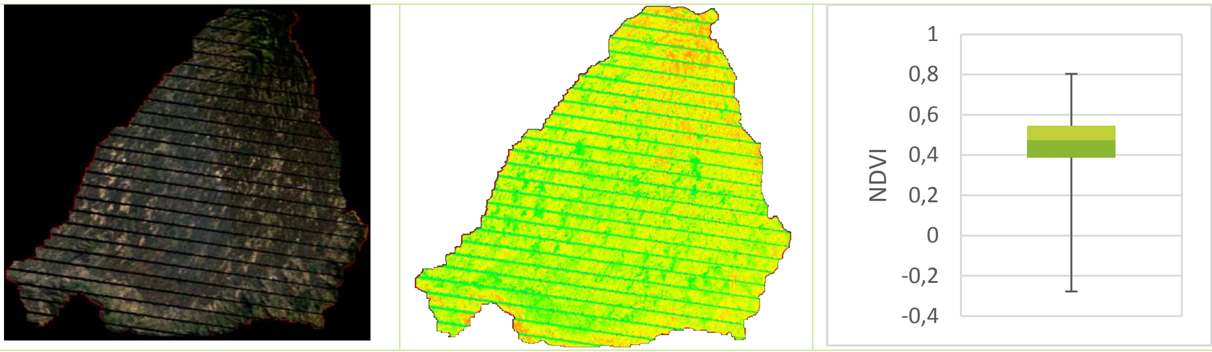
There are many vegetation-cover characteristics, but not all are useful for this research. To be useful for this study, they must meet six requirements. Table 1 identifies the vegetation-cover characteristics and requirements. As discussed in paragraph 3.3.1, useful vegetation-cover characteristics for this research include the leaf coverage (LAI), vegetation height, understory, vegetation density, stand diameter and size of area with healthy vegetation. These vegetation-cover characteristics are studied because they fit the research aim.

4.2.2 NDVI

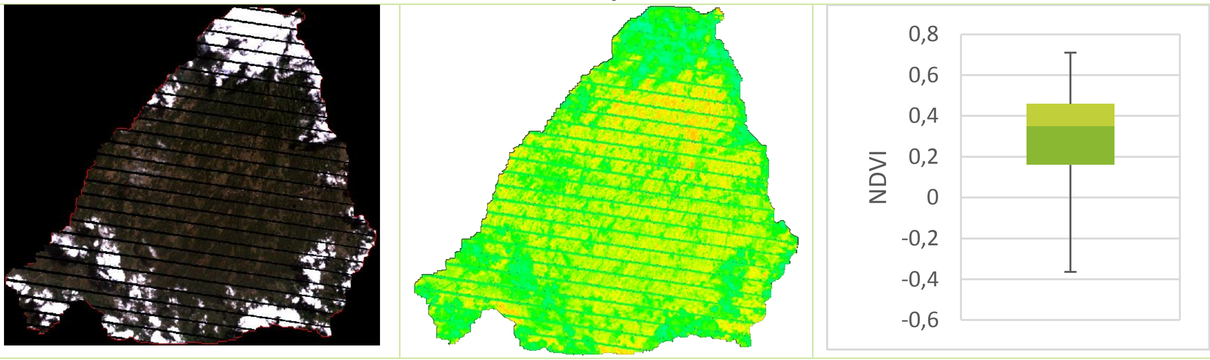
NDVI was calculated using the Landsat images. The NDVI has only been calculated for the years selected in section 4.1.2 (1991, 1992, 2006, 2007, 2010, 2011 and 2012),because these years can be compared to the discharge. The Landsat images were only available since 1994, so instead of 1991 and 1992, the NDVI of 1994 was calculated. Table 2 shows the radiometric calibration, the NDVI and the values of the NDVI in a boxplot. Radiometric calibration was used to calibrate the image data to radiance, reflectance or brightness temperatures. The image for the year 2010 contains some cloud cover (9% on the whole image). This means that the actual values of NDVI should be a bit higher.

Table 2. Distribution of NDVI

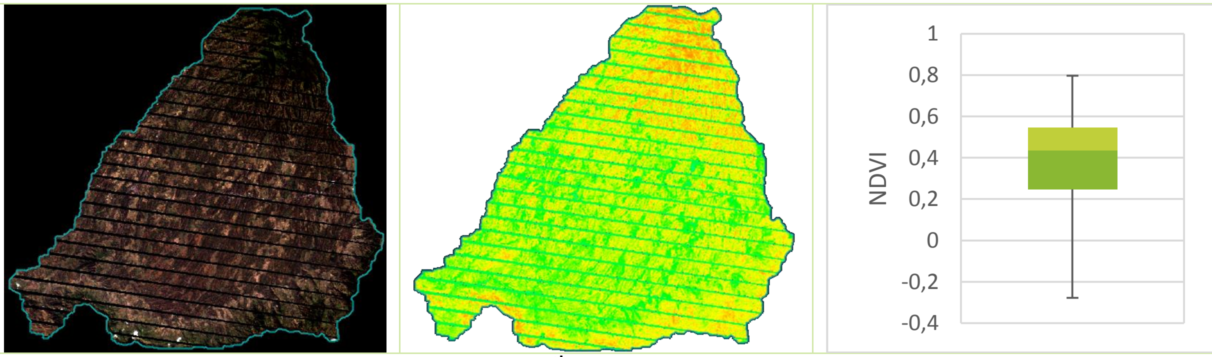
Radiometric calibration	NDVI	Boxplot
31st July, 1994		
		
8th July, 2006		
		
25th June, 2007		



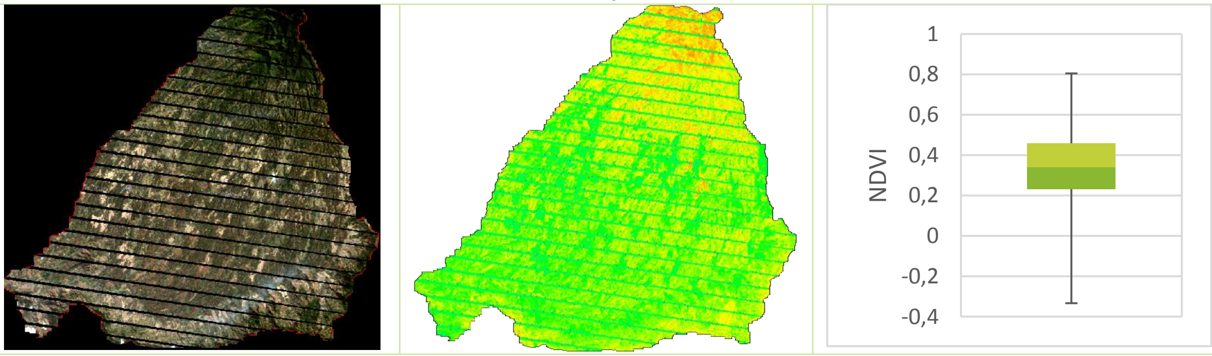
19th July, 2010



20th June, 2011



25th July, 2012



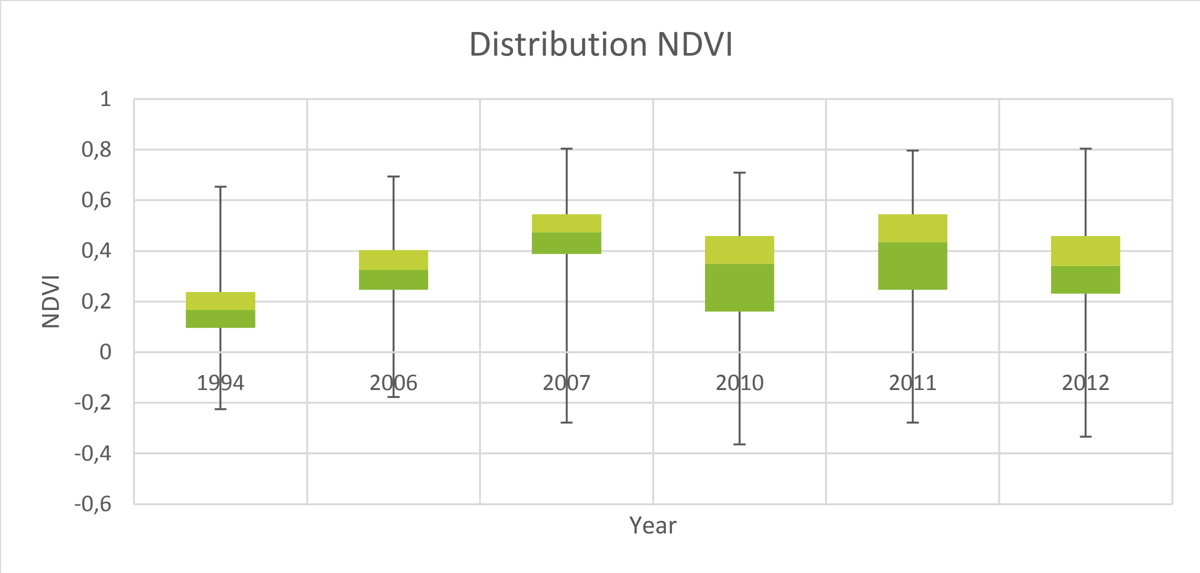


Figure 17. Distribution NDVI

Figure 17 shows notable differences between the years. A possible explanation is that the dates are not all the same. To compare the different years, the days should be the same. Therefore, a scaling method was used. See Figure 18 for the distribution of NDVI after the scaling (9th of June).

To compare the different years, the 9th of June was studied. This date was chosen because it is close to the date of the fieldwork. All distributions of the 9th of June show a large range of NDVI values. However, only two years also show a large range of the middle fifty percent. For the other four years, the middle fifty percent is more concentrated around one value. This means that the greenness is better distributed in the years 2010 and 2011.

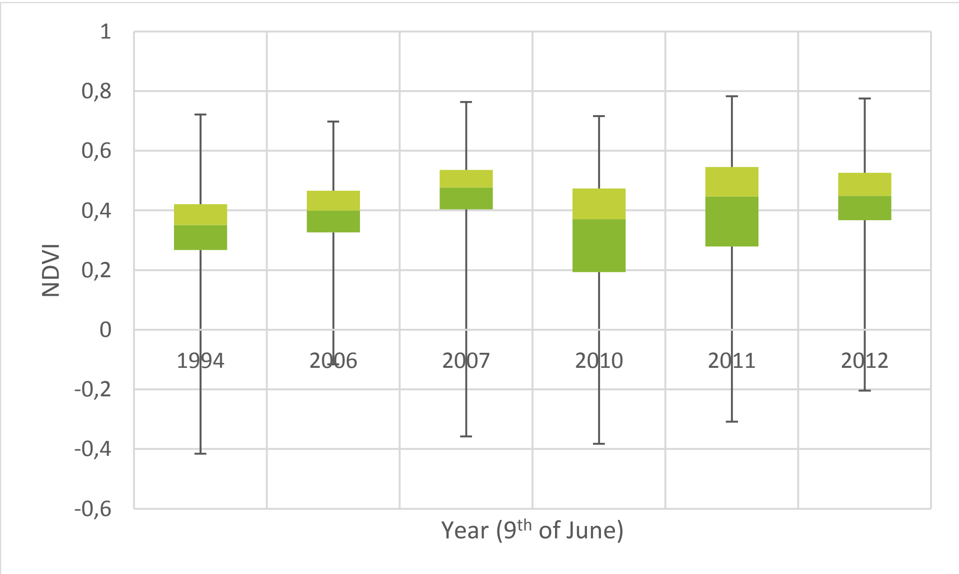


Figure 18. Distribution NDVI after scaling

4.3 Fieldwork and processing

This paragraph will answer the third research question: How should vegetation-cover characteristics be measured, and how should this data be processed? The first section describes the results of the fieldwork. The second section deals with the processing of the hemispherical images. Finally, the third section compares the NDVI of section 4.2.2 with the LAI from the hemispherical images.

4.3.1 Fieldwork

This section describes the results of the fieldwork. **Error! Reference source not found.** shows the locations where the measurements were taken. The coordinates and elevation of the locations of the fieldwork are given in Appendix C Locations fieldwork. Table 3 presents the results of the vegetation-cover characteristics.

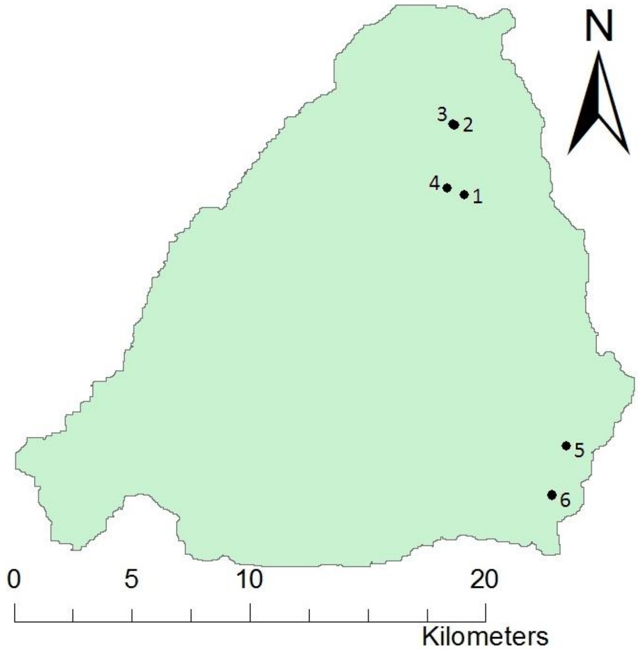


Figure 19. Locations of fieldwork

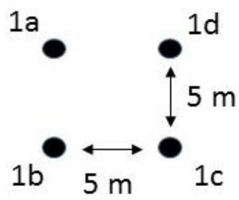


Figure 20. Distribution measurements at one location

4.3.2 Processing hemispherical images

As mentioned in section 3.4.2, the hemispherical images were processed with GLA software. The results of this processing and the other results are shown per location in Table 3.

Table 3. Results of fieldwork

Location one	
What	**Result**
LAI 1a	4.57
LAI 1b	4.06
LAI 1c	2.18
LAI 1d	2.93
Average LAI	3.43
Number of trees	8
Average diameter	32.1 cm
Average height	15.5 m

Location two	
What	**Result**
LAI 2a	2.83
LAI 2b	1.74
LAI 2c	3.14
LAI 2d	3.88
Average LAI	2.90
Number of trees	12
Average diameter	11.5 cm
Average height	6.1 m

Location three	
What	**Result**
LAI 3a	3.17
LAI 3b	3.83
LAI 3c	3.27
LAI 3d	3.12
Average LAI	3.35
Number of trees	6
Average diameter	30.6 cm
Average height	13 m

Location four	
What	**Result**
LAI 4a	3.85
LAI 4b	3.03
LAI 4c	4.21

Location five	
What	**Result**
LAI 5a	2.68
LAI 5b	3.66
LAI 5c	3.89

Location six	
What	**Result**
LAI 6a	2.89
LAI 6b	3.23
LAI 6c	2.48

LAI 4d	2.51		LAI 5d	3.35		LAI 6d	3.37
Average LAI	3.40		Average LAI	3.39		Average LAI	2.99
Number of trees	6		Number of trees	13		Number of trees	5
Average diameter	26.8 cm		Average diameter	56.2 cm		Average diameter	53.7 cm
Average height	10.4 m		Average height	20.5 m		Average height	22 m

As can be seen in Table 3, the LAIs were calculated, the trees were counted, the average diameter was calculated and the average height was calculated. Table 4 shows the results of the height of trees. As can be seen from the table, the diameter of the trees follows the height of trees. A linear trend line of the height of trees to the diameter of trees gives a determination coefficient of 0.9534. From this we can conclude that the diameter of trees depends on the height of trees. The LAI is not dependent on the height of the tree; it gives a R^2 of 0.0311.

Table 4. All data

Location	Height of trees (m)	Number of trees	Diameter of trees (cm)	Average LAI
2	6.1	12	11.5	2.9
4	10.4	6	26.8	3.4
3	13	6	30.6	3.35
1	15.5	8	32.1	3.43
5	20.5	13	56.2	3.39
6	22	5	53.7	2.99

4.3.3 Validating NDVI to LAI

The values of the NDVI were found in the computer software ENVI using the coordinates of the fieldwork locations (Exelis, 2013). At every location, four measurements of five by five meters in a square were taken. A Landsat pixel is a square of 30 by 30 meters. The locations should fit the Landsat pixels, but four of the six measurement locations contain two Landsat pixels. There are ten different NDVI values in combination with the measurements. Those ten different NDVI values were compared with the LAI values of the matching hemispherical images.

Table 5 shows the NDVI values and matching LAI values. Every matching combination was used one time, though when the combination take place more than one time. Some NDVI values had more than one LAI value; therefore, the average value of the LAI was used. For example, location one has four different values of LAI for only one value of NDVI. Therefore, the average value of the LAI values was used. The results show a linear relation with a R^2 value of 0.8386. See Figure 21.

Table 5. NDVI and matching LAI

Location	NDVI	LAI
1a-1d	0.615611	3.43
2a,2b	0.605447	3.60
2c,2d	0.603817	3.51
3a-3d	0.576458	3.35
4a,4d	0.531048	3.18
4b,4c	0.538691	3.13
5a,5d	0.496525	3.01
5b,5c	0.505061	3.27
6a-6c	0.494047	2.87
6d	0.468765	2.85

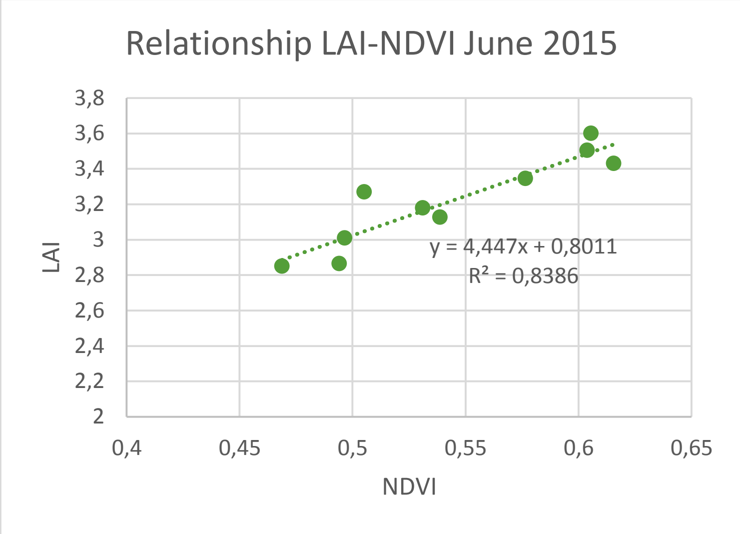


Figure 21. Relationship LAI-NDVI June 2015

The formula for the LAI ($LAI = 4.447 * NDVI + 0.8011$) was used for the other years. As mentioned in the methods section, the LAI was calculated only for values higher than 0.3 NDVI. Figure 22 shows the distribution of six Landsat pictures for the selected years. The accompanying size of areas of healthy vegetation is shown in Figure 23.

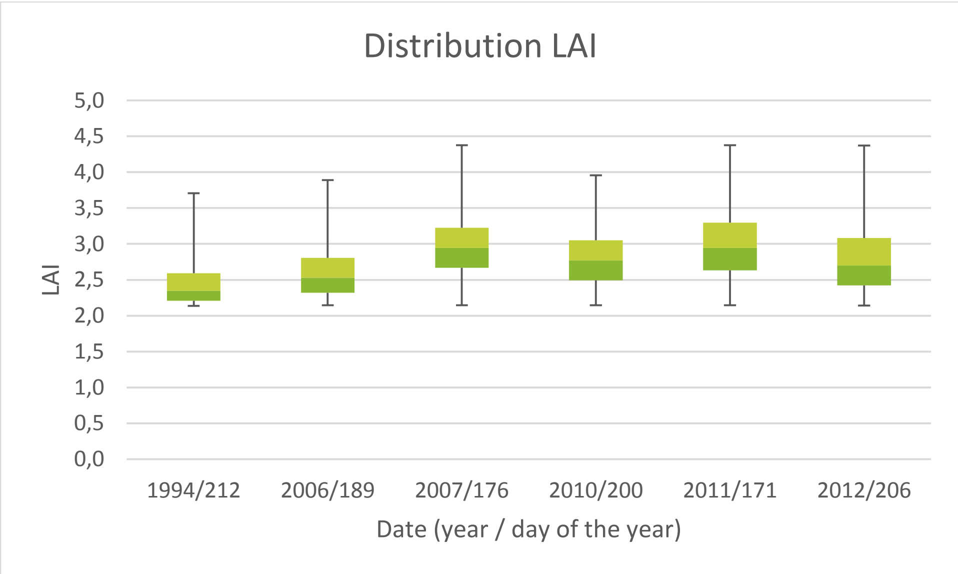


Figure 22. Distribution LAI at different days

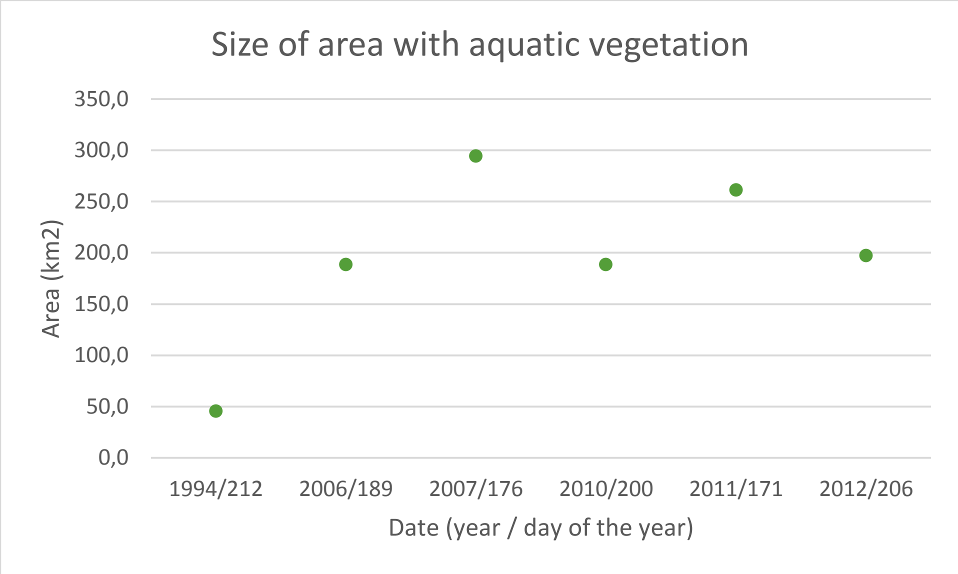


Figure 23. Size of area with aquatic vegetation

As mentioned in section 4.2.2, a scaling method was used for the NDVI. This scaling method was also used for the LAI. This was done to compare the same dates of the selected years instead of different dates from the selected years. Figure 24 shows the distribution of LAI after the scaling. As can be seen from the figure, the minimum value of the LAI is identical for every year. This is because the LAI was calculated for NDVI values of 0.3 and higher. The maximum value of the LAI does not vary much for the selected years. The middle fifty percent of the LAI values are concentrated the most for the year 2007. For the other years, the twenty-five percent parts are more evenly distributed. In general, it can be said that the distributions of the LAI do not vary a great deal.

Besides the values of the LAI, the size of the area of healthy vegetation (NDVI > 0.3) is important. Figure 25 shows the size of the area with healthy vegetation for every year. The size of the area with healthy vegetation is importan, because when the area is bigger, more water will be absorbed through vegetation, which affects the discharge

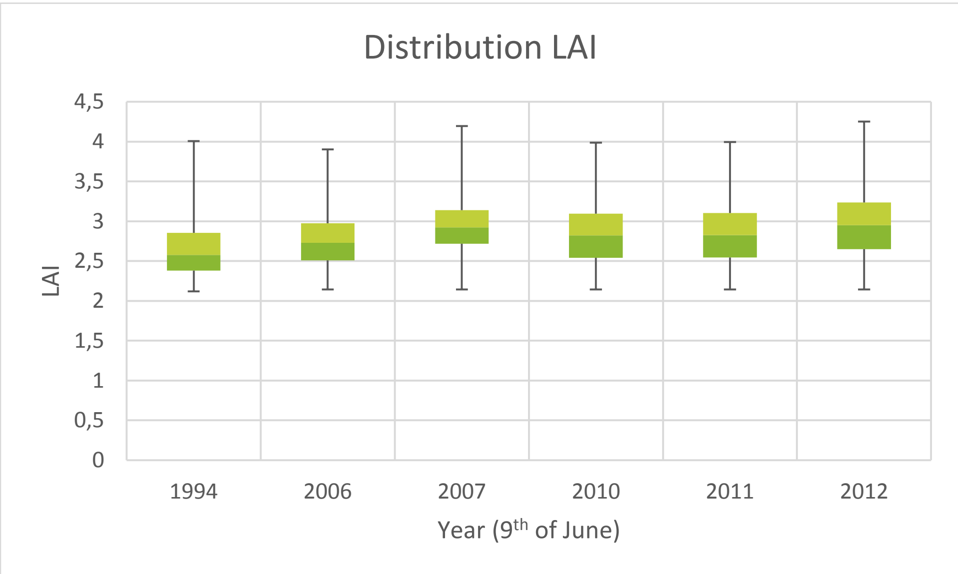


Figure 24. Distribution LAI after scaling

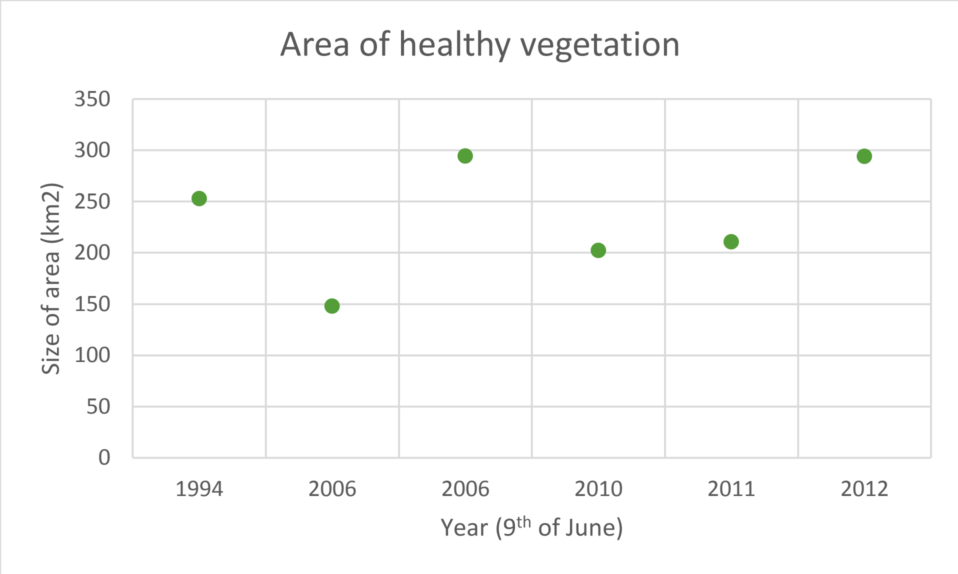


Figure 25. Area of healthy vegetation after scaling

4.4 Relating discharge and vegetation-cover characteristics

This paragraph answers the fourth research question: What is the relationship between discharge variation and vegetation-cover characteristics in the Keduang sub-catchment?

The discharge and the rainfall in the Keduang sub-catchment are shown in Figure 26. Using the scaling method, the LAI $(LAI = 4.447 * NDVI + 0.8011)$ for all the same dates of the selected years was calculated, as shown in Figure 27. Only NDVI values obtained by Landsat images of 0.3 or higher were converted to LAI values. The size of the area of the LAI was calculated (size of area with healthy vegetation), as shown in Figure 28.

The discharge and rainfall show high and low points, but only values between 1000 and 4000 mm of discharge are realistic. This means that values for the years 1992, 2011 and 2012 are probably not realistic. However, the water balance (section 4.1.2) is correct, so those years will be used to compare with the LAI.

The minimum value for LAI is identical for every year. This is because the starting point is the same NDVI value for every year. The year 2007 shows the most concentrated middle fifty percent of values of LAI. In general, there are no big differences in the distribution of the LAI. Every year is approximately the same as the year before. The biggest difference is between 2007 and 2010. So the LAI values do not alternate with the rainfall and discharge values.

Because the LAI does not alternate with the discharge and rainfall, another factor must be important. Therefore, the size of the area with healthy vegetation (NDVI > 0.3) was used. 2007 shows a low yearly discharge; however, the size of the area with healthy vegetation is very high. 2010 shows a higher discharge, but the size of the area with healthy vegetation is smaller. So when the size of the area with healthy vegetation is higher, the discharge is lower.

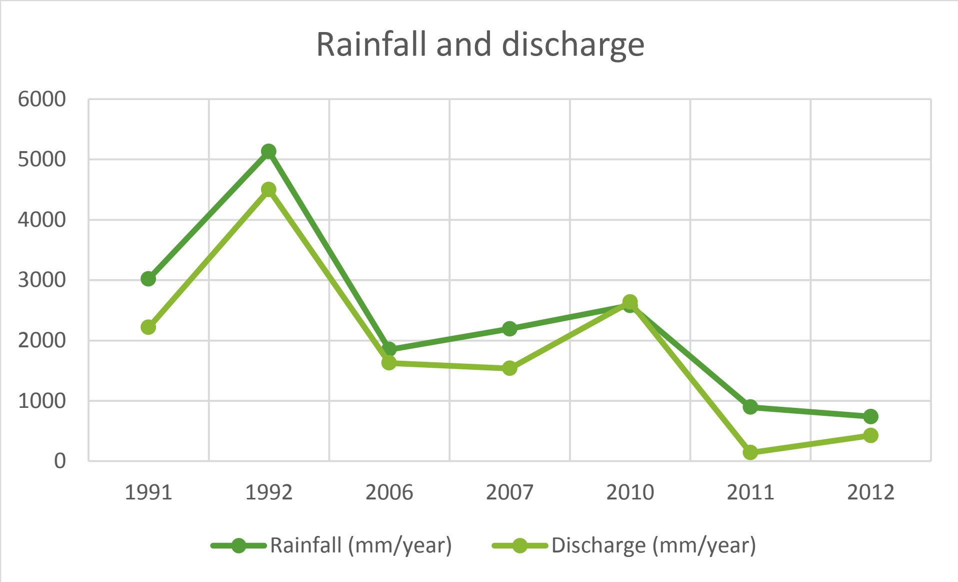


Figure 26. Discharge and Rainfall Keduang

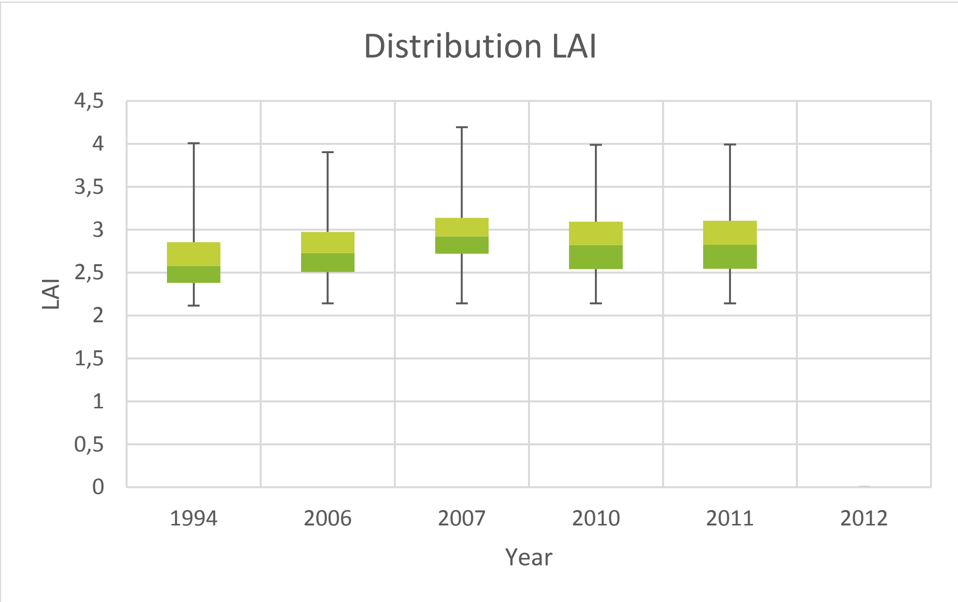


Figure 27. Distribution LAI Keduang

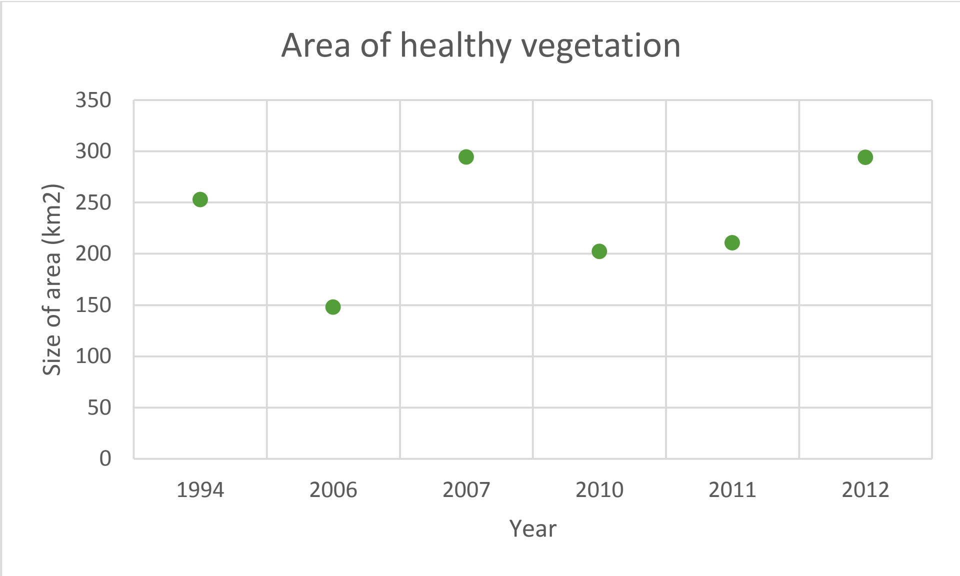


Figure 28. Size of area with healthy vegetation

5 Discussion

This study is intended to prove a relationship between discharges and vegetation-cover characteristics of the Keduang sub-catchment. This chapter discusses the results. The validity of the results of the research questions is discussed first. In the second paragraph, the limitations of this study are discussed.

5.1 Validity results

As mentioned in section 2.2.1, station data for the first research question was obtained from BPDAS Solo. Not all of the data was valid, because the water balance was not correct for every year. Furthermore, realistic values of discharge for Indonesia are between 1000 and 4000 mm per year. Some years showed much higher or lower values for discharge, so those values are probably not realistic and may indicate that an error occurred during measuring. For this study, only years with a correct water balance were used. A few years were selected for use for use in this study (1991, 1993, 2006, 2007, 2010, 2011 and 2012).

During the fieldwork, the most important measurement was of the hemispherical images used to calculate the LAI. During the fieldwork, different conditions (such as light, camera height above ground) were considered. Those factors affected the hemispherical images. An attempt was made to use the same conditions as much as possible. During the processing of the hemispherical images, some factors influenced the LAI results. These factors include, for example, differences in luminosity, the height of the camera above the ground and the angle of the picture. GLA software was used to identify the LAI. To obtain these results, a working image of the hemispherical image was made. This working image contains two colors: white and black. The LAI was calculated where the black appeared (see Figure 12 section 3.4.2). The amount of black and white can be changed with a tool. See Figure 12. So it was important to use the tool by looking carefully at the hemispherical image. This was done to obtain the most accurate results.

A haga-meter was used to calculate the height of the trees. It is hard to use this tool very accurately. Sometimes it was not possible to stand at the right distance (15, 20 or 25 m). Instead of a fixed distance it was possible to determine a distance by yourself, in this case the percentage has been used. The height was then calculated, as it could be read out using the selectable distances. Another difficulty was the smoothness of the ground. When the ground was not flat, the measurement was not exact. To calculate the diameter of trees, the DBH was used. This is the most commonly used method. Other methods can give other results.

As mentioned in the literature review, several reports have shown the impact of vegetation changes on the water yield (Bosch and Hewlett, 1982b; Brown et al., 2005). The current research emphasizes the impact of LAI on the discharge. It is surprising that the distribution of LAI remains similar over the years while the discharge varies considerably. The size of the area with healthy vegetation must also be taken into account. This vegetation-cover characteristic shows a weak relation with the discharge. When the size of the area with healthy vegetation (NDVI > 0.3) increases, the discharge decreases. However, this has only been proven for the years with realistic discharge and rainfall values.

5.2 Limitations

This research has a few limitations. The first limitation concerns the station data. This study is unable to use the whole range of data obtained from BPDAS Solo because it does not engage with correcting or missing and incorrect values. It is important that subsequent studies have more and correct data.

Hemispherical images for only one date were taken for this research. The same linear trend line was used for different years. It was not possible to take hemispherical images in other years. To get correct LAI values, it would be better to take hemispherical images in different years. In this case, trend lines accompanying the year can be calculated so that correct values for LAI are obtained.

An issue that was not addressed in this study is whether the season is of influence on the water yield. For further research, it is recommended that the rainy and dry seasons be distinguished so that differences between the seasons can be noted.

Furthermore, this study is only applicable to a tropical climate. This study is not recommended for other regions.

6 Conclusions and recommendations

The main goal of the current study is to determine the relationship between discharge variation and vegetation-cover characteristics in the Keduang sub-catchment. This relationship is described in the first paragraph. The second paragraph deals with some recommendations for further research.

6.1 Conclusions

The main aim of this study is to investigate the relationship between variation in discharge and changes in vegetation-cover characteristics in the Keduang catchment. Therefore, the discharge was measured first. The discharge used for this research is from the years 1991, 1992, 2006, 2007, 2010, 2011 and 2012 because these years show a correct water balance. Subsequently, the most important VCCs were determined to compare them with the discharges of the selected years. The most important VCCs were LAI, size of area with healthy vegetation, number of trees, diameter of trees and tree height. The first two characteristics were chosen because they directly fit the research aim. The others were qualitative measurements. The NDVI was used to determine the LAI. To extract the NDVI from spatial data, a program called ENVI was used.

A linear relationship was found between the NDVI and LAI in June 2015. Using this relationship, the LAI for the other selected years was calculated. All the selected years show a similar distribution of LAI values. These LAI values were compared with the discharges of the accompanying years. No relationship was found between the LAI values and the discharges, because the distribution of the LAI is approximately the same for every year. However, the size of the area with healthy vegetation shows a relationship with the discharge. When the size of the area with healthy vegetation increases, the discharge decreases. This is because vegetation absorbs water.

6.2 Recommendations

This topic is important for the future, so a few recommendations will be made for further research. It is recommended for further research to use a LICOR LAI-2200 plant canopy analyzer to determine LAI. This tool is more accurate and is already at the site from which the LAI will be calculated. (http://www.licor.com/env/products/leaf_area/LAI-2200/) Using this tool, a more precise value of LAI can be obtained. This analyzer was not available at BPDAS; only a fish-eye lens was available. When the LICOR tool is used, software is not needed to process the hemispherical images. Without the LICOR LAI-2200 tool, a program is still needed to process hemispherical images. In that case, it would be better to use another fish-eye processing software. A software that needs more information about the sun elevation, day of the year and etc. would be better for obtaining a more accurate LAI value. An example of software is CAN-EYE or Hemi-View.

Another recommendation is that the hemispherical pictures or the LAI be determined with the LICOR LAI-2200 tool. For further research, it is recommended that some pictures be taken at the same time of the day, to get the same magnitude of sun light. Furthermore, the pictures should be taken in different years and not in only one year. Different years will give different trend lines to convert the NDVI to LAI. Using different trend lines will give more accurate values of LAI.

Moreover, the pictures should not only be taken at one time of the year. It is recommended for further research that pictures be taken in the rainy and dry season in a tropical climate. Values for LAI will be different in the rainy and dry season, and discharges will be different as well. Using the two seasons of a tropical climate will increase the accuracy of the results.

7 References

Awal, M. a., Wan Ishak, W. I., and Bockari-Gevao, S. M. (2010). Determination of leaf area index for oil palm plantation using hemispherical photography technique. *Pertanika Journal of Science and Technology*, *18*(1), 23–32.

Bosch, J. M., and Hewlett, J. D. (1982a). A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology*, *55*(1-4), 3–23. http://doi.org/10.1016/0022-1694(82)90117-2

Bosch, J. M., and Hewlett, J. D. (1982b). A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology*, *55*(1-4), 3–23. http://doi.org/10.1016/0022-1694(82)90117-2

Brown, A. E., Zhang, L., McMahon, T. A., Western, A. W., and Vertessy, R. A. (2005). A review of paired-catchment studies for determining changes in water yield resulting from alterations in vegetation. *Journal of Hydrology*, *310*(1-4), 28–61. http://doi.org/10.1016/j.jhydrol.2004.12.010

Dutta, R. (2014). Review of vegetation indices for vegetation monitoring. In *35th Asian Conference on Remote Sensing 2014*.

Exelis. (2013). ENVI Tutorial : Vegetation Analysis.

Farid, M., Mano, A., and Udo, K. (2010). Flood Runoff Characteristics Due To Land Cover Change in Upper Ciliwung River Basin Indonesia Using 2D Distributed Model Coupled With Ncf, *54*, 157–162.

Frazer, G. W. (1999). Gap light analyzer (GLA). *Users Manual and Program Documentation, Version …*. Retrieved from http://ci.nii.ac.jp/naid/10013243107/

Green, E. P., Mumby, P. J., Edwards, A. J., Clark, C. D., and Ellis, A. C. (1997). Estimating leaf area index of mangroves from satellite data. *Elsevier*, *31*(3), 11–19. http://doi.org/10.1109/36.225538

Gu, Z., Sanchez-Azofeifa, G. A., Feng, J., and Cao, S. (2015). Predictability of leaf area index using vegetation indices from multiangular CHRIS / PROBA data over eastern China. *Journal of Applied Remote Sensing*, *9*, 15. http://doi.org/10.1117/1.JRS.9.096085

Guzha, A. C., Nobrega, R. L. B., Kovacs, K., Rebola-Lichtenberg, J., Amorim, R. S. S., and Gerold, G. (2014). Characterizing rainfall-runoff signatures from micro-catchments with contrasting land cover characteristics in southern Amazonia. *Hydrological Processes*, *521*(March 2014), 508–521. http://doi.org/10.1002/hyp.10161

Mahmood, R., Pielke, R. A., Hubbard, K. G., Niyogi, D., Dirmeyer, P. A., McAlpine, C., … Fall, S. (2014). Land cover changes and their biogeophysical effects on climate. *International Journal of Climatology*, *34*(4), 929–953. http://doi.org/10.1002/joc.3736

Payero, J. O., Neale, C. M. U., and Wright, J. L. (2004). C e v i e p h a g, *20*(3), 385–394.

Silleos, N. G., Alexandridis, T. K., Gitas, I. Z., and Perakis, K. (2006). Vegetation Indices: Advances Made in Biomass Estimation and Vegetation Monitoring in the Last 30 Years. *Geocarto International*, *21*(4), 21–28. http://doi.org/10.1080/10106040608542399

Twente, U. of. (2015). 都市流出モデルに及ぼす 土地利用データの影響について Effect of Land Use Data. Retrieved from http://www.utwente.nl/ctw/wem/research/projects/rustanto/

Van Gardingen, P. R., Jackson, G. E., Hernandez-Daumas, S., Russell, G., and Sharp, L. (1999). Leaf area index estimates obtained for clumped canopies using hemispherical photography. *Agricultural and Forest Meteorology*, *94*(3-4), 243–257. http://doi.org/10.1016/S0168-1923(99)00018-0

Wiegand, C. L., Richardson, A. J., Escobar, D. E., and Gerbermann, A. H. (1991). Vegetation indices in crop assessments. *Remote Sensing of Environment*, *35*(2-3), 105–119. http://doi.org/10.1016/0034-4257(91)90004-P

Zhan, C., Xu, Z., Ye, A., and Su, H. (2011). LUCC and its impact on run-off yield in the Bai River catchment - Upstream of the Miyun Reservoir basin. *Journal of Plant Ecology*, *4*(1-2), 61–66. http://doi.org/10.1093/jpe/rtr003

Zhang, Y., Chen, J. M., and Miller, J. R. (2005). Determining digital hemispherical photograph exposure for leaf area index estimation. *Agricultural and Forest Meteorology*, *133*(1-4), 166–181. http://doi.org/10.1016/j.agrformet.2005.09.009

Zhao, F., Zhang, L., Xu, Z., and Scott, D. F. (2010). Evaluation of methods for estimating the effects of vegetation change and climate variability on streamflow. *Water Resources Research*, *46*(3), n/a–n/a. http://doi.org/10.1029/2009WR007702

Appendix A List of Landsat images

Table 6 shows the dates of the Landsat images which have been used during the research. After downloading the images it was important to open the ZIP-files with 7-Zip instead of WinRAR. Subsequently the file should be opened inside. Opening the files in this way ensures that the Metafile can be opened. The Metafile is necessary to open the images in ENVI. Furthermore all of the file names contain the day of the year (1 = 1st of January, 2 = 2nd of January, 32 = 1st of February, etc.), so these numbers has been converted to dates.

Table 6. Landsat images used for this research

Landsat	Year	Date	Quality (out of 9)	Cloud cover (%)
Landsat 4-5 ETM	1994	9 March	9	36
Landsat 4-5 ETM	1994	4 May	9	3
Landsat 4-5 ETM	1994	10 May	9	30
Landsat 7 ETM+	2006	5 May	9	7
Landsat 7 ETM+	2006	8 July	9	4
Landsat 7 ETM+	2006	9 August	9	14
Landsat 7 ETM+	2007	25 June	9	3
Landsat 7 ETM+	2007	11 July	9	0
Landsat 7 ETM+	2007	28 August	9	0
Landsat 7 ETM+	2010	13 March	9	11
Landsat 7 ETM+	2010	19 July	9	9
Landsat 7 ETM+	2010	23 October	9	55
Landsat 7 ETM+	2011	19 May	9	17
Landsat 7 ETM+	2011	20 June	9	5
Landsat 7 ETM+	2011	8 September	9	3
Landsat 7 ETM+	2012	21 May	9	6
Landsat 7 ETM+	2012	24 July	9	1

Appendix B Scaling method

As can be seen in Appendix A not all Landsat images have the same dates. It is important to compare the same dates of each year with each other. Therefore a scaling method has been used.

Table 7 shows the data to make a boxplot. Subsequently trend lines has been made of the data of the boxplots, shown in Figure 29. See Table 8 for the accompanying trend lines. With these trend lines the distribution of the NDVI on the 9th of June (day 160) has been calculated.

Table 7. Data for boxplot NDVI

NDVI	13-03	19-07	23-10
Min	-0,51373	-0,36471	-0,427451
Q1	0,380392	0,160784	0,215686
Median	0,498039	0,34902	0,388235
Q3	0,568627	0,458824	0,498039
Max	0,772549	0,709804	0,741176

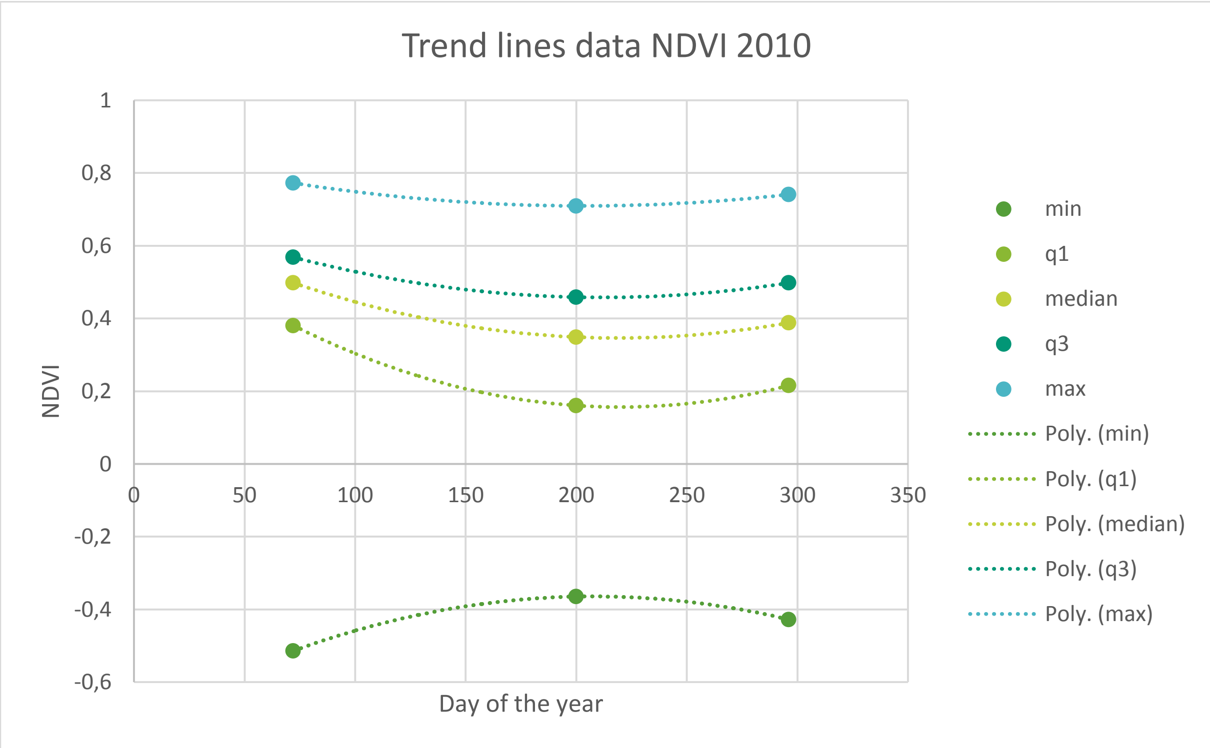


Figure 29. Trendlines of boxplot data NDVI

Table 8. Accompanying trend lines (D = day of the year)

NDVI	Trend line
Min	$-0{,}0000081152 * \mathrm{D}^2 + 0{,}0033715452 * \mathrm{D} - 0{,}7144070603$
Q1	$0{,}0000102124 * D^2 - 0{,}0044934673 * D + 0{,}6509804286$
Median	$0{,}000007021 * D^2 - 0{,}0030739187 * D + 0{,}6829643638$
Q3	$0{,}0000056532 * D^2 - 0{,}0023955169 * D + 0{,}7117978281$
Max	$0{,}0000036473 * D^2 - 0{,}0014822509 * D + 0{,}860363654$

This has been done for the LAI as well. First the NDVI values (0,3 and higher) has been converted to LAI vales with the trend line ($LAI = 4{,}447 * NDVI + 0{,}8011$). Then the same process as for the NDVI has been repeated. Table 9 shows the data for the LAI boxplots, there has been made trend lines of these data shown in Figure 30. The trend lines are presented in Table 10. The graph of these trend lines is shown in Figure 31.

This scaling method has also been done for the size of the area with healthy vegetation.

Table 9. Data for boxplot LAI

LAI	13-03	19-07	23-10
Min	2,143923	2,143923	2,143923
Q1	2,806607	2,492703	2,562459
Median	3,120514	2,771729	2,876366
Q3	3,39954	3,050755	3,19027
Max	4,236617	3,957591	4,097102

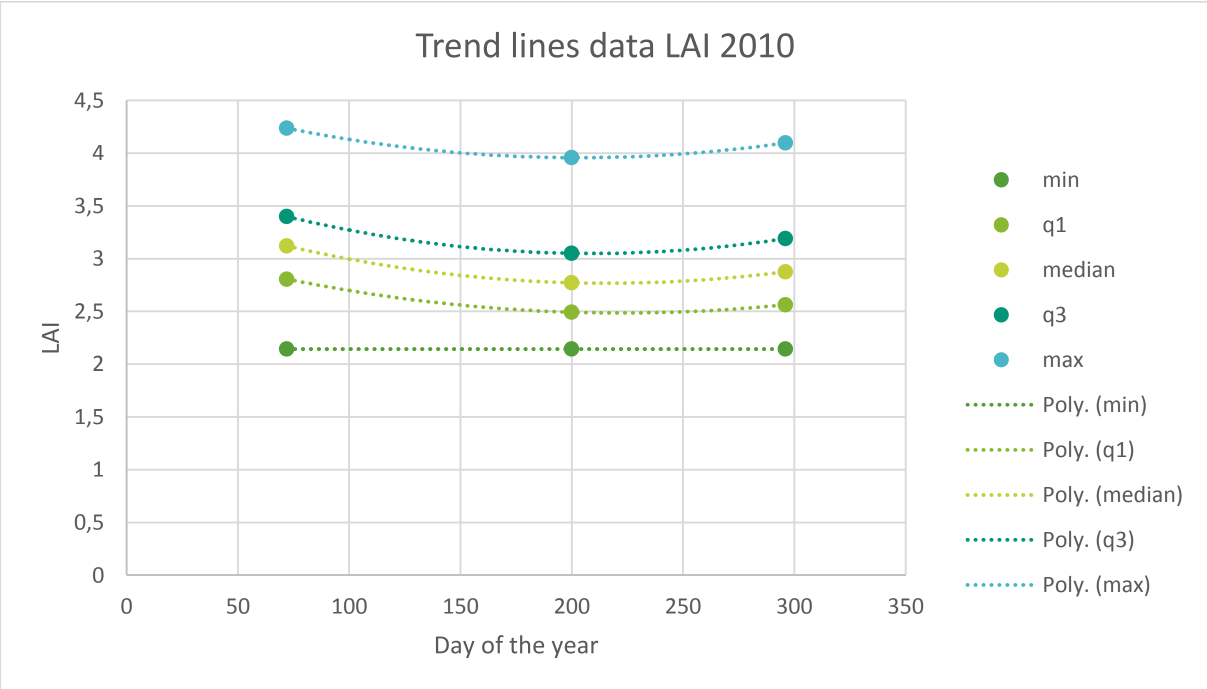


Figure 30. Trend lines of boxplot data LAI

Table 10. Accompanying trend lines (D = day of the year)

LAI	Trend line
Min	$2{,}143923$
Q1	$0{,}0000141919 * D^2 - 0{,}0063125672 * D + 3{,}1875406431$
Mean	$0{,}0000170306 * D^2 - 0{,}0073572131 * D + 3{,}5619469576$
Q3	$0{,}0000186525 * D^2 - 0{,}0077983738 * D + 3{,}8643281202$
Max	$0{,}0000162193 * D^2 - 0{,}0065915364 * D + 4{,}6271265032$

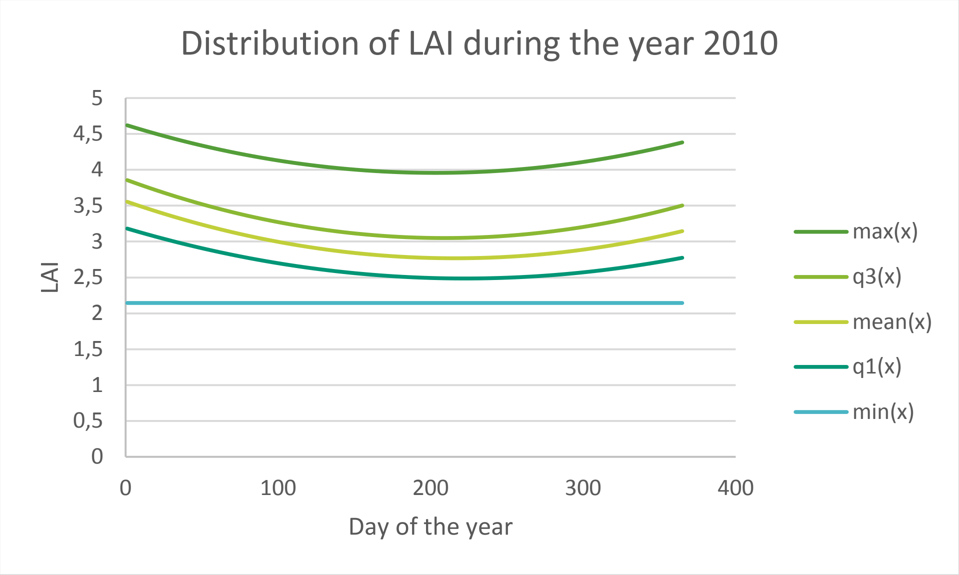


Figure 31. Distribution of LAI during the year 2010

Appendix C Locations fieldwork

Table 11 shows the coordinates and the elevation of the locations of the fieldwork.

Table 11. Locations fieldwork

	Elevation (m)	Latitude	Longitude
1a	757,6392	7° 46' 54,629" S	111° 9' 33,231" E
1b	753,313	7° 46' 54,559" S	111° 9' 33,162" E
1c	757,8794	7° 46' 54,449" S	111° 9' 33,200" E
1d	758,3601	7° 46' 54,723" S	111° 9' 33,166" E
2a	1025,124	7° 45' 19,072" S	111° 9' 20,152" E
2b	1025,364	7° 45' 19,140" S	111° 9' 20,119" E
2c	1022,72	7° 45' 19,109" S	111° 9' 19,856" E
2d	1027,527	7° 45' 18,997" S	111° 9' 19,914" E
3a	1022	7° 45' 18,021" S	111° 9' 18,531" E
3b	1021,519	7° 45' 18,109" S	111° 9' 18,545" E
3c	1020,317	7° 45' 18,091" S	111° 9' 18,377" E
3d	1018,635	7° 45' 17,897" S	111° 9' 18,354" E
4a	728,3191	7° 46' 45,837" S	111° 9' 10,407" E
4b	727,5981	7° 46' 45,919" S	111° 9' 10,249" E
4c	727,5981	7° 46' 45,784" S	111° 9' 10,234" E
4d	726,1563	7° 46' 46,019" S	111° 9' 10,363" E
5a	455,0663	7° 52' 41,119" S	111° 11' 54,532" E
5b	454,105	7° 52' 40,992" S	111° 11' 54,440" E
5c	456,5083	7° 52' 40,825" S	111° 11' 54,558" E
5d	459,3922	7° 52' 41,195" S	111° 11' 54,684" E
6a	589,8901	7° 53' 48,489" S	111° 11' 35,109" E
6b	590,3709	7° 53' 48,341" S	111° 11' 35,238" E
6c	594,937	7° 53' 48,280" S	111° 11' 35,364" E
6d	595,1772	7° 53' 48,539" S	111° 11' 35,368" E