BSc thesis Civil Engineering

Determination of the changes in annual and seasonal runoff and determine if the changes in runoff can be attributed to land cover change or climate change in the Merawu catchment, central Java.

Denise Thus

Supervisor University of Twente: Martijn Booij
Supervisor Universitas Gadjah Mada: Hero Marhaento

UNIVERSITY OF TWENTE.

UNIVERSITAS GADJAH MADA

Preface

This report presents the findings of my bachelor thesis: Determination of the changes in annual and seasonal runoff and determine if the changes in runoff can be attributed to land cover changes or climate change in the Merawu catchment, central Java.. This research was the final part of my bachelor Civil Engineering at the University of Twente in The Netherlands. The research has been conducted at the faculty of Forestry at the Universitas Gadjah Mada in Indonesia.

I am very grateful for the opportunity to do the research for my Bachelor thesis at the Universitas Gadjah Mada. I have gained a lot of knowledge on the characteristics of tropical catchments and the impacts of big elevation differences.

I would like to thank my external supervisor Hero Marhaento and my internal supervisor Martijn Booij for providing their assistance and feedback throughout this bachelor thesis. In addition, I want to thank the group of students who will do research in the Merawu catchment as well. I want to thank them for joining me on taking land cover samples of the Merawu catchment before their research even started.

I hope you will enjoy reading my bachelor thesis. If there are any questions you can contact me through email: d.j.h.thus@student.utwente.nl.

Denise Thus

Yogyakarta, 7th of July 2023.

Summary

Deforestation has impacts on the water balance in tropical catchments. Deforestation tends to increase the annual discharge. However,a few studies have also shown that deforestation can result in lower runoff during the dry season. This is called the "sponge effect hypothesis". This hypothesis states that deforestation results in lower runoff during the dry season and higher runoff during the wet season. Currently there are still contradicting results regarding this hypothesis.

The objective of this research is to determine the changes in annual and seasonal runoff and determine if these changes can be attributed to land cover changes or climate change. The study area is the Merawu catchment located on central Java, Indonesia.

Firstly, the land cover classifications and the normalized difference vegetation index (NDVI) values have been determined by using satelite imageries of the Landsat and MODIS satellites. The mean areal rainfall (MAR) has been determined using the Thiessen polygon method. Subsequently, a Mann-Kendall trend test and Sen's slope estimator have been used to determine the changes in annual and seasonal runoffs, rainfall and evapotranspiration.

The land cover classifications indicate deforestation between 1992 and 2000 and afforestation between 2000 and2014. However, the accuracy of the land cover classifications is low, namely 66%. This results in uncertainty in the land cover changes found in this research.

There have been no significant trends in the discharge of the catchment. A significantly positive trend has been found in the annual rainfall between 2000-2014. As this same trend has not been found in the discharge values this means that it is probable that there has also been a positive trend in actual evapotranspiration. No trend has been found in the average temperature of the Merawu catchment, which means that the plausible increase in actual evapotranspiration is not because of an increase in temperature due to climate change. Why the increase in precipitation has not resulted in an increase in discharge cannot be attributed to land cover change or climate change based of this research. To be able to do this, further research and an increase in the amount of quality data are necessary.

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Glossary

sponge effect The effect that forestation affects the water balance in such a way that it holds water during a wet season and releases this during the dry season.

Acronyms

AET actual evapotranspiration.

LST Land Surface Temperature.

MAR mean areal rainfall.

MODIS Moderate-resolution Imaging Spectroradiometer.

NDVI normalized difference vegetation index.

NIR Near-infrared radiation.

P rainfall.

PET potential evapotranspiration.

Q discharge.

S Soil storage.

t time.

1 Introduction

1.1 Background

On earth, the land cover has been changing. Between 1961 and 2015 about three-quarters of the global ice-free land surface was affected by humans (Arneth et al., 2019). Most of the land surface used by humans is used for agriculture. Of all of the habitable land surface , half is covered with agriculture. After agriculture the biggest land cover areas are forests and shrublands (Ritchie and Roser, 2013).

Between 2010-2014 around half of the tropical deforestation in the world took place in Brazil and Indonesia, with Brazil accounting for most of the deforestation (Ritchie, 2021). Tropical forests store and release a lot of fresh water, and therefore are big water reservoirs (van Emmerik et al., 2017). Because tropical forests are big water reservoirs, changes in forestation can disrupt the water balance. This is because vegetation & forestation influence the rainfall interception, the rooting depth, leaf area and plant available water. By affecting these factors, the evapotranspiration decreases with deforestation and that leads to an increase in annual runoff (Ogden et al., 2013).

The effects of deforestation have in some studies shown to result in higher discharges during high-flow seasons and lower discharges during the dry season. This means that deforestation can lead to more floods but also to more droughts. In addition, also the sedimentation transport increased with deforestation (Bruijnzeel, 1989). Deforestation can also result in more landslides. This is because of a smaller rooting depth and more excessive runoff (Van Asch et al., 1999).

In this research the effects of a change in forestation on the seasonal and annual runoff will be further researched. A case study will be used to conduct the research. The study area that will be used as a case study is the Merawu catchment located in central Java, Indonesia. The study area is further described in the methodology section.

1.2 State of the art

In the research field the effect of a change in forestation on the runoff in the catchment has already been studied many times. One of these studies, by Cavalcante et al. (2019), was conducted on the effects of deforestation on the annual average river flow in the Amazon in Brazil. In this study, the evaporation was determined using data of the rainfall and the discharge. The Mann-Kendall test was used for detecting a significant change in the rainfall time series. This study showed that there was an annual and seasonal increase in discharge with deforestation. In this study also the effects of climate change were considered. The results showed that climate change only affected the evaporation positively and did not affect the rainfall. The study concluded that the discharge would have been even higher without the effects of climate change.

The research by Mwangi et al. (2016) analyzed the contribution of land use change and climate variability on the discharge. Discharge and climatological data were used for this research. For the potential evapotranspiration the Penman-Monteith method was used. The average annual areal rainfall for the watershed was estimated by the Thiessen polygon method. The trend analysis in streamflow data was detected using the Mann-Kendall test. This test showed an increasing trend in discharge. The Budyko framework was used to estimate the actual evapotranspiration and through this, the effects of climate variability and land use change could be separated. This separation showed that most of the changes could be attributed to land use changes and only a small percentage (2.5%) of the changes could be attributed to climate change.

Also a study has been conducted on Java, Indonesia. This study by Marhaento et al. (2021) investigated the impacts of increased forestation on the annual and seasonal water balance of a tropical catchment under climate change. For this study also the SWAT model and the Mann-Kendall statistical test were used. The results showed that the effects of climate change were bigger than those of afforestation. However, the minor effects of the increased forestation were that the discharge decreased during the wet season but that there were also more severe droughts during the dry season.

All of these studies have shown that forestation results in lower discharges or deforestation in higher discharges. However, these studies have not found proof for the "sponge effect hypothesis". This is the hypothesis that forestation results in lower discharges during wet seasons and higher discharges in dry seasons. A study conducted in Panama did find proof for this hypothesis. This study used a paired catchment methodology to analyze the hydrological data of three catchments with different land use types (Ogden et al., 2013).

A multi-continental research was conducted towards forests as 'sponges' and 'pumps' in tropical countries. Forests act as pumps by the high amount of evapotranspiration, and as sponges by enhancing the soil infiltration capacity and moisture retention. The study by Peña-Arancibia et al. (2019) specifically focused on the impact of deforestation on dry-season flows across the tropics. The results of this study show that deforestation could result in decreasing dry season flows. Nevertheless, the study also described that the occurrence of the sponge effect depends on some factors. This means that the sponge effect is more likely to occur when an area meets the following requirements under forested conditions; strong seasonality, high infiltration capacity, sufficient wet rainfall, sufficient soil water storage to carry wet season storage into the dry season and slow groundwater recession.

1.3 Problem statement and research gap

There have been different studies regarding the effects of land cover changes on the discharge. Some of these studies have conflicting results regarding the "sponge effect hypothesis". All of the studies have shown that deforestation results in a higher annual runoff, or that afforestation results in a lower annual runoff. However, there are conflicting results whether deforestation leads to less discharge during dry seasons. In the study of Peña-Arancibia et al. (2019) factors that result in a sponge effect have been named. Since there are conflicting results on the effects of deforestation on dry seasons, it is still beneficial to research the effects of land cover changes on seasonal and annual runoff. When researching the effects of land cover changes it is important to consider the effects of climate change as well, since climate change can also affect the discharge in a catchment. In the Merawu catchment, no research has been conducted towards the effects of deforestation on the discharge of the catchment. However, there are problems in the area related to excessive runoff resulting in landslides and excessive sedimentation transport. Furthermore, there have also been problems with droughts in the area. Therefore, this is an interesting study area for research towards the effects of land cover changes on the discharge.

1.4 Research objective and research questions

1.4.1 research objective

The objective of this research is to determine if there have been changes in the annual and seasonal runoff and if these changes can be attributed to land cover change or climate change in the Merawu catchment, located in central Java.

1.4.2 Research questions

1. What was the land-cover and vegetation density change over the years in the Merawu catchment?

The first research question is to determine the land cover changes in the catchment over the years. In addition to land cover classification also the change in vegetation density will be determined. This is because, with only land cover classification, it can be confusing whether there has been deforestation. As there might have been a decrease in dense forest area, but a bigger increase in agro-forestry area. By determining the change in vegetation density, it can be better understood if there has been a change in forestation.

2. What was the change in the annual and seasonal discharge over the years in the Merawu catchment?

The next research question is to determine the annual and seasonal discharge and if the discharge has changed over the years. The seasonal runoff is the runoff separated for dry seasons and wet seasons. The annual runoff tends to increase with deforestation. However, for the seasonal runoff in the dry season it is possible that the runoff decreases. Analyzing both the seasonal and annual runoff is beneficial for determining if there is a sponge effect. As there might be a difference in the annual change in runoff and the seasonal change in runoff.

3. What was the change in areal rainfall and evapotranspiration over the years in the Merawu catchment?

It is important to determine if there has been a change in climate in the catchment since the rainfall and evapotranspiration influence the amount of discharge. Climate change can affect the amount of rainfall and evapotranspiration in the area. This means that if the results of the previous research questions have shown a change in discharge as well as a change in land cover, that this could also be because of climate change instead of the change in land cover.

4. If there have been changes in discharge are those changes influenced by climate change or by land cover changes?

In the last research question the previous findings will be combined to determine if the possible changes in discharge can be attributed to land cover change or climate change. Firstly, the results of research question 2 will be used to see if there has been a change in discharge. Then the results of research question 3 will be used to see if there was a change in climate as well and if this has had effects on the discharge. Subsequently, it will be researched if there is a causal relationship between the discharge and the land cover changes and if this has been affected by climate change.

1.5 Scope

The research is a data-based research. Data is necessary to determine trends in the discharge, rainfall and temperature. Because there is only enough data available between 1992-2014, the research is conducted for these years.

The land cover classes which will be considered to determine if there has been land cover change are agriculture, forestry, settlements, shrubland and bareland. This means that no land cover changes within agriculture areas or forestry areas are considered. Such as a change from cropland to paddy fields.

For the potential evapotranspiration (PET) there is no solar radiation data available. Therefore the change in PET will only be based on the temperature in the area. This decreases the accuracy of PET, because there are more factors, such as sunshine hours per day, which affect PET.

The research will be conducted for the Merawu catchment, which is located in Indonesia. This catchment has large elevation differences. Therefore, the geographical scope of the research is a tropical mountaineous catchment.

1.6 Outline thesis

In this thesis firstly the study area will be further described in chapter 2 Methodology. Subsequently the methodology for the different research questions is explained. The methodology for detecting trends will be explained at the end of the methodology chapter. This method will be used for multiple research questions. After the methodology the results are presented per research question. In the last research question the results of the previous research questions are combined. After the results there is a discussion of the methods, data and results, followed with a conclusion of the research.

2 Methodology

In this chapter, the material and methods which will be used are discussed. Firstly the study area will be further elaborated on. Afterwards, the methods of the different research questions will be described. The methodology for the trend analysis will be described in one section, namely in section 2.5.

2.1 Study area

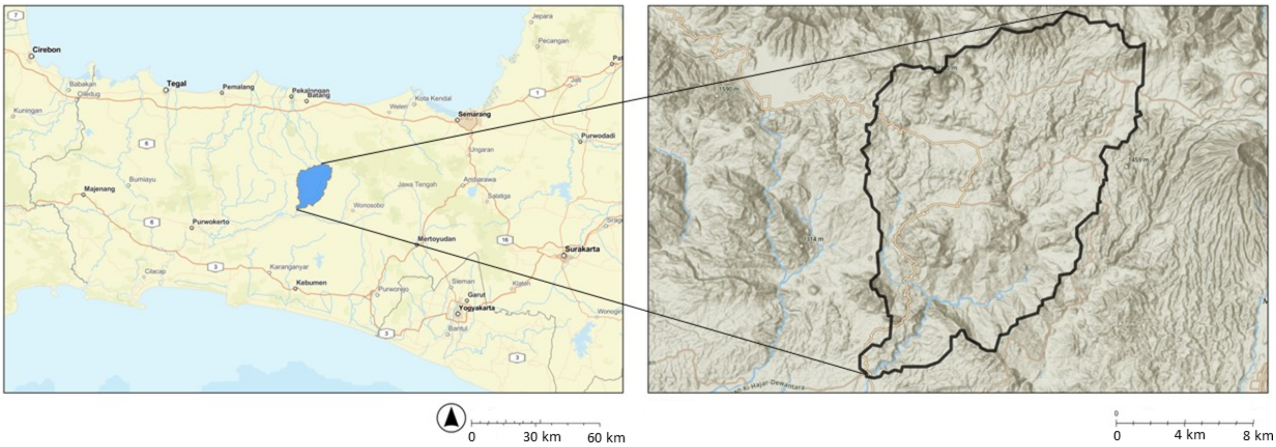


Figure 1: Merawu catchment

The study area is the Merawu catchment located in central Java, in the district Banjarnegara. The catchment has an area of 230 km^2. The Merawu catchment is part of the Serayu catchment and is located upstream within this catchment. The catchment is mountainous with elevations ranging from 225-2215 meters above sea level. Because the catchment is located in a mountain area the rainfall and temperature in the study area vary dependent on elevation (Paudel, 2010). Especially the upstream area of the catchment is mountainous and then towards the downstream area the catchment becomes more flat (Syahli, 2015).

Indonesia has a tropical climate, where there are high rainfall levels and high temperatures, so there is also a lot of evapotranspiration. During the monsoon season there are high levels of rainfall, this is between November and March. In the other months, there is less rainfall. The highest rainfall intensity occurs in December and the smallest rainfall intensity in September. This also results in the catchment having strong seasonality and sufficient rainfall, which are two factors that are important for the sponge effect to occur (Peña-Arancibia et al., 2019).

The Banjarnegara district is prone to landslides, the worst landslide of the past 20 years occurred in 2014 (Dariah et al., 2014). The chance of landslides can be reduced by vegetation on the slopes and by improving the water management in the area (Dyah Susanti et al., 2021). Landslides occur often after heavy rain. This was also the case for the heavy landslide in 2014 (Suaydhi and Siswanto, 2015). In addition to the district being exposed to heavy rain and thus also high runoffs, the district has also been exposed to droughts (Maryonos, 2015).

Downstream of the catchment there is a reservoir named "Mrica". In this reservoir there have been problems with excessive sedimentation inflow. This has resulted in a rapid decrease of total and dead storage. The dam is used for irrigation and for generating electricity. The excessive sedimentation will result in a shorter life span of the dam. Of the catchments contributing to the Mrica reservoir, the Merawu catchment has the highest soil erosion. Soil sedimentation occurs due to high land erosion which results from heavy rainfall and deforestation or other land cultivation (Utomo, 2017).

To determine the effect of land cover changes on the runoff, it is necessary that there have been land cover changes in the catchment. According to two studies, there have been land cover changes in the Merawu catchment (Syahli, 2015; Paudel, 2010). These land cover changes have most likely resulted in deforestation. The two studies on land cover changes in the catchment give conflicting results regarding the deforestation aspect. This might also be because of the difference in land cover classes that have been assessed.

In the paper by Syahli (2015) the land use changes have been monitored using image classification. In Table 1 the land use in the area according to this paper is shown.

Table 1: Land use between 1994 and 2014 (Syahli, 2015)

Land use	1994 (ha)	2002 (ha)	2014 (ha)
Agro-forestry	8890	8126	9248
VegeTable cropland	5810	5466	4776
Plantation forest	1833	2252	1504
Paddy field	1329	1528	1009
Plantation	3175	3554	4037
Shrub rangeland	1363	1390	1369

In 2010 another research was conducted towards the effects of land cover change on top soil properties and erosion in the Merawu catchment. In this research the land cover changes were classified, which can be seen in Figure 2.

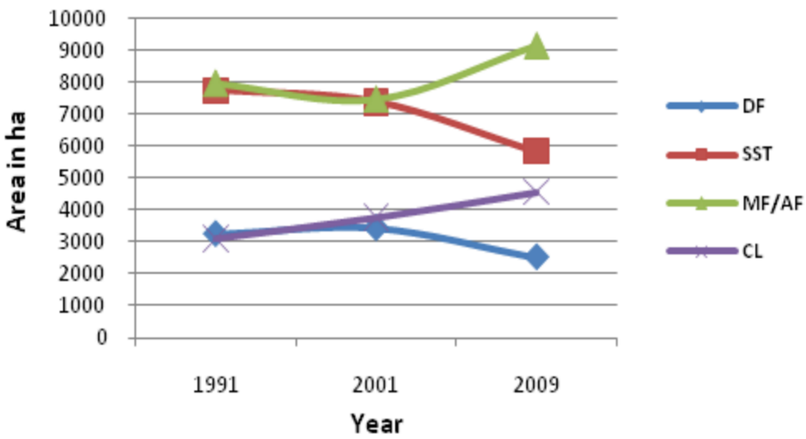


Figure 2: Land cover change in the Merawu catchment. Abbreviations in the legend; DF= Dense forest, SST = Shrub & Parse trees, MF/AF = Agroforestry / mixed forest, CL= Cropland (Paudel, 2010)

This research and the research which determined the land use between 1994 and 2014 contradict each other. Where cropland had decreased in the first research, it had increased in the second research. In addition, no dense forest is included in the classification of the first research, while there is dense forest in the second research. The land use classifications are also for different years. However, 1991-2001 is a similar time frame compared to 1994-2002.

2.2 What was the land-cover and vegetation density over the years?

2.2.1 Method for the land cover classification

To determine the change in forestation over the years a land cover classification will be made. There are two methods for land cover classification. One is unsupervised classification, which is automated, and the other is supervised classification which is based on training data. For this research supervised classification will be used because supervised classification gives a higher accuracy (Mohd Hasmadi I, 2009).

The land cover classifications will consist out of the following land covers; agriculture, forestry, settlements and optionally shrubland and bareland. The forestry land cover class consists out of plantation and native forests. The agriculture land cover consists of croplands, paddy fields, and agroforestry such as a (mixed) Salak plantation (snake fruit). Bareland are areas with no vegetated cover which are not settlements. Shrublands are areas with grasses, shrubs and short trees.

Two methods for the training data will be used. two methods will be used because it is not clear which one will give better results. An accuracy assessment will be used to determine which set of training data results in the most accurate land cover classifications.

The first set of training points described here is based on the land cover map classified by the Indonesian government. This land cover classification is available for 2019 and 2011. For the training data the map of 2019 is used, because for this year satellite imageries from both the Landsat 8 and Landsat 7 satellites are available. The first land cover classification, based on the map of the Indonesian government, consists for the study area out of the following land covers; forestry, shrubland, agriculture, settlements and bareland. In this classification different types of forestry and agriculture have been merged. This land cover map is presented in Figure 3. For the first training data set, points within the different land cover areas have been randomly taken and attributed to the specific land covers from the land cover map by the Indonesian government. From now onward the land cover classifications based on these training points will be called land cover classification 1.

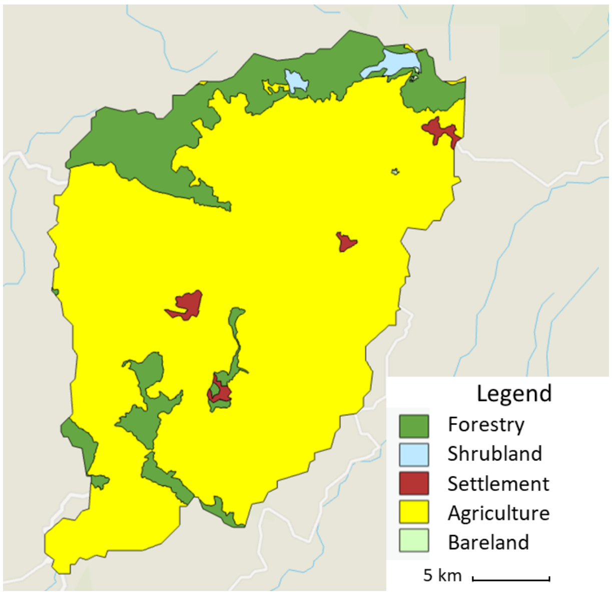


Figure 3: Land cover classification map Indonesian government 2019

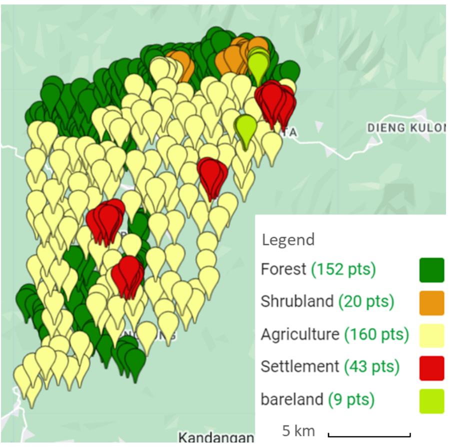
This land cover map does not consider the smaller settlement areas, as well as smaller forested areas. This can result in that the training data for agriculture or forestry also consists of settlement pixels, which can result in misclassifications.

A second set of training data is used to test if this set of training data gives a higher overall accuracy. This training data is based on comparing the Landsat 8 satellite data to Google Earth imagery. In Google Earth imagery satellite imageries of various satellites are combined. This has resulted in a higher spatial resolution. The higher spatial resolution makes it easier to distinguish between different types of land covers. The second classification will not include bareland and shrubland. The reasons for this are that these areas were not found in the Google Earth Engine imagery and that the areas of these land covers are relatively small in the land cover map shown in Figure 3. This results in only agriculture, forestry and settlements in the second land cover classification.

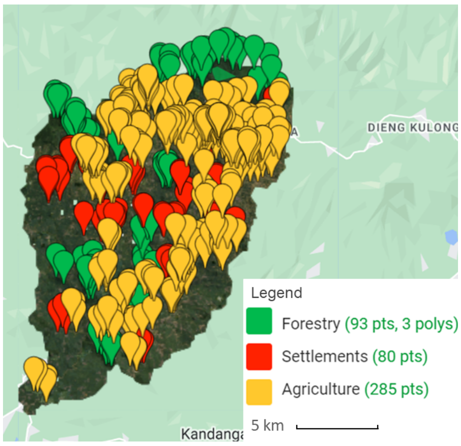
The two land cover classifications will be compared in the accuracy assessment to determine which one has the highest accuracy. The map with the highest overall accuracy will be used to determine if there has been deforestation.

The satellite imagery which will be used for the training datasets is Landsat 8. This is because of the Landsat 7 satellite the scan Line Corrector (SLC) failed in 2003. Which has resulted in stripes in the imagery (Ihlen, 2019). It would be possible to remove these stripes but due to time constraints this will not be done. Of the different Landsat 8 satellite imageries, the surface reflectance data will be used. The surface reflectance does not include contributions from clouds and atmospheric aerosols, while TOA (top of atmosphere) reflectance does include these (USGS, n.d.). Therefore, it is recommended to use surface reflectance for comparing satellite imagery. The bands which are used are blue red and green surface reflectance. These bands give satellite imagery in color which make it easier to distinguish the different land cover types in making the training data for the second land cover classification (USGS, n.d.). In addition, they have given the highest accuracy's for Landsat 8 data (Kulkarni and Vijaya, 2021). Only the satellite images for the months May, June, July and August are used. This is because the satellite imagery and especially the vegetation is different between wet and dry months. By choosing the dry months for the satellite imagery, there is more imagery available because there are less clouds in these months.

In Figure 4 the two sets of training points that are used for the land cover classification are shown. Most training points are for forestry and agriculture. This is because these are also the biggest land covers for the study area. Because the focus of the research is on forestry a relatively high number of training points compared to the amount of forested area have been selected.



(a) Training points based on the map of the Indonesian government



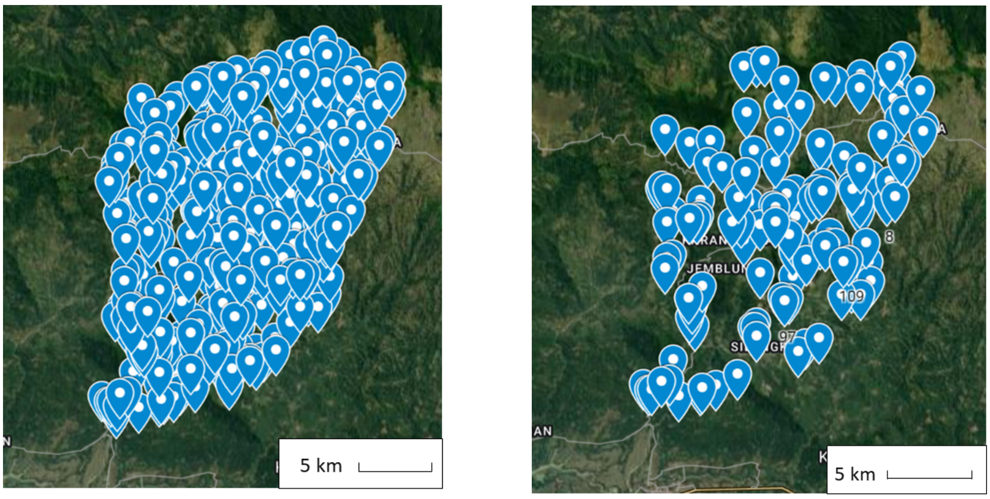
(b) Training points based on Google Earth and Satelite 8 imagery

Figure 4: The two sets of training points

Afterwards, the land cover classification for the years 1992-2014 can be determined using the training data. Because of the stripes in Landsat 7 data, only data from 2001 and 2002 are used. This has resulted in less data being available between 2002-2014. For the study area there is very little data after 2000 available of Landsat 5 and Landsat 8 has only been launched in 2013.

The accuracy of the land cover maps will be assessed using land cover samples from the study area. For the samples a method of random sampling has been used. According to the central limit theorem, 30 sample points are the minimum number of sample points (Ross, 2017). That is why 30 sample points were chosen as the minimum for the accuracy assessment. Although, it is better to collect more sample points, as a minimum of 50 sample points per land cover class has also been suggested (Congalton and Green, 2019; Olofsson et al., 2014). However, as there are only 2 days to take samples it is not possible to take between 150-250 samples. Through the random sample function from Google Earth Engine, 350 sampling points were acquired. Half of these points were not located near any roads. To be able to take many samples it is necessary for the sampling points to be located near roads. This resulted in all of the points being located further than 200 meters from the road being deleted from the samples. After deleting these points there were 124 sampling points left out of 350. Even though it is already known that it will not be possible to acquire 124 samples in 2 days these were used as possible sample points. This is because it is possible that some roads might not be accessible by car. The random sample points and the points that are accessible by roads can be seen in Figure 5. By deleting points far away from roads the quality of the accuracy assessment decreases. This is because for parts located far away from roads of the study area have a zero percent change of the sample point being taken (Olofsson et al., 2014).

The samples from the land cover classifications are from the Landsat 8 2021 surface reflectance data. This is because this is the latest available surface reflectance data. However, using more recent imagery data would be better for the accuracy assessment. This is because the area might have undergone land cover changes between 2021 and 2023. Which might result in a lower overall accuracy than the accuracy is in reality.



(a) 350 sample points (b) 124 sample points

Figure 5: Sample points before and after deleting points far from roads

After getting the sample points a confusion matrix will be constructed. In this confusion matrix the land cover of the sample points from the physical collection in the study area will be compared to the land cover of the sample points in the land cover classification maps. After constructing the confusion matrix the overall accuracy can be calculated using equation 1 (Rwanga and Ndambuki, 2017). According to Anderson et al. (1976) the overall accuracy must be at least 85%.

$$Overall \quad accuracy = \frac{Number \quad of \quad correct \quad points}{total \quad number \quad of \quad points} \tag{1}$$

2.2.2 Method for determining normalized difference vegetation index (NDVI)

The vegetation density will be determined using the normalized difference vegetation index (NDVI). The NDVI is based on the Near-infrared radiation (NIR) and red light bands in satellite data. If the NDVI is closer to 1 then there is a high possibility that there are dense green leaves while if it is close to -1 then it is more likely water, settlements are often close to 0. The NDVI values for a tropical rainforest are approaching 1. The following formula is used for determining NDVI:

$$NDVI = \frac{(NIR - red)}{(NIR + red)} \tag{2}$$

NIR is reflected by vegetation while red light is absorbed by vegetation (GISGeography, 2022). From previous research, it is assumed that dense forestry has decreased in the area while agro-forestry has increased. This makes it difficult to know if there has actually been deforestation/ a decrease in vegetation. The NDVI can help in understanding this, as the NDVI is influenced by the density of forestation. However, the NDVI is also influenced by other factors such as the amount of rainfall and temperature in a year (Wang et al., 2003). This means that it is possible that there is the same amount of forestation but the NDVI values are higher because the health of the forestation has increased. Therefore, it is important to consider the NDVI results together with the land cover classification when determining if there has been deforestation. In addition, the years with high NDVI values must be compared to the years with high rainfall values. The NDVI values will be determined for the years 1992-2014 using satellite data in Google Earth engine. There is no satellite which has data for all of the years between 1992-2014. Therefore, two different satellites will be used for determining the NDVI. From 1992-2000 data from the Landsat 5 satellite will be used. This data has the bands for NIR and red light. From 2000 onwards data from the Terra satellite of the MODIS instrument will be used. In previous studies the MODIS instrument has proved to be successful in determining the vegetation change detection (Maranganti, 2009). Because the NDVI values are from different satellites, the results from the satellites should be compared seperately, as the spatial resolution is different for the satellites and this can influence the NDVI results.

In Google Earth Engine the data will be filtered on the Merawu catchment, and through this the mean NDVI value of the catchment can be determined. This will be determined for the following period; 1992-2014.

The trend in NDVI will be determined using the trend analysis methods described in section 2.5.

2.3 Has there been a change in seasonal and annual discharge over the years in the catchment?

There is daily data available of the discharge station located at Clangap between 1992 and 2019. In some years data is not available for more than 250 days. This is the case for 1996, 2001, 2010 and 2019. In 2002 and 2004 data is missing for 2-3 months. All of these years will not be used for determining trends in discharge. There are some anomalies within the discharge data. These problems are for example that sometimes data is not available for one day or that a measurement is extremely high for a day. The adaptations to the data can be found in appendix A. From 2005 onwards the discharge data is unrealistically high, and a lot higher than the years before. This can also be seen in Figure A2a in appendix A. Most likely there has been a mistake in the rating curve which is used for this data. The mistake in the rating curve results in higher discharge values. However, a trend analysis can still be performed separately for the years 1992-2004 and 2005-2014. This is because although the values of the discharge might be too high, the trend in discharge will stay the same. However, if the high discharges from 2005 onwards do not originate from a mistake in the rating curve but from wrong water height measurements then this might give wrong results in the trend analysis.

2.4 What has been the areal rainfall and evapotranspiration over the years in the Merawu catchment?

2.4.1 Methodology for determining the areal rainfall

In and near the catchment there are rain gauge stations that measure the rain in the area. The locations of these rain gauge stations can be found in Figure 6. It should be noted that the exact coordinates of the rain gauge stations are not known. Only the village or area name is known and the centre of this area has been chosen as the rain gauge station location.

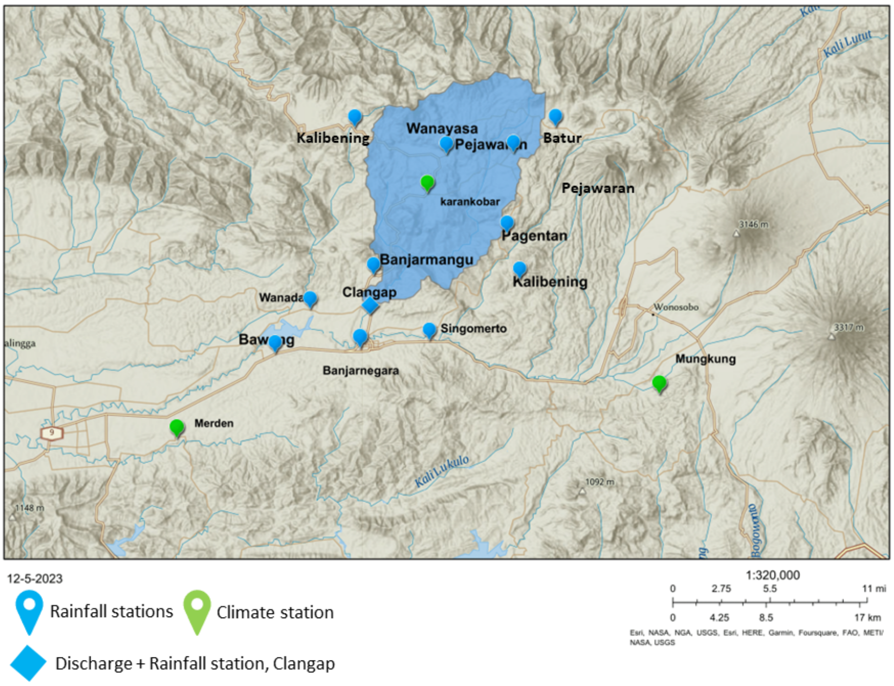


Figure 6: Discharge measuring point, rainfall stations and climate stations in or near study area

The rainfall stations can be used to determine the rainfall and the climate stations can be used to determine the evapotranspiration. However, not from all rainfall stations there is data for the entire research period (1992-2014). In Appendix A, Table A2 the availability of data from the rain gauge stations is shown. Only for 1998 there is data available of 11 out of 12 stations in the catchment. Therefore, the areal rainfall is determined for this year. Only for the Banjarnegara, Clangap and Wanadadi rain gauge stations data is available for almost all years, with the exception for some months in 2013 and 2014. Since the Banjarnegara and Clangap rainfall stations are the closest to the catchment, these rain gauge stations are used for the other years, with a bias correction factor obtained from 1998.

There are different methods for determining areal rainfall. The most common methods are the arithmetic mean, Thiessen polygon method and isohyetal analysis. Of these methods the Thiessen polygon method is the most common one (Arianti et al., 2018). The arithmetic mean method only gives accurate results when the rain gauge stations are spread evenly throughout the catchment. For the Merawu catchment there are more rainfall stations in the downstream part of the catchment compared to the upstream part. Consequently, this method is not recommended. The isohyetal analysis considers the orographic effect in rainfall, and can therefore result in more accurate areal rainfalls (Kang et al., 2019). However, personal judgement is an important factor in the isohyetal method. A study conducted on Java, Indonesia concluded that the Thiessen polygon method was the most favored (Balany, 2011). Therefore, the Thiessen polygon method is used to determine the areal rainfall in the Merawu catchment. In the Thiessen polygon method the rainfall is seen as equal to the rainfall measured at the nearest neighboring station (Thiessen, 1911). It should be noted that the areas from the Thiessen polygon method are based on the locations of the rain gauge stations.

Since the exact locations of the rain gauge stations are not known, it is possible that the areas from the Thiessen polygon method are slightly bigger or smaller than they should be based on the exact locations of the rain gauge stations.

The area of each rainfall station is used as a 'weight' for the attribution of each rainfall station towards the mean areal rainfall. With the weights a mean areal rainfall (MAR) can be determined by using the following equation;

$$MAR = \sum_{1}^{n} \frac{A_i P_i}{A_t otal} \tag{3}$$

In equation 3, n is the number of stations, A_i is the area of a polygon in km^2 and P_i is the rainfall of the nearest rain gauge station in mm. A_{total} is the total area of the catchment in km^2. then the mean rainfall of the Banjarnegara and Clangap station in the year 1998 is determined. Because these stations are located in the south of the catchment and on a different altitude it is expected that the rainfall from these stations will be lower than the average rainfall from the Thiessen polygon method. Therefore, a bias correction factor is necessary to improve the estimation of rainfall from the Banjarnegara and Clangap rainfall station. The bias correction factor is determined by calculating the how much higher the rainfall results are for the Thiessen polygon method compared to the Banjarnegara and Clangap station in 1998. Subsequently, the mean areal rainfall for the years between 1992 and 2012 can be determined.

$$Bias \quad correction \quad factor = \frac{Rainfall \quad Thiessen \quad polygon}{Rainfall \quad Banjarnegara \quad and \quad Clangap \quad station} \tag{4}$$

2.4.2 Determining potential and actual evapotranspiration

With the discharge and rainfall known a water balance can be set up. With this water balance the actual evapotranspiration (AET) can be determined. At this point it is not known if the rainfall and discharge values are correct. For validating these values the potential evapotranspiration (PET) can be determined. PET is the evapotranspiration that occurs under ideal soil moisture and vegetation conditions (Maskey, 2022). Therefore, AET must be lower than PET to validate the rainfall and discharge values.

Equation 6 is the water balance, which is used for determining AET.

$$AET = P - Q - \frac{\Delta S}{\Delta t} \tag{5}$$

In this equation P is the rainfall, Q is the discharge, AET is the actual evapotranspiration, and $\frac{\Delta S}{\Delta t}$ is the change in soil storage. Evapotranspiration is the transpiration and evaporation in a catchment. The change in storage in a catchment is close to zero in a long-term water balance. So when setting up a water balance for 365 days, the change in soil storage can be neglected. The water balance must be for a year because the seasonal changes in soil storage cannot be neglected, while the annual changes can be neglected. This is only the case when the water balance is set up for the hydrological year. This means starting in a low flow period. (Ridder and Boonstra, 1994). Therefore, the water balance should be set up for the hydrological year, where the start month is the month with the lowest rainfall values. Neglecting the change in soil storage results in the following equation;

$$AET = P - Q \tag{6}$$

Setting up a water balance can validate the areal rainfall which has been determined before. With the areal rainfall and the discharge the actual evapotranspiration can be determined using equation 6. For the years that climatological data is available the potential evapotranspiration will be calculated. If the actual evapotranspiration according to the water balance is higher than the potential evapotranspiration then it is expected that the areal rainfall is not correct. For the years between 2002-2010 climatological data is available,

Since in none of the years the solar radiation is known the widely accepted Penman Monteith method cannot be used for this area. For this method a lot of climate data has to be known. Another method that can be used for calculating the potential evapotranspiration is the Blaney Criddle method. The equation according to the Blaney Criddle method is equation 7.

$$PET = p(0.457 * T_{mean} + 8.128) \tag{7}$$

In this equation PET (mm/day) is the potential evapotranspiration in , T_{Mean} (Celsius) is the average daily temperature and p is the mean daily percentage of annual daytime hours (Zhan and Shelp, 2009). The evapotranspiration also changes with elevation. As temperature decreases evapotranspiration also decreases. However, the wind speed increases with altitude which increases the evapotranspiration due to a decrease in air pressure. Since the Blaney Criddle method does not include the wind speed, evaporation would only decrease with height. Therefore it is best to use the data of the Karankobar station, since this station is located at an elevation of 1000 meters, and the elevations in the catchment range from around 200-2000 meters. However, the uncertainty in evapotranspiration at different altitudes makes the evapotranspiration results more uncertain. There are a few anomalies in the evapotranspiration data, the anomalies and the adaptations can be found in Appendix A.

The change in temperature is also important to determine if the evapotranspiration and therefore the discharge as well have been affected by climate change. In the Blaney Criddle equation, equation 7, the only variable influenced by climate change is the temperature. Therefore, the change in temperature will be analysed using a trend analysis which is described in subsection 2.5. The Karankobar climate station in the area only has data between 2002-2008. To have more data for the trend analysis satellite data will be used to determine Land Surface Temperature (LST). For the years 2000-2014 again the MODIS data from the Terra satellite will be used. These values of LST determined by MODIS will be validated by comparing them to the temperatures measured by the Karankobar climate station.

2.5 Trend analysis for the discharge, rainfall, temperature and NDVI

For all of the previous research questions it has to be determined if one or more variables have changed between 1992-2014. Therefore a statistical test will be performed to determine if there has been a change in annual and seasonal discharge, rainfall, temperature and NDVI. A statistical test that is often used to detect trends in hydrological data is the Mann-Kendall test. The first equation for the Mann-Kendall test is given below:

$$S = \sum_{k-1}^{n-1} \sum_{j-k+1}^{n} sgn(x_j - x_k) \quad (8)$$

In this equation n is the time, x is the data collected over time. $Sgn(x_j - x_k)$ is the indicator function, if x_j - x_k is bigger than 0 it is 1, equal to 0 it is 0 and lower than 0 it is -1. If S is a positive number, observations obtained later in time tend to be larger than observations made earlier.

$$VAR(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p-1}^{g} t_p(t_p - 1)(2t_p + 5)] \quad (9)$$

In this equation, the variance of S is determined. g is the number of tied groups, this is the number of equal values in the measurement. t_p is the number of observations made for a tied group. After S and $VAR(S)$ are determined the MK statistic can be determined.

$$ifS > 0 \quad Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \quad (10)$$

$$ifS < 0 \quad Z_{MK} = \frac{S+1}{\sqrt{VAR(S)}} \quad (11)$$

A positive value of Z_{MK} indicates that the data tends to increase while a negative value indicates that the data tends to decrease (Mondal et al., 2012). A significance level of α = 0.05 will be used since this is typically used to test the null hypothesis that there is no trend in the data (Holbert, 2019).

This test can be used to determine the changes annually but also seasonally. To indicate if there is a trend seasonally, the seasonal Mann-Kendall test can be used. In this test data is only compared for the same season (Hirsch et al., 1982). The seasons will depend on the amount of rainfall in the area and will be determined after determining the areal rainfall. The seasons will consist of a dry season and a wet season. This test will also be used for the rainfall and temperature data. For the NDVI the seasonal test will not be performed. This is because the NDVI is determined for indicating if there has been a change in forestation. While the NDVI value will change between the wet and the dry season, it is not expected that a trend within the wet and dry season will indicate on any deforestation or afforestation that is different from the annual trend. As there is no (de)forestation only in the wet or dry season. Because 1992-2014 is a long period, it might be possible that there are different trends in this period in time. Therefore the Mann-Kendall test is determined for different periods in time. Because there are differences in the availability of data for the different hydrological variables the periods are slightly different. For the NDVI this is 1992 until 2000 and 2000 until 2015, for discharge 1992 until 2005 and 2005 until 2015, for rainfall 1992 until 2003 and 2003 until 2015 and for the temperature only 2000 until 2015.

The Sen's slope estimation can be a good addition for indicating a trend in discharge and rainfall. This is because if a trend is found with the Mann-Kendall test then the Sen's slope estimator can be used to indicate the magnitude of the trend:

$$Q_i = \frac{x_j - x_i}{j - i}, i = 1, 2, 3...N \tag{12}$$

In equation 12, N is the number of sample pairs, X_j and X_i are data values at time j and $i(j > i)$. The following equations are used to estimate the value of Q_{med} , the median of Q.

$$Q_{med} = Q_{\frac{N+1}{2}} \quad if \quad N = odd \tag{13}$$

$$Q_{med} = \frac{1}{2}[Q_{\frac{N}{2}} + Q_{\frac{N+1}{2}}] \quad if \quad N = even \tag{14}$$

The confidence interval of the median of Q will be determined to assess if the slope is significant. The confidence interval will be determined using a probability of α is 0.05 and 0.1. This is because the Mann-Kendall test has already shown a significant trend. Therefore, a lower significance is accepted for the Sens slope estimator. The confidence interval can be calculated as follows:

$$c_\alpha = Z_{1-\alpha/2}\sqrt{VAR(S)} \tag{15}$$

The lower bound (M1) and the upper bound (M2) will be calculated using the equations below (Gilbert and O., 1997).

$$M1 = \frac{N - C_\alpha}{2} \tag{16}$$

$$M1 = \frac{N - C_\alpha}{2} \tag{17}$$

With the Sen's slope estimator, it is also possible to see how much the discharge has changed in mm^3/s and how much the rain has changed in mm. The lower and upper bounds are calculated to determine if the slope is significant. If the confidence interval includes zero, then the slope is not significant. The Sen's slope estimator will only be used if the Mann-Kendall test has indicated a significant trend over the years (Aditya et al., 2021).

3 Results

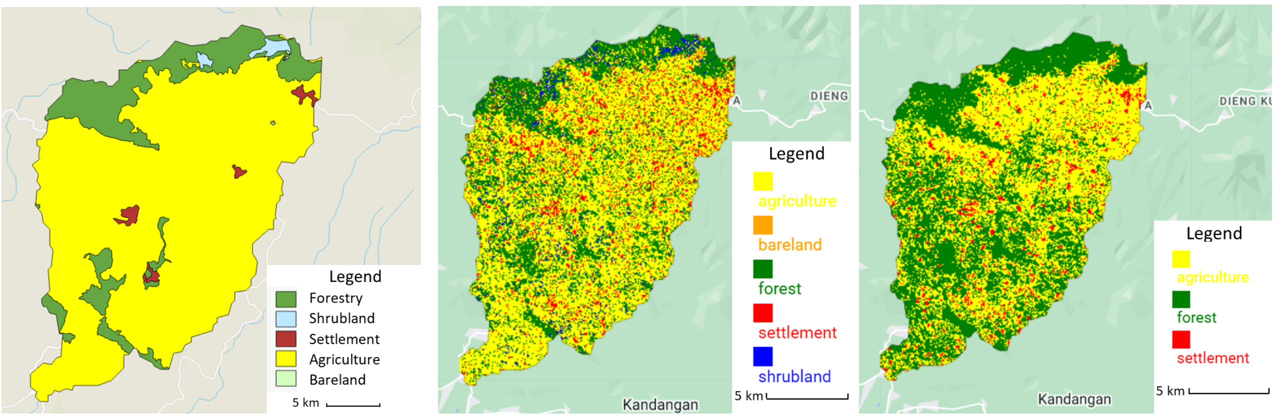
In this chapter the results will be presented. The results are presented per research question.

3.1 Land cover and NDVI change in the Merawu catchment

In this section the results of the land cover classification and the normalized difference vegetation index (NDVI) are presented. These results should indicate what the changes in forestation have been in the area.

3.1.1 Land cover classification

The two sets of training data have resulted in two differen land cover classifications. The two different land cover classifications for 2019 are shown in Figure 7. In all land cover maps there is a big area of forestation in the upstream part of the catchment. Further downstream there are also some forested areas. A difference between the land cover maps is that the land cover map in Figure 7c has more forested area than the other land cover maps in Figure 7.



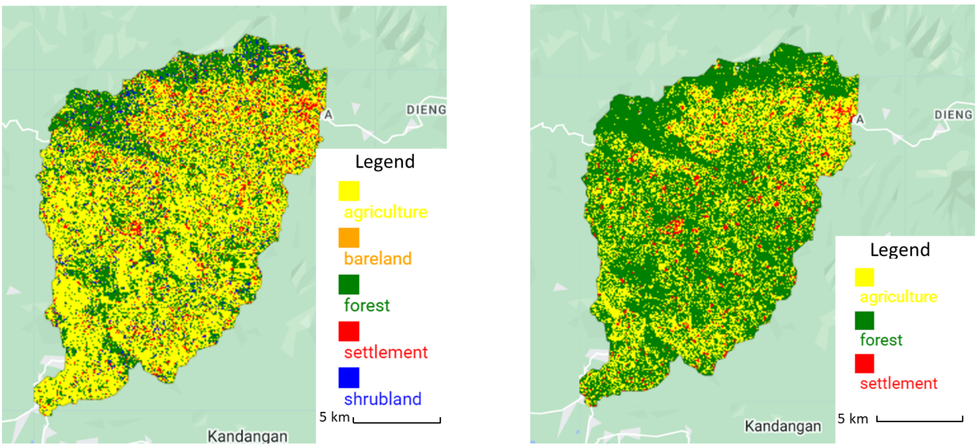
(a) Land cover map government of Indonesia

(b) Land cover map 1 (Based of Figure 7a and Landsat 8)

(c) Land cover map 2 (Google Earth imagery and Landsat 8)

Figure 7: Land cover map comparison for 2019

For the accuracy assessment the land cover classifications from 2021 have been used. The maps of 2021 based on the two sets of training points are shown in Figure 8.



(a) Land cover map 1 (b) Land cover map 2

Figure 8: Land cover map comparison for 2021

In the study area the land cover samples from the sample points have been collected. From this two confusion matrices have been formed. The confusion matrix for the land cover classification 1 are shown in Table 2, and the confusion matrix for land cover classification 2 in Table 3. The land cover samples that have been taken and their comparison to the land cover classifications are presented in appendix C.

Table 2: Confusion matrix land cover classification 1

	agriculture	forest	settlements	bareland	shrubland	total
agriculture	31	2	5	0	0	38
forest	7	4	1	0	0	12
settlements	2	0	3	0	0	5
bareland	2	0	1	0	0	3
shrubland	1	1	1	0	0	3
total	43	7	11	0	0	61

In the confusion matrix the columns are the physical sample data and the rows are the samples from the land cover classification. The table shows that most sample points for agriculture were correct, and that most misclassifications of agriculture samples happened with forestry. Out of 43 agriculture areas in the physical sample points, seven were classified as forestry in the land cover classification. Two out of these misclassifications were agroforestry, while the other five were cropland or rice fields. From the forest areas some were classified as agriculture as well. For the settlements there were more misclassifications than correct classifications. most of the misclassifications happened with agriculture. In the samples that were taken in the study area none were classified as shrubland and bareland. All of the land cover have been classified as either forestry, agriculture and settlements. The overall accuracy, determined by dividing the number of correct points by the number of total points, is 0.62.

Table 3: Confusion matrix land cover classification 2

reference data	agriculture	forest	settlements	total
agriculture	28	0	6	34
forest	14	7	0	21
settlements	1	0	5	6
total	43	7	11	61

Through the confusion matrix in Table 3 it was found that more agriculture areas have been wrongly classified compared to the confusion matrix of land cover classification 1. Most of these misclassifications happened with forestry and only one with settlements. However, it should be noted that 8 out of 14 misclassifications were confused with densely agroforest. Often consisting out of a Salak (snake fruit) plantation mixed with coconut and banana trees. It is likely that the effects of these types of plantations on the water cycle are closer to forestry than to cropland. Four rice field/cropland areas were classified as forestry, which is less than for land cover classification 1. Two not densely agroforestry regions were classified as forestry. All of the forest samples have been correctly classified. This is positive as the research is towards the effect of deforestation. For the settlements there were again more misclassifications than correct classifications. The overall accuracy for the second land cover classification is 0.66 which is slightly higher than the overall accuracy of the first land cover classification.

Both accuracies of the land cover classifications are lower than 85% which was a criteria set by Anderson et al., 1976. Which means that it is preferred to improve the land cover classifications based on these results. However, due to time constraints it was not possible to improve the land cover classifications. Therefore, one of the land cover classifications will still be used for indicating if there have been land cover changes in the area. However, the low overall accuracy should be kept in mind when deriving conclusions from the results. Especially, the uncertainty whether forestry in the land cover map is forestation or agroforestry must be considered.

From the two land cover classifications the second land cover classification gives a higher accuracy. Additionally the misclassifications are also more logical, while they seem more at random for the first land cover classification. Even though agroforestry has been confused with forestry in the second land cover classification this might not be a problem for this research. This is because the research investigates the effects of deforestation on the water balance. Although Agroforestry has a different land use compared to plantation or native forests in the area, the land cover characteristics are similar, so their effect on the water balance is expected to be similar as well Therefore, the land cover classifications made based of the second batch of training samples will be used for this research.

In Figure 9 the areas of land cover in the Merawu catchment are shown for the years with available satellite data in the period of 1992 to 2014. Figure 9 shows some increases and decreases of forestation over time, with the lowest amount of forestation in 1999. However, the figure also shows some illogical trends, such as that forestation decreases in 1994 and then increases again in 1995. Because the overall accuracy is not high it is difficult to determine if the increases and decreases are from changes in forestation or from misclassifications. The accuracy assessment also shows that agroforestry is sometimes classified as agriculture and sometimes as forestry, it is possible that it also differs per classification how often agroforestry is classified as forestry. Moreover, it is illogical that the settlement areas have decreased over time, for example between 1997-1998. This is in accordance with the many misclassifications for settlements in the accuracy assessment. In the time period (1992-2014), the population of Indonesia has only increased Liu and Yamauchi, 2014.

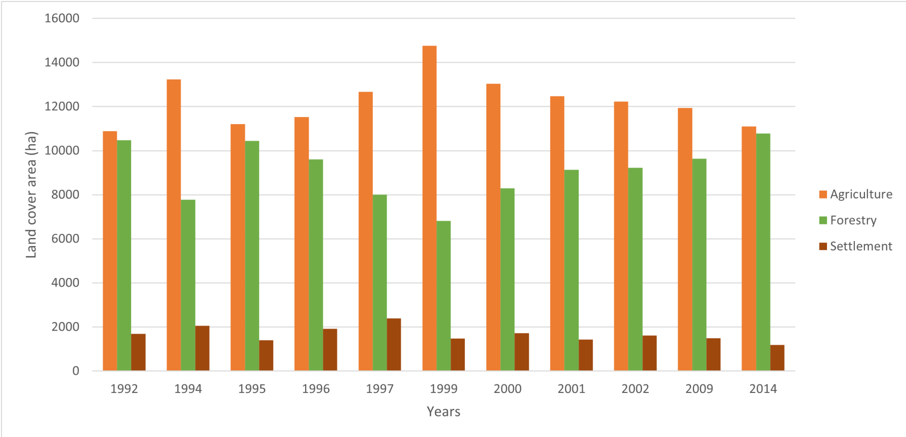


Figure 9: Land cover areas Merawu catchment 1992-2014

In Figure 10 the land cover classification maps are shown. These land cover maps all have a large area of forestation in the north, and some forestation area in the middle. The main differences are in the south of the catchment. In some maps there are a lot of smaller areas (2000,2002, 2014), while other maps show clearer distinctions (1992,1994 and 2009). This is possibly due to agroforestry sometimes being classified as agriculture and sometimes as forestry in the maps.

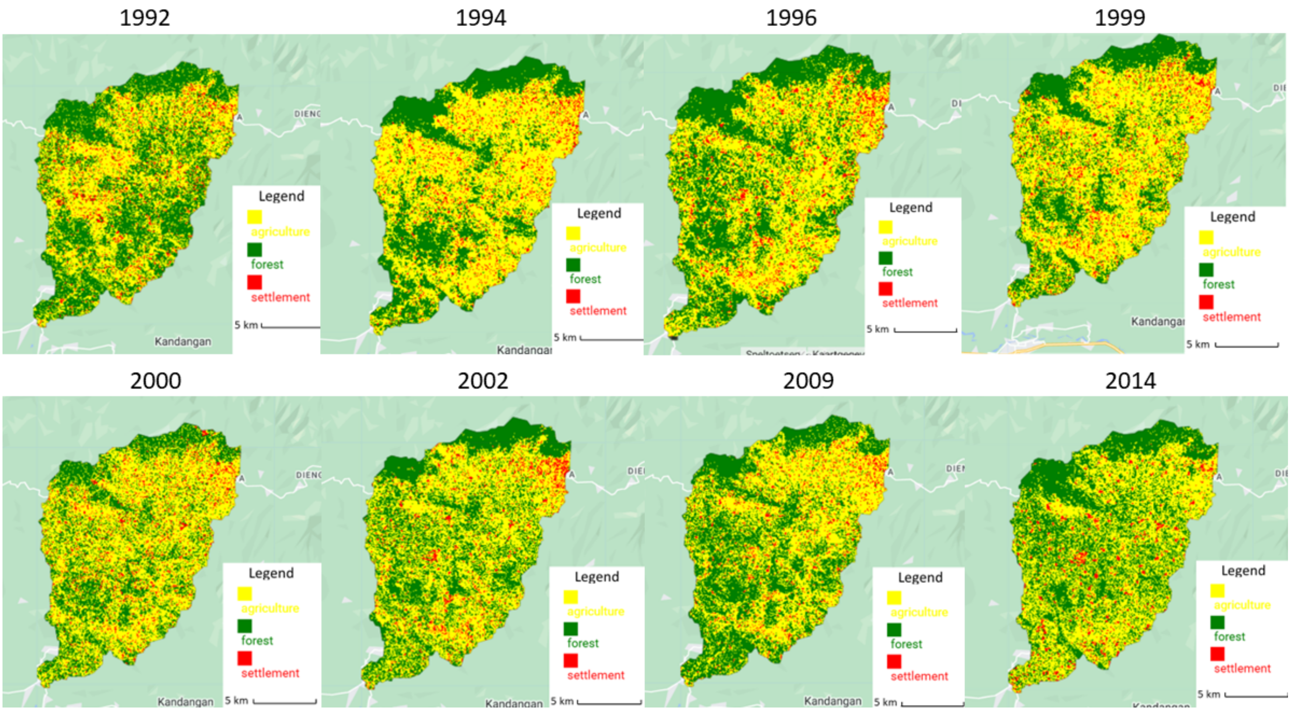


Figure 10: Land cover classification map 1992-2014

Overall the land cover classifications do not prove that there has been deforestation in the area. From the accuracy assessment it is known that agroforestry has been wrongly classified as forestation in the land cover classifications. Because of this it is possible that the forestation has changed into agroforestry over the years, but that this is not visible in the land cover maps. However, solely looking at the areas of land cover, these do indicate a period of deforestation between 1992-1999 and a period of afforestation between 2002-2014.

3.1.2 Vegetation density change

The results of the calculations of the NDVI can be seen in Figure 11. For the year 2000 there is no data of January and February since the Terra satellite only started collecting data at the end of February 2000. Therefore, the average NDVI values of January and February of the years 2001-2014 are used for January and February 2000.

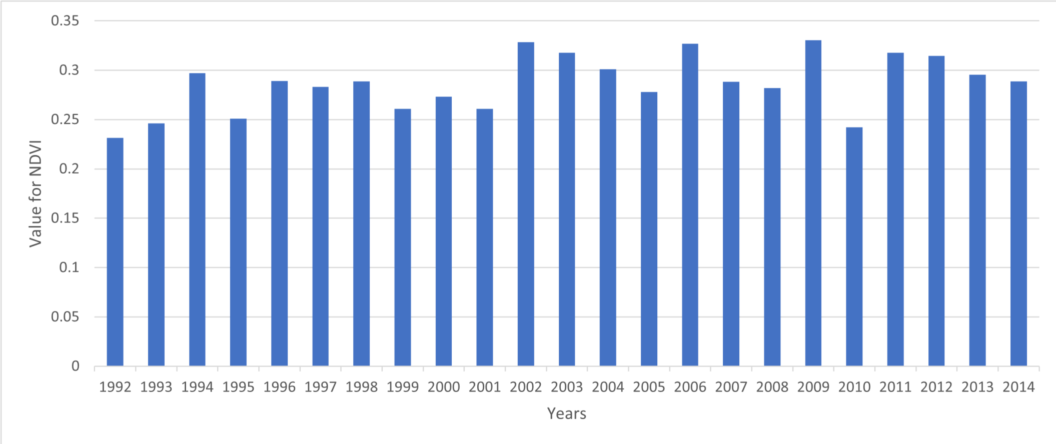


Figure 11: Values for NDVI 1992-2014

It can be seen that the NDVI peaks after 2000 are in the years 2002, 2006 and 2009. Before 2000 the peaks are in the years 1994, 1996 and 1998. These years should be compared to the years with the most rainfall. This is to get an indication if the peak NDVI values are because of land cover change or because of a better climate for the vegetation in the area.

The results of the Mann-Kendall trend tests for the NDVI values are shown in Table 4. The table shows that there is no significant trend in the NDVI values. This is because none of the P values are lower than 0.05. Solely looking at the Z values there is a positive trend in NDVI values, but these trends are not significant. Therefore, these results show that there has been no significant change in the health of vegetation or the amount of vegetation in the study area. However, between 2000-2014 the annual Mann Kendall test is very close to a significant positive trend. As the P value is 0.05 and a p value of under 0.05 can be seen as significant. The positive trend is in accordance with the increase of forestation from the land cover areas.

Table 4: Results Mann-Kendall test NDVI

Mann kendall test results	Z value	P value
Annual (1992-2000)	0.87	0.19
Annual (2000-2014)	1.64	0.05

3.2 Change in annual and seasonal discharge of the Merawu catchment

The discharges that have been used for the trend analysis are shown in Figure 12. This figure clearly shows that there is an unrealistic increase in discharge from 2005 onwards. Because the reason for this has not been figured out yet, these discharge values are used for the trend analysis.

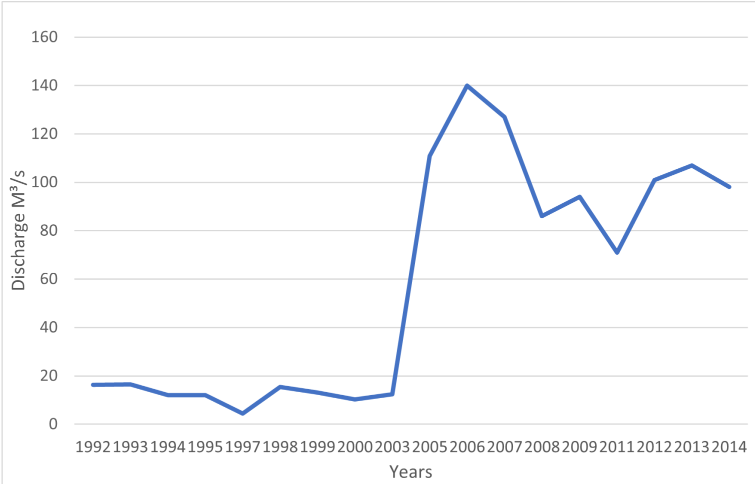


Figure 12: Mean annual discharge measured at Clangap station

The results of the Mann-Kendall trend analysis are presented in Table 5. The results of the Mann-Kendall tests show no significant trends, as none of the P values are below 0.05. The tests over the whole time period (1992-2014) have not been done because of the increase in discharge from 2005 onwards. As these tests would show trends that are not actually present. Because this gives a short time period for 2005-2014 it is not likely that the Mann-Kendall trend test will indicate a significant trend. Therefore, also a trend test for 2005-2018 is included to see if this trend would be significant.

Table 5: Results Mann-Kendall test discharge

Mann-Kendall test results	Z_{MK}	P value
Annual (1992-2014)	-	-
Annual (1992-2005)	-0.94	0.17
Annual(2005-2014)	-0.94	0.17
Annual (2005-2018)	1.04	0.15
Wet Seasonal (1992-2014)	-	-
Wet seasonal (1992-2005)	-1.20	0.11
Wet seasonal (2005-2014)	-1.36	0.09
Wet seasonal (2005-2018)	0.75	0.23
Dry seasonal (1992-2014)	-	-
Dry seasonal (1992-2005)	-0.18	0.43
Dry seasonal (2005-2014)	-1.15	0.13
Dry seasonal (2005-2018)	0.31	0.38

3.3 Change in areal rainfall and evapotranspiration in the Merawu catchment

In this section the results of the trend analysis of the areal rainfall and temperatures are presented. In addition, also the water balance is presented.

3.3.1 Areal rainfall

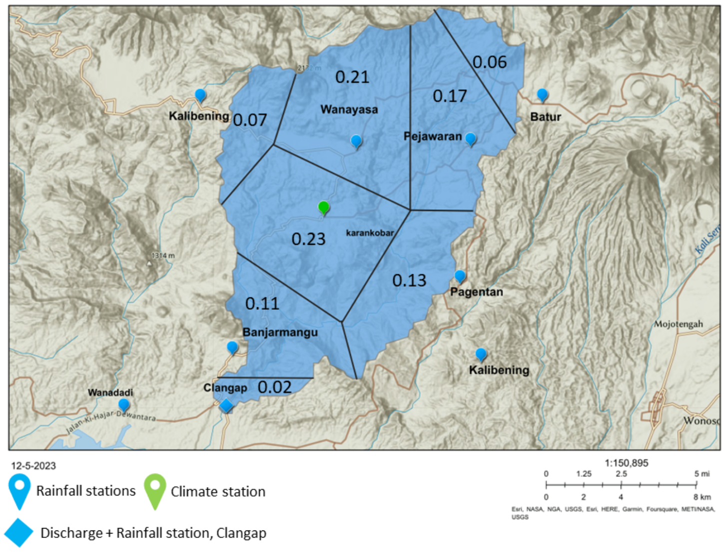
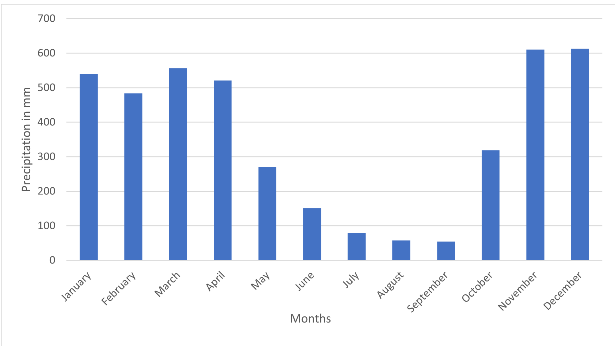


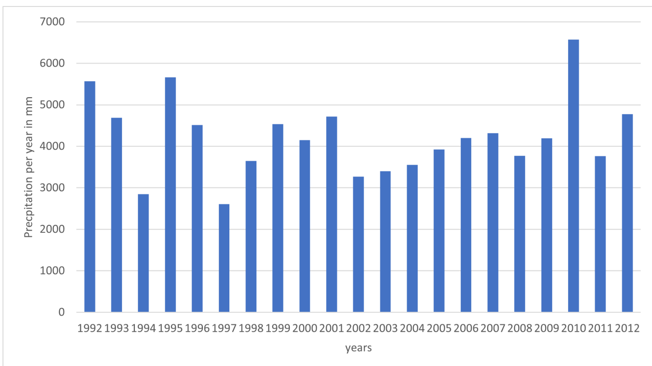
Figure 13: Catchment divided in Thiessen polygon area's

The mean areal rainfall for 1998 has been determined using the Thiessen polygon method. The Thiessen polygons resulting from this method are shown in Figure 13. The mean areal rainfall resulting from equation 3 is 3648 mm in the year 1998. The average rainfall for the Banjarnegara and Clangap station is 3332 mm. This is lower than the rainfall from the Thiessen polygon method, therefore a bias correction factor will be used. The bias correction factor that is used for the areal rainfall in the years (1992-2014) is 1.095.

The rainfall in the Merawu catchment that result from the data in the Banjarnegara and Clangap stations can be seen in Figure 14.



(a) Areal mean rainfall per month



(b) Rainfall merawu catchment 1992-2012

Figure 14: Average rainfall per month and per year

The average areal rainfall in the catchment is 340 mm/month. The months November-April have a higher monthly rainfall than the average while the months May-October have a lower rainfall than the average. In the trend analysis the wet season will consist of the months with a higher than average rainfall, and the dry season of the other months.

From Figure 14b it can be seen that the peaks of rainfall are in the years 1992, 1995 and 2010. These years should be compared to the years with peak values for the NDVI. This comparison is to get an indication where the peak values of NDVI come from.

3.3.2 Results trend analysis areal rainfall

To determine a trend in the rainfall data the Mann-Kendall test is used. Table 6 shows that there is only a significant trend for the annual test between 2003 and 2014. This trend has a positive Z_{MK} which indicates a trend of increased rainfall between 2003 and 2014.

Table 6: Mann-Kendall test results rainfall

Mann-Kendall test results	Z_{MK}	P value
Annual (1992-2014)	0.13	0.45
Annual (1992-2003)	-0.93	0.18
Annual(2003-2014)	1.77	0.04
Wet Seasonal (1992-2014)	0.78	0.22
Wet seasonal (1992-2003)	-0.31	0.38
Wet seasonal (2003-2014)	0.94	0.17
Dry seasonal (1992-2014)	-0.94	0.17
Dry seasonal (1992-2003)	-0.78	0.38
Dry seasonal (2003-2014)	0.18	0.43

For the annual Mann-Kendall test 2003-2014 also the Sen's slope estimator test has been conducted. The results of the Sen's slope estimator are presented in Table 7. These results indicate that there is a significant trend with a 90 % confidence interval, but not with a 95 % confidence interval. This is because 0 is included in the bounds of the 95 % confidence interval. The Mann-Kendall test has a significance of 95% while Sen's slope estimator only has a significance of 90%, this is most likely because of the small increases between 2002-2007 which are visible in Figure 14b. The magnitude of the change is not relevant in the Mann-Kendall test while it is relevant in the Sen's slope estimator test.

Table 7: Sen's slope estimator rainfall

	95% confidence interval	90% confidence interval
Lower bound	-107	49
Upper bound	1005	742
Slope	409	409

3.3.3 Results potential evapotranspiration and trend analysis

In Figure 15 the temperature data from the Karankobar climate station and the Land Surface Temperature from satellite data are shown. It shows that there is a difference in the temperatures, but that the difference in temperature is small (within 1.2 degrees). These differences could come from the temperature being measured at the climate station at 7 am, 12pm and 7pm, and the average of this was used. While for the LST data from MODIS the average of day and night during an 8 day period is used. Furthermore, the differences could also come from that the Karankobar climate station is located at one point in the catchment, while the temperatures from satellite data the average is taken from the entire area. The MODIS data is provided by NASA and have undergone quality control assessments. Therefore, it is expected that the quality of this data is good. One concern about the temperature values is that the increases and decreases between years seems to be different. Where the temperatures of the climate station increase between 2003-2004, they decrease for the LST values from the satellite data. The same happens for 2002-2003 and 2007-2008.

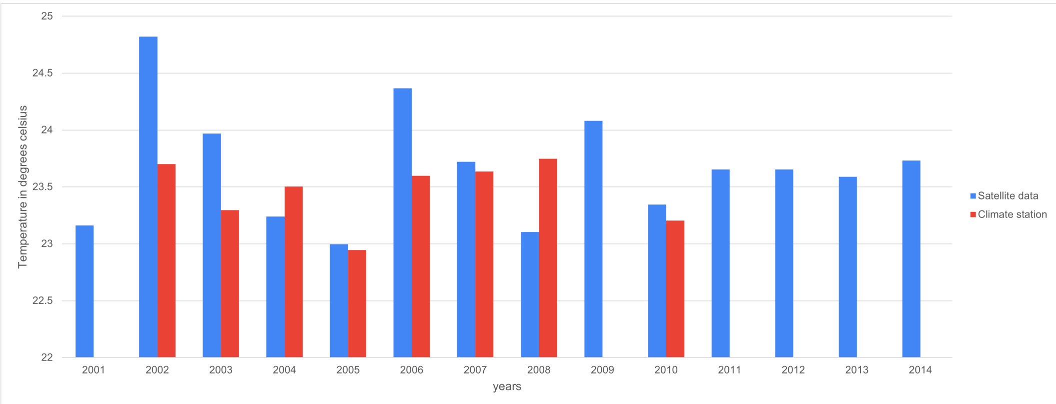


Figure 15: Temperature comparison in Merawu catchment between climate station measurements and temperatures derived from satellite data

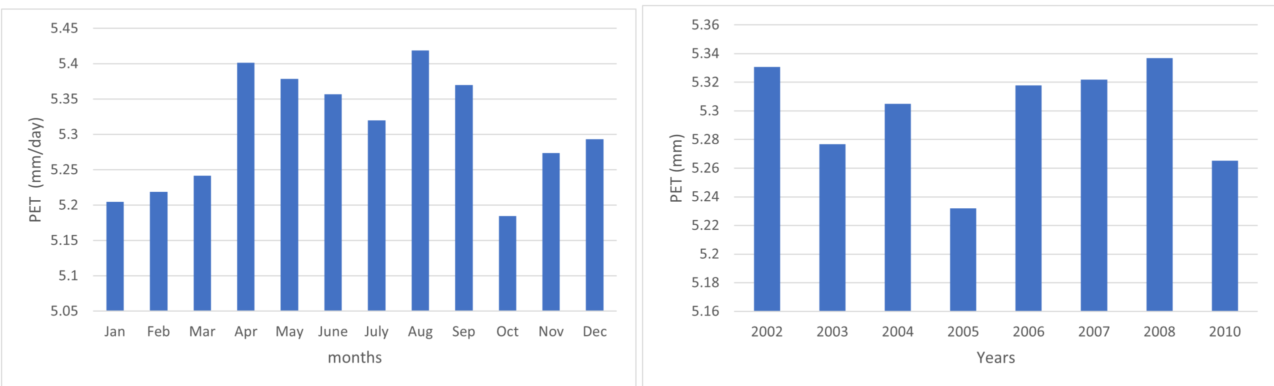
For the temperature values derived from satellite data the Mann-Kendall test was performed. This was done for these temperature values and not for the values from the climate station because less data is available from the climate station. Table 8 shows no significant trend in the temperature values. This means that there has been no effect of climate change on the temperature in the study area between 2000-2014. Since temperature is an important variable affecting the evapotranspiration, this decreases the chance of evapotranspiration being affected significantly by climate change. It is still be possible that there would be a trend when the values between 1992-2000 are included, but the Z values in Table 8 are really low, so it is unlikely that there would be a significant trend.

Table 8: Results Mann-Kendall test potential evapotranspiration

Mann-Kendall test results	Z value	P value
Annual (1992-2014)	-	-
Annual (1992-2003)	-	-
Annual(2000-2014)	-0.18	0.43
Wet Seasonal (1992-2014)	-	-
Wet seasonal (1992-2003)	-	-
Wet seasonal (2000-2014)	-0.344	0.37
Dry seasonal (1992-2014)	-	-
Dry seasonal (1992-2003)	-	-
Dry seasonal (2000-2014)	0.21	0.58

3.3.4 Water balance

In Figure 16, the potential evapotranspiration per month and per year is shown. The PET is based off the temperature measurements from the Karankobar climate station. The evapotranspiration is quite similar throughout the year because the temperature and percentage of sun hours do not change substantially. In the dry season the potential evapotranspiration is slightly higher, due to a slight increase in the number of sun hours.



(a) PET per month (mm) (b) PET in Merawu catchment 2002-2011

Figure 16: Average potential evapotranspiration per month and per year

In Table 9, the water balance is shown. The hydrological year for the water balance starts in September and ends in August. This is because the rainfall is the lowest in September. The water balance shows that for the years 1992-2003 it is likely that the rainfall has been overestimated or that the discharge has been measured incorrectly and that the discharge data is too low. This is because the potential evapotranspiration (PET) is supposed to be higher than the actual evapotranspiration (AET). It is possible that the rainfall correction factor for determining the rainfall is too high. From the water balance it can be seen that 1997-1998 and 1998-1999 are the only logical years, as only in these years AET is lower than PET. 1998 was also the year that the rainfall was determined with the

Thiessen polygon method. This suggests that the mean areal rainfall determined from this method is accurate. It also suggests that there is either something wrong with the bias correction factor used or with the measurements at the Banjarnegara and Clangap rain gauge stations.

Moreover, the water balance also proves that the the discharge values from 2005 onwards are extremely high. The discharge data is at least 10 times as high as the rainfall, which is not possible.

Table 9: Water balance Merawu catchment

	1992-1993	1993-1994	1994-1995	1997-1998	1998-1999	1999-2000	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010
P (mm)	5411	3830	4527	3231	3856	3913	4886	3646	3867	4523	5891
Q (mm)	2415	1860	1545	1651	2016	1333	19716	18357	13414	11147	11344
AET (mm)	2996	1970	2982	1581	1840	2580	-14829	-14711	-9547	-6625	-5453
PET(mm)*	1933	1933	1933	1933	1933	1933	1931	1945	1945	1933	1933

* For the years (1992-2000 and 2008-2010) for the potential evapotranspiration the average evapotranspiration from Figure 16b has been used. This is because there have been no measurements at the Karankobar climate station for these years.

3.4 Change in discharge and attributing this change to land cover change or climate change

The trend analysis of the discharge does not show a significant trend. The land cover classifications have indicated that there have been some land cover changes, namely deforestation between 1992-2000 and afforestation between 2000-2014. However, the overall accuracy of these land cover maps is low so these decreases and increases in forestation can also be a result from that. Additionally, the land cover maps do not show a clear change in forest area.

For the NDVI values no significant trend was found, but the Z value for 2000-2014 indicated a positive trend which was close to being significant. This positive trend possibly comes from the increase in afforestation from 2000 onwards. But can also be because of the positive trend in rainfall that has been found between 2003-2014. However, the peak values of rainfall are in different years than the peak values of NDVI. In another research it has been found that the NDVI values are highly correlated with rainfall received during the current growing season and seven preceding months (Wang et al., 2003). The years with peak values for NDVI are 1994, 1996, 1998, 2002, 2006 and 2009. The years with peak values for rainfall are 1992, 1995 and 2010. So only for the year 1996 there is a high NDVI value and in that year or the year before there is a high rainfall value. This indicates that the (not significant) trend in NDVI is not likely from the trend in rainfall. Which hints to that the afforestation found from the land cover classification is an accurate land cover change. For the deforestation that might have taken place between 1992-2000 no NDVI trend has been found.

For the discharge in these years the trend is not significant but the trend according to the Mann-Kendall test would be negative. While a positive trend would be expected, based on the positive trend in rainfall. Although, no trend analysis has been done for the actual evapotranspiration, the absent trend in discharge is likely because of an increase in evapotranspiration. This increase of evapotranspiration can be because of multiple effects. One of these is because of an increase in forestation, which was also indicated by the land cover classification and the change in NDVI.

However, this is not the only change which can result in a higher evapotranspiration. The difference between actual evapotranspiration and potential evapotranspiration is that the potential evapotranspiration is the evapotranspiration that occurs under ideal soil moisture conditions. As there has been an increase in rainfall in the catchment, it is likely that the soil moisture conditions have become closer to ideal in the catchment. This means that the increase in rainfall probably has resulted in an increase in AET (Ma and Zhang, 2022).

No seasonal trends have been found in the results, this means that no proof has been found for the "sponge effect hypothesis".

4 Discussion

In this section the results of the previous chapter are discussed, placed into the context of already existing literature and the limitations of the research are described.

4.1 Key findings and their relation to existing literature

The results indicate that there have been no trends in annual and seasonal runoff. Additionally, the results indicate that there has been an increase in forestation between 2000-2014. However, Because the overall accuracy of the land cover classifications is low this cannot be said with certainty. At the start of the research a negative trend in forestation was expected. This was expected because the land cover classifications by Syahli (2015) showed a decrease in plantation forest and the land cover classifications by Paudel (2010) showed a decrease of dense forestry. However, in both of these studies there was an increase in agroforestry. This further indicates that agroforestry is included in the forestry land cover class in the classifications used in this research. This is also indicated by comparing the amount of land cover area in the Merawu catchment classified by Syahli (2015), which are shown in Table 1. This classification consists out of the following land cover classes; cropland, paddy field, agroforestry and plantation forest. Since the combined areas of agro-forestry and plantation forest in Table 1 give similar results to the forestry land cover area in Figure 9. And the combined areas of vegetable cropland, paddy field and plantation from Table 1 give similar results to the land cover areas in Figure 9. From the study by Syahli (2015) it is not clear if there is also such a big peak of agriculture in 1999 in the land cover classifications by Syahli (2015). This is because only the areas of 1994, 2002 and 2014 are known.

The rainfall results suggest a significantly positive trend in the amount of rainfall in the area. In another study towards change in rainfall in Java it has been found that rainfall has decreased over the period 1955 to 2005 (Aldrian and Djamil, 2007). Another study to a nearby catchment found that there was not a significant change in rainfall (Marhaento et al., 2016). However, the study by Aldrian and Djamil (2007) also found that the orographic effect played a big role in the effects of climate change on rainfall. In the study by Aldrian and Djamil (2007) the decreasing trend in rainfall mainly occurred in lower areas. Therefore, it is possible that climate change has different effects on the rainfall in this high elevation catchment.

Because there has not been a trend in discharge, the increase in rainfall suggests that the evapotranspiration has increased in the area. No trends have been found in the temperature values in the area. This suggests that the increase of evapotranspiration originates from another factor, and not from an increase of temperature due to climate change. The evapotranspiration has likely increased because of the increase in rainfall. However, from other studies it seems unlikely that the increase in rainfall has only resulted in an increase in evapotranspiration and not in an increase in discharge as well (Garbrecht et al., 2004; Huntington and Billmire, 2013). This suggests that other effects such as afforestation have also affected the evapotranspiration. The possibility that the afforestation has resulted in increased evapotranspiration is in accordance with existing theory regarding the effects of afforestation (Zhang et al., 2020; Zheng et al., 2016). However, a change in water management can also play a role in increasing the evapotranspiration. An example of this is an increase in irrigation (liu zhaofei, 2022) . Hence, there are indications in this research that the discharge has been affected by land cover change. However, this cannot be concluded from this research alone as it is possible that other factors not considered have played a role as well.

4.2 Limitations of the research

4.2.1 Limitations in data

There were several limitations in the data used in this research. Data has been used for detecting trends in the discharge, rainfall and evapotranspiration.

For the land cover classifications one of the limitations were the stripes in the Landsat 7 imagery. Because of the stripes the land cover classifications of several years were not available. This makes it more difficult to determine if there has been a change in forestation over the years. This is especially the case for the years 2002-2014,as only for three years in this period there are land cover classifications. It is possible to remove the stripes and then more years in data would be available. Because of time constraints this has not been done for this research, but this would have increased the numbers of years with land cover classifications.

The next limitations are in the discharge data. The discharge data increased unrealistically from 2005 onwards. It is likely that this is because of an error in the rating curve. That is why this data has still been used for trend detection between 2005-2019. However, if the error is not because of the rating curve but because of wrong water level measurements, then the trend in discharge has possibly been wrong as well. In addition this increase in data has also resulted that the trend for the whole period of time could not be detected. Therefore, it is not known if there is a trend in discharge for the period 1992-2014.

The discharge measurements before 2005 are manual, this has resulted in some illogical values in the discharge data. Some of these consisted of data being 100 times as high. These values have been changed as is presented in Appendix A. However, sometimes the same discharge values were recorded for several days. This is not logical and it is expected that this means that measurements have not been taken every day. Therefore, there is more uncertainty in the discharge results. It is possible that because of these errors in discharge data, trends in the Merawu discharge were present but have not been detected.

Another limitation is that there are also several years with missing data for at least one month in the discharge data (1996, 2001, 2002, 2004 and 2010). This has made it more difficult to detect significant trends, as there are less data points.

The next limitations are in the rainfall data. The validity of the rainfall values are impacted by the locations of the rain gauge stations. Because the exact locations are not known, the middle of the village or area is used as the location for the measuring station. These locations impact the area's which have been determined by the Thiessen polygon method. If these areas are different then the resulting rainfall value for 1998 will also be different. However, the areal rainfall for 1998 seems accurate from the water balance.

Moreover, the data availability for most of the rain gauge stations is low. Therefore, the rainfall could only be determined with the Thiessen polygon method for 1998. The uncertainty of the rainfall values would decrease if there was more data available. Especially since it seems from the water balance in Table 9 that the rainfall values are too high. From this water balance it should also be noted that the only logical years are 1997-1998 and 1998-1999. These are seen as logical values as the actual evapotranspiration is lower than the potential evapotranspiration. For the year 1998 the Thiessen polygon method was used to determine the mean areal rainfall. Therefore, it is likely that if there would be more years with data for many stations, it would be possible to determine better rainfall values.

For the evapotranspiration the main limitations come from the data unavailability as well. There is only data available between 2002-2008, and only from one station in the catchment. However, for the evapotranspiration satellite imagery has been used to combat this data unavailability. The temperatures from the satellite imagery do differ from the climate station. This is possibly due to different measurement times and measurement locations.

4.2.2 Limitations in methods

For the land cover classification an accuracy assessment has been used. The accuracy assessment has been done using sample points. However, all of these sample points were located near roads as these are easier to access. Because of this a big part of the area had a 0% chance of being a sample point. This creates more uncertainty in the accuracy results, as it is possible that the points further away from roads have a higher or lower accuracy. Especially because land covers often change near roads (from settlements to agriculture or from agriculture to forestry), while the land covers are more consistent farther away from roads. It is possible that the points have been wrongly assessed to a specific land cover in the field, as a sample point has a very specific coordinate location, and the spatial resolution of the Landsat images is 30 meters. As in the pixel of Landsat the area might largely consist out of agriculture, and a small area consists of a house. Then the pixel will be classified as agriculture, but the sample point coordinates can be exactly on the house. While taking the land cover samples it was noticed that this has resulted in some different classifications between the physical samples and the land cover classification.

The limitations because of the stripes in the Landsat 7 data have also affected the NDVI results. This is because of these stripes only two separate trend tests for 1992-1999 and 2000-2014 could be done.The spatial resolutions of Landsat 5 and MODIS are different, the NDVI results could not be used in one trend test. Therefore it is not known if there has been a change between 1992-2014.

From the climate station in Karankobar important variables for determining evapotranspiration are missing, such as the number of sunshine hours on a day. Because of this the Blaney Criddle method has been used for determining the evapotranspiration values. However, there are methods available which give more accurate evapotranspiration values. But these methods could not be used because of the lack of data.

To determine if climate change has affected the evapotranspiration, a trend in temperature has been determined. This resulted in that there was no trend. However, there are also other factors which affect the evapotranspiration which could have changed because of climate change as well. For example, the number of sunshine hours and wind speed (Tabari and Hosseinzadeh Talaee, 2014). Because of this it is more difficult to attribute the plausible change in evapotranspiration to climate change or land cover change.

4.3 Potential

An important takeaway from this research is the importance of good data collection. Without quality data it is difficult to research the water balance and its changes in an area. In this research the limitations in data have caused uncertainty in the results. Moreover, because of data inavability it was more difficult to determine trends in the data. Therefore, to be able to do research towards for example the water balance in a catchment, the collection of data should be improved.

5 Conclusion and recommendations

5.1 Conclusion

The objective of this research was to determine if there have been changes in the annual and seasonal runoff and if these changes can be attributed to land cover changes or climate change. In this research the Merawu catchment has been used as a case study.

Firstly the land cover and vegetation density change have been determined. Both the land cover classifications and the normalized difference vegetation index (NDVI) indicate that there has been an increase in forestation in the area in the period 2000-2014. From the land cover changes there is also an indication that there has been deforestation in the period 1992-2000. However, this change is not supported by a change in the NDVI trend analysis. Nevertheless, the land cover classification has a low accuracy so that increases the uncertainty of these land cover changes. Therefore, this research does not prove that there have been land cover changes in the area.

Subsequently, a trend analysis was used to determine if there have been changes in discharge. Based of the data available no trends have been found in seasonal and annual discharge in the periods 1992-2005 and 2005-2014.

To determine the effects of climate change on this catchment the change in rainfall and temperature were determined. For the rainfall a positive annual trend has been found in the period 2003-2014. In the available temperature data no trends have been found. The trend in rainfall does suggest that there has been an effect of climate change on the water balance in this catchment. The absent trend in discharge suggests that the actual evapotranspiration has increased in the area as well. However, a trend in actual evapotranspiration has not been researched.

From this research alone the research objective cannot be answered clearly. This is partially due to the uncertain results. In addition, no trends have been found in the discharge data, so these trends also cannot be attributed to either land cover or climate change. Further research is necessary to determine why the positive trend in rainfall has not resulted in a positive trend in discharge. Additionally, no seasonal trends have been found. Therefore, the sponge effect could not be researched.

5.2 Recommendations

Further research could result in clearer conclusions regarding why there is a a positive trend in rainfall while there is not a positive trend in discharge. It is probable that this is because of an increase in actual evapotranspiration. However, for this research there was not enough data available to determine if there is a trend in actual evapotranspiration with certainty. This is because, there are no years from 2000 onwards with quality data for both the discharge and the rainfall. Therefore, especially the quality of discharge data should be improved.

Even if it would have been possible to determine a trend in actual evapotranspiration, it would not have been possible to attribute this trend to either land cover change or climate change. To attribute this change further research is necessary. Firstly, the accuracy of the land cover classifications should be improved so that the results are less uncertain. The land cover classifications could be improved by including agroforestry in the land cover forestry instead of agriculture. This could improve the land classification because it is difficult to differentiate between forestry and agroforestry in satellite data as they look similar. Although the land use of agroforestry and forestry is different, the land cover characteristics are similar in terms of leaf area and rooting depth. Additionally, it should be determined if there have been changes in water management in the area, as these changes can also affect evapotranspiration.

From this catchment there is currently very little quality data available. This has made this research more difficult. And because of this it has also not been possible to determine if the discharge has been affected by land cover change or climate change. Therefore, an important recommendation based of this research is that the data collection should be improved for this catchment. Furthermore, good data collection is not only important for this catchment, but important everywhere in order to do quality research.

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Zheng, H., Wang, Y., Chen, Y., & Zhao, T. (2016). Effects of large-scale afforestation project on the ecosystem water balance in humid areas: An example for southern china. *Ecological Engineering*, *89*, 103–108. https://doi.org/https://doi.org/10.1016/j.ecoleng.2016.01.013

Appendix A Adaptations and availability of data

In 2011, 2012 and 2016 there are 1 or 2 consecutive days with missing data. Because this is only a short period of time it might be possible to implement this data using the average values of the day before and the day after. To determine if this is possible the linearity of the discharge data has been assessed. This has been done for the year 2008. This year was chosen because this year does not have any missing days and the year is after the discharge data has been automatically recorded.

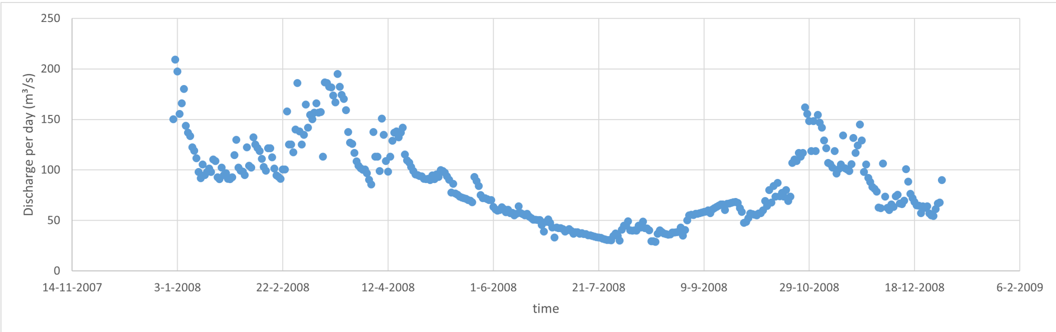


Figure A1: Scatterplot discharge data 2008

Figure A1 represents a scatterplot of the discharge data in 2008. What can be seen in this figure is that the data points close to each other in time often tend to have similar values. This effect is stronger in the dry season than in the wet season. In the wet season there are more outliers. These outliers do not differ more than 50 m^3/s per day. However, on a seasonal or annual average this difference is negligible. Because the data is correlated with time and the effect on the seasonal and annual discharge is small it is chosen to still use the years with missing data for 1 or 2 days. For these days the average value of the day before and after the missing data is used. For which years this is the case can be seen in table A1.

In Table A1 the adaptations in the discharge data are shown. For the years, 2009 and 2013, the formula used for the rating curve was different than from the other years. The correct formula for the rating curve is:

$$Q = C(h - a)^{\beta} \tag{A1}$$

However, for 2009 and 2013 the rating curve was according to the following equation:

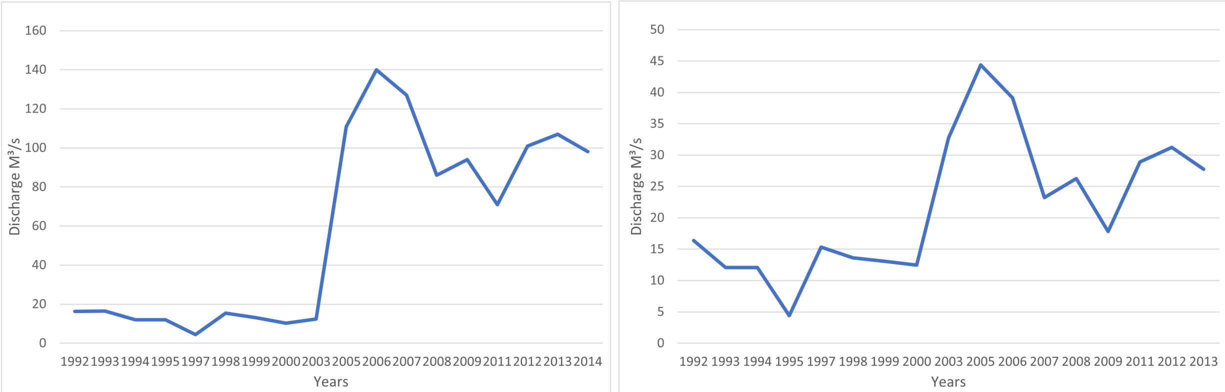
$$Q = \frac{C^{(}h - a)}{\beta} \tag{A2}$$

In the equation for the rating curve C and β are curve constants. And a represents the gauge reading (in m) corresponding to 0 discharge, which is zero for this rating curve. And h is the gauge height (in m). Q is the discharge in m^3/s (Robsen and Reed, 2008).

Table A1: Adaptations in discharge data

Year (and date)	Adaptation
2004	There were two data sets of 2004, one was exactly the same as 2009. The one with an extra day in February was chosen
Oct 2007	The gauge height measurements were not used, while there were measurements. Changed it so that the gauge height measurements are used for the discharge
14-1-2009	The water height measurement was 50 m –> changed to 0.50 m, same as afternoon and the morning after
25-2-2009	The water height measurement was 55 m –>changed to 0.55 m
2009	Changed the rating curve from Q=CR^(G-a)/ B to Q=CR(G-A)^B
29-9-2011	No data for this afternoon, average of morning and evening measurements are used
30-9-2011	No data for this afternoon, average of morning and evening measurements are used
30-5-2012	There was no data for the evening measurement, average of the afternoon and morning after has been used
23-6-2012	The gauge height measurements were not used, while there were measurements. Changed it so that the gauge height measurements are used for the discharge
2013	Changed the rating curve from Q=CR^(G-a)/ B to Q=CR(G-A)^B
31-8-2014	Formula for rating curve was not used for this cell, changed it so that the formula is used now
30-9-2014	Formula for rating curve was not used for this cell, changed it so that the formula is used now
30-8-2017	Measurement in afternoon changed from 56.0 m to 0.56m. In the morning the measurement was 0.57 m and the evening 0.56 m
19-10-2017	Measurement in morning changed from 79 m to 0.79m. The day before the measurement was 0.84 m and the afternoon 0.78 m
31-8-2017	No data for this day, the average of the day before and after has been used
30-3-2016	No data for this day, average of 29th of march and first of april is used
31-3-2016	No data for this day, average of 29th of march and first of april is used
30-4-2016	No data for the evening, average between afternoon and morning following day is used

In addition to the changes already made in the discharge data there is still something wrong with discharge data from 2005 onwards. From 2005 the data becomes around 5 times as high. Because there is no knowledge about any changes in the area which could have resulted in this it is expected that something is wrong with the measurements. In 2008 a different rating curve formula is used than in the other years. In the other years CR is equal to 14.11, α to 0 and β to 2.9. In this rating curve 1.5 meter is added to the water height, this is probably because the measurements start at 1.5 meter. However, in 2008 CR is equal to 9.43, α to 0 and β to 2.9, and 1 meter is added to the water height measurement.These two rating curves give different results. In figure A2a the rating curve is used which was already used for the years 2005-2007 & 2011-2014. This rating curve was used for all discharges after 2005. In figure A2b the rating curve from 2008 was used for all discharges after 2005. However, also with this rating curve there is a big increase in discharge after 2005.



(a) Mean discharges with rating curve which is used 2005-2007 & 2011-2014

(b) Mean discharges with rating curve which is used in 2008

Figure A2: Mean discharges per year with different rating curves from 2005 onwards

Table A2: Data availability rain gauge stations

Year	Banjar-negara	Clangap	Wana-dadi	Karang-kobar	Pagentan	Bawang	Kali-bening	Batur	Pejawaran	Wanayasa	Banjarmangu	Singomerto
1992	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No
1993	Yes	Yes	Yes	No	No	No	No	Mostly**	Yes	Partly*	Yes	No
1994	Yes	Yes	Yes	No	No	No	Yes	Yes	Mostly**	No	Yes	No
1995	Yes	Yes	Yes	No	No	No	No	No	Mostly**	No	Yes	No
1996	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	No
1997	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	No
1998	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
1999	Yes	Yes	Yes	No	Mostly**	Yes	Yes	Mostly**	Yes	No	Yes	No
2000	Yes	Yes	Yes	No	Partly*	Partly*	Yes	No	Yes	No	Yes	No
2001	Yes	Yes	Yes	No	No	No	Yes	No	Yes	No	Yes	No
2002	Yes	Yes	Yes	Yes	No	No	Yes	No	Mostly**	No	Yes	Yes
2003	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	No	Yes	Yes
2004	Yes	Yes	Yes	Yes	No	No	Mostly**	No	Yes	No	Mostly**	Mostly**
2005	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	No	Yes
2006	Yes	Yes	Yes	Yes	No	No	No	No	Mostly**	No	No	Mostly**
2007	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	No	Yes
2008	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	No	Yes
2009	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	No	Yes
2010	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	No	No
2011	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	No	Yes
2012	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	No	Yes
2013	Mostly**	Mostly**	Yes	Yes	No	No	No	No	Yes	No	No	Yes
2014	Mostly**	Mostly**	Yes	Yes	No	No	No	No	No	No	No	Yes

Table A3: Climate data availability

climate stations	years	Temperature	Humidity	PET	Wind	Sunshine
Karankobar	2002-2010	Yes	Yes	No	Yes	No
Singomerto	2003-2009	Yes*	Yes	Sometimes	Yes	No
Singomerto	2002-2003	Yes	Yes	Yes	Yes	No

Table A4: Adaptations in climate data measured at the Karankobar climate station

Date	Adaption
2004 June-December	Temperature data *100, the data was 100 times as small
2005 January-Juli	Temperature data *100, the data was 100 times as small

Appendix B Google Earth Engine coding

B.1 Code for training data

```
Imports (5 entries)
  var imageCollection: ImageCollection "USGS Landsat 8 Level 2, Collection 2, Tier 1"
  var polygon: Table projects/landclassification123/assets/shapefile
  var Forestry: FeatureCollection (96 elements)
  var Settlements: FeatureCollection (80 elements)
  var Agriculture: FeatureCollection (285 elements)

// Include the shapefile of the Merawu catchment
var shp = ee.FeatureCollection(polygon);

function maskL8sr(image) {
  // Bits 3 and 5 are cloud shadow and cloud
  var cloudShadowBitMask = (1 << 3);
  var cloudsBitMask = (1 << 5);
  // Get the pixel QA band.
  var qa = image.select('pixel_qa');
  // Both flags should be set to zero, indicating clear conditions.
  var mask = qa.bitwiseAnd(cloudShadowBitMask).eq(0)
                 .and(qa.bitwiseAnd(cloudsBitMask).eq(0));
  return image.updateMask(mask);
}

// Load Landsat data for the study area
var landsat = ee.ImageCollection("LANDSAT/LC08/C01/T1_SR")
  .filterBounds(shp)
  .filterDate('2019-05-01', '2019-08-31')
  .map(maskL8sr)
  .map(function(image) {
    return image.clip(shp);
  });
```

```
//Load the bands to the map
var visParams = {
  bands: ['B4', 'B3', 'B2'],
  min: 0,
  max: 3000,
  gamma: 1.4,
};
//Add the landsat layer imagery to the map

Map.addLayer(landsat, visParams, 'True Color (432)');
// Center the map on the study area.
Map.centerObject(shp, 11);

//Merge the training points to one collection
var training = Forestry
                    .merge(Agriculture)
                   .merge(Settlements)


Export.table.toAsset({
 collection: training,
  description: 'LCtraining15-06',
 assetId: 'LCtraining15-06'

});
```

B.2 Code for supervised classification

```
Imports (6 entries)
 var polygon: Table projects/landclassification123/assets/shapefile
 var imageCollection: (Deprecated) ImageCollection "USGS Landsat 8 Surface Reflecta…
 var table5: Table users/djhthus/Trainingdata15-06
 var table7: Table users/djhthus/Training16-06
 var table9: Table users/djhthus/finalsample
 var table10: Table users/djhthus/NewestTraining16-06
//Load the study area map
var shp = ee.FeatureCollection(polygon);
// Center the map on the study area.
Map.centerObject(shp, 11);

function maskL8sr(image) {
  // Bits 3 and 5 are cloud shadow and cloud, respectively.
  var cloudShadowBitMask = (1 << 3);
  var cloudsBitMask = (1 << 5);
  // Get the pixel QA band.
  var qa = image.select('QA_PIXEL');
  // Both flags should be set to zero, indicating clear conditions.
  var mask = qa.bitwiseAnd(cloudShadowBitMask).eq(0)
                 .and(qa.bitwiseAnd(cloudsBitMask).eq(0));
  return image.updateMask(mask);
}
//Load landsat data, adjust the dates for the year in question, and load the correct
// landsat data for the year in question
var landsat = ee.ImageCollection('LANDSAT/LC08/C02/T1_L2')
```

```
      .filterDate('2014-05-01', '2014-08-31')
      .map(maskL8sr)
      .filterBounds(shp)
       .map(function(image) {
                    return image.clip(shp)});

// Applies scaling factors, which is necessary to prepare the imagery data before use
function applyScaleFactors(image) {
  var opticalBands = image.select('SR_B.').multiply(0.0000275).add(-0.2);
  var thermalBands = image.select('ST_B.*').multiply(0.00341802).add(149.0);
  return image.addBands(opticalBands, null, true)
              .addBands(thermalBands, null, true);
}

var landsatscaled = landsat.map(applyScaleFactors);

// Define the visualization parameters
var bands = ['SR_B4', 'SR_B3', 'SR_B2'];
var visParams = {
  min: 0,
  max: 3000,
  gamma: 1.4,
};

// Load training points
var points = ee.FeatureCollection(table10);
```

```

// This property stores the land cover labels as consecutive
// integers starting from zero.
var label = 'label';

var landsatImage = landsatscaled.median();

//combine the training data and the landsat image
var training = landsatImage.select(bands).sampleRegions({
  collection: points,
  properties: [label],
  scale: 30
});

// Train a CART classifier with default parameters.
var trained = ee.Classifier.smileCart().train(training, label, bands)

// Classify the image with the same bands used for training.
var classified = landsatImage.select(bands).classify(trained);
// Display the inputs and the results.
Map.addLayer(landsatImage,
             {bands: ['SR_B4', 'SR_B3', 'SR_B2'], min: 0, max: 0.25},
             'image');
Map.addLayer(classified,
             {min: 0, max: 2, palette: ['yellow','green', 'red']},
             'classification');
```

```
 // Define the legend
var legendDict = {
  'Agriculture': { color: 'yellow', value: 0 },
  'Forestry': { color: 'green', value: 1 },
  'Settlements': { color: 'red', value: 2 },
};

// Create the legend panel.
var legend = ui.Panel({
  style: {
    position: 'bottom-right',
    padding: '8px',
    width: '200px'
  }
});
// Iterate over the legend dictionary and add color and label to the legend panel.
for (var key in legendDict) {
  var classColor = legendDict[key].color;
  var classValue = legendDict[key].value;

  // Create a panel for the legend item.
  var item = ui.Panel({
    style: {
      margin: '0 0 4px 0',
      padding: '0 0 0 4px',
      color: classColor
```

```
    }
  });
  // Create the color box for the legend item.
  var colorBox = ui.Label({
    style: {
      backgroundColor: classColor,
      padding: '8px',
      margin: '0 4px 0 0'
    }
  });

  // Create the label for the legend item.
  var label = ui.Label({
    value: key,
    style: { margin: '0 0 0 4px' }
  });
 // Add the color box and label to the legend item.
  item.add(colorBox);
  item.add(label);
// Add the legend item to the legend panel.
  legend.add(item);
}
// Add the legend panel to the map.
Map.add(legend);
```

```

//Calculate the area for each landcover class
var areaDict = {};
for (var key in legendDict) {
  var classColor = legendDict[key].color;
  var classValue = legendDict[key].value;
  var mask = classified.eq(classValue);
  var area = mask.multiply(ee.Image.pixelArea()).divide(10000).rename('area_ha');
  areaDict[key] = area.reduceRegion({
    reducer: ee.Reducer.sum(),
    geometry: shp,
  scale: 30,
   maxPixels: 1e13
  }).get('area_ha');
}

// Create a feature for each landcover class with its corresponding area
var features = [];
for (var key in areaDict) {
 var feature = ee.Feature(null, {
    'Landcover': key,
    'Area_ha': areaDict[key]
  });
  features.push(feature);
}
```

```
// Create a feature collection from the features
var featureCollection = ee.FeatureCollection(features);

// Print the feature collection
print('Landcover Areas:', featureCollection);

// Export the feature collection to Google Drive
Export.table.toDrive({
collection: featureCollection,
 description: 'Landcover_Areas',
 fileFormat: 'CSV'
});

//testing the sample points

// include sample points
var sample = ee.FeatureCollection(table9)
Map.addLayer(sample,
         {'color': 'black'},
          'Geometry [black]: point');
// Extract land cover values at sample points

var sampledLandCover = classified.sampleRegions({
  collection: sample,
  scale: 100, // Resolution of the land cover dataset
 tileScale: 16 // Adjust this value to control memory usage
```

```
});

// Perform land cover classification based on the extracted values
var classifiedPoints = sampledLandCover.map(function(feature) {
 var landCoverValue = feature.get('classified');
 var landCoverClass = legendDict[landCoverValue];
 return feature.set('landcover_class', landCoverClass);
});

// Export the classified points to Google Drive
Export.table.toDrive({
  collection: classifiedPoints,
 description: 'classified_points',
 folder: 'LandCoverClassifications',
 fileFormat: 'CSV'
});
 //Export the classified image to an Earth Engine asset
 Export.image.toAsset({
  image: classified,
  description: 'Landcover_2021',
  assetId: 'users/your_username/Landcover_2021'
});
```

B.3 Code for NDVI

```
// Load shapefile of Merawu catchment
var shp = ee.FeatureCollection(polygon);
Map.addLayer(shp, {}, 'My Polygon');

// How to Extract Monthly Normalized Difference Vegetation Index (NDVI)

// 2. Select NDVI values for a specific year
var modis = ee.ImageCollection("MODIS/MOD09GA_006_NDVI")
            .select('NDVI')
            .filterDate('2001-01-01','2001-12-31')
            .map(function(img){
              var d = ee.Date(ee.Number(img.get('system:time_start')));
              var m = ee.Number(d.get('month'));
              var y = ee.Number(d.get('year'));
              return img.set({'month':m, 'year':y});
            });
//Select year and months
var months = ee.List.sequence(1, 12);
var years = ee.List([2000]);

var byYearMonth = ee.ImageCollection.fromImages(
      years.map(function(y){
        return months.map(function(m) {
            return modis.filterMetadata('year', 'equals', y)
                        .filterMetadata('month', 'equals', m)
                        .select('NDVI').mean()
```

```
                        .set('year', y)
                        .set('month', m)
                        .set('date', ee.Date.fromYMD(y,m,1));
        });
      }).flatten()
    );

//print("byYearMonth", byYearMonth.first());

var proj = ee.Image(modis.first()).projection()

var NDVI_merawu = byYearMonth.map(function(img) {
  var features = shp.map(function(f) {return f.set('date', img.get('date'), 'month', img.get('month'), 'year', img.get('year'))})
  return img.reduceRegions(features, ee.Reducer.mean(), 250, proj);//.select("NDVI")
}).flatten();
print(NDVI_merawu.limit(10));
//print(NDVI.limit(10).getDownloadURL('csv'));

// 3. Export NDVI as CSV file format
Export.table(NDVI_merawu, 'NDVI_merawu', {fileFormat: 'CSV'});
//print("NDVI Brazil", NDVI_Brazil.limit(5).getDownloadURL('csv'));
```

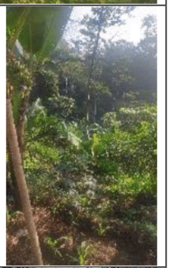
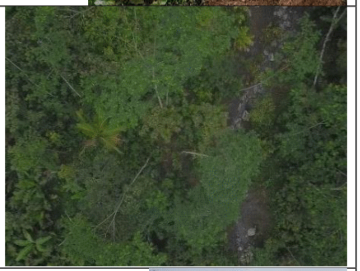
B.4 Code for LST

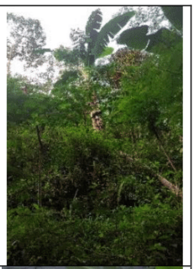
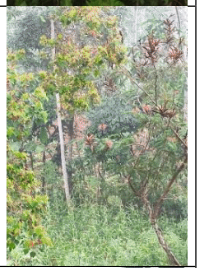
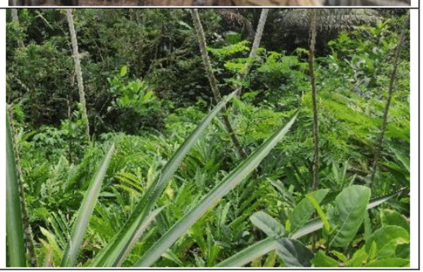
```
Imports (1 entry)
var polygon: Table projects/landclassification123/assets/shapefile
// Load Merawu shapefile
var shp = ee.FeatureCollection(polygon);
Map.addLayer(shp, {}, 'My Polygon');

// Center on the Merawu catchment
Map.centerObject(shp,11);
// 2. Monthly Time Series Land Surface Time
var modis = ee.ImageCollection('MODIS/MOD11A2')
            .select('LST_Day_1km')
            .filterDate('2001-01-01','2001-12-31')
            .filterBounds(shp);
//Find the LST values in celsius
var LST_Res = function(image) {
    var LST_temp = image.toFloat().multiply(0.02).subtract(273.15);
    image = image.addBands(LST_temp);
    return image;
}
var LST_new = modis.map(LST_Res);
// Get the LST values for the right day
var modis = LST_new.select('LST_Day_1km_1')
            .map(function(img){
              var d = ee.Date(ee.Number(img.get('system:time_start')));
              var m = ee.Number(d.get('month'));
              var y = ee.Number(d.get('year'));
              return img.set({'month':m, 'year':y});
            });

var months = ee.List.sequence(1, 12);
var years = ee.List([ 2001]);

var byYearMonth = ee.ImageCollection.fromImages(
      years.map(function(y){
        return months.map(function(m) {
            return modis.filterMetadata('year', 'equals', y)
                        .filterMetadata('month', 'equals', m)
                        .select('LST_Day_1km_1').mean()
                        .set('year', y)
                        .set('month', m)
                        .set('date', ee.Date.fromYMD(y,m,1));
        });
      }).flatten()
    );

print("byYearMonth", byYearMonth.first());

var proj = ee.Image(modis.first()).projection()

var lstshp = byYearMonth.map(function(img) {
  var features = shp.map(function(f) {return f.set('date', img.get('date'),
  'month', img.get('month'), 'year', img.get('year'))})
  return img.reduceRegions(features, ee.Reducer.mean(), 250, proj);//.select("EVI")
}).flatten();
//print("lstBrazil Mean", lstBrazil.limit(10));
//print("lstBrazil Mean Download", LlstBrazil.limit(10).getDownloadURL('csv'));

// 3. Export LST
Export.table(lstshp, 'lstshp', {fileFormat: 'CSV'});
```

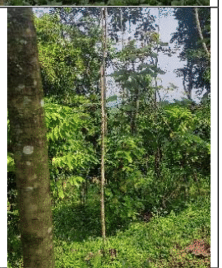
Appendix C Samples for accuracy assessment

Table C1: Table of land cover samples with pictures

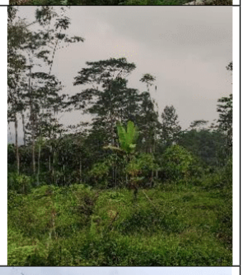
Number (in map)	Classification in field	Classification map 1	Classification map 2	latitude	longitude	
4	Agroforestry (salak)	Forest	Forest	-7.29818	109.7635	
5	Forestry	Forest	Forest	-7.2611	109.742	
6	Agriculture (cropland)	Agriculture	Agriculture	-7.2269	109.7601	
9	Agriculture (rice field)	Forest	Forest	-7.30915	109.7616	
10	Agroforestry	Agriculture	Forest	-7.3091	109.7111	

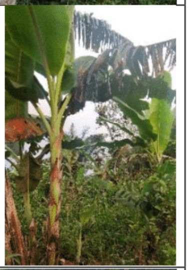
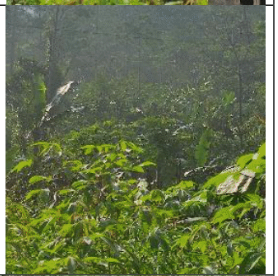
15	Forestry	Agriculture	Forest	-7.28571	109.7638	
19	Agroforestry (banana's, mixed)	Agriculture	Forest	-7.28205	109.7651	
20	Agriculture (cropland)	Settlement	Agriculture	-7.20129	109.8098	
21	Forestry	Forest	Forest	-7.31123	109.7137	
24	agriculture (cropland)	Agriculture	Agriculture	-7.1972	109.7982	
25	Agriculture (cropland)	Agriculture	Agriculture	-7.22303	109.8304	

26	agroforestry (salak, coconut)	Agriculture	Forest	- 7.26545	109.703	
30	Agroforestry	Agriculture	Agriculture	- 7.32318	109.7146	
34	agriculture	Forest	Forest	- 7.26306	109.7535	
38	settlements (surrounded by agriculture)	Agriculture	Agriculture	- 7.26779	109.7164	
39	settlements	Bareland	settlements	- 7.35499	109.7171	
40	agriculture (pineapple, ginger) agroforestry	Agriculture	Agriculture	- 7.35288	109.7246	

41	Agroforestry (salak bamboo coconut)	Agriculture	Agriculture	-7.31886	109.7113	
44	agriculture	Shrubland	Forest	-7.24132	109.7551	
45	settlement	Agriculture	settlements	-7.20235	109.8172	
46	agriculture (mixed) (crop)	Agriculture	Agriculture	-7.35224	109.6879	
48	settlements	Agriculture	Agriculture	-7.35485	109.691	
50	agroforestry (salak, coconot)	Agriculture	Agriculture	-7.3583	109.7063	

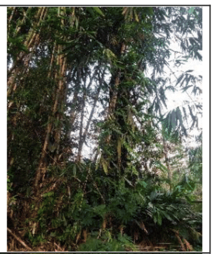
54	settlements	Agriculture	Agriculture	-7.26519	109.7978	
56	agriculture (salak)	Agriculture	Agriculture	-7.3007	109.8026	
57	agriculture (cropland)	Agriculture	Agriculture	-7.2475	109.8029	
58	agriculutre (rice fields)	Agriculture	Forest	-7.25902	109.7733	
60	agroforestry	Agriculture	Forest	-7.34008	109.7036	
61	agriculture (cropland)	Forest	Agriculture	-7.22565	109.7571	

62	agriculture	Agriculture	Agriculture	-7.25779	109.7769	
63	agroforestry	Agriculture	Agriculture	-7.27252	109.747	
64	settlements	Shrubland	Agriculture	-7.25522	109.7789	
65	agriculture (cropland)	Agriculture	Agriculture	-7.19829	109.7795	
66	forestry	Agriculture	Forest	-7.19063	109.7455	
68	Agriculture (Salak)	Agriculture	Forest	-7.30724	109.7981	

73	agriculture (cropland)	Forest	Agriculture	-7.25289	109.7932	
76	agroforestry	Agriculture	Forest	-7.30297	109.718	
77	agriculture (papaia, corn, banana)	Forest	Agriculture	-7.27118	109.7379	
82	agriculture (cropland)	Bareland	Agriculture	-7.21293	109.7673	
83	mixed agriculture	Agriculture	Agriculture	-7.2773	109.7615	
84	agroforestry (salak)	Agriculture	Agriculture	-7.35412	109.7178	

85	settlements	Settlement	settlements	- 7.27117	109.7328	
86	Agriculture	Forest	Forest	- 7.28726	109.7027	
88	Agriculture	Bareland	Forest	- 7.26945	109.715	
91	Forestry	Forest	Forest	- 7.30857	109.7583	
92	Agriculture (salak)	Settlement	settlements	- 7.34767	109.7352	
96	Agriculture (cropland)	Agriculture	Agriculture	- 7.20402	109.7975	

97	Agroforestry	Agriculture	Agriculture	-7.31092	109.7595		
99	settlements	Agriculture	Agriculture	-7.35021	109.7011		
100	settlements	Settlement	settlements	-7.28918	109.6996		
101	agriculture (cropland)	Agriculture	Agriculture	-7.26103	109.7975		
103	settlements	Settlement	settlements	-7.20501	109.8284		
104	Agriculture (cropland)	Agriculture	Agriculture	-7.22556	109.8293		

113	agroforestry (bamboo)	Agriculture	Forest	-7.26926	109.7115	
114	agroforestry (salak)	Agriculture	Agriculture	-7.29413	109.6992	
115	agriculture (cropland)	Agriculture	Agriculture	-7.2581	109.8152	
120	Agriculture (cropland)	Agriculture	Agriculture	-7.20038	109.7597	
121	Agroforestry(salak)	Agriculture	Agriculture	-7.35071	109.6969	
122	settlements	Forest	Agriculture	-7.26389	109.7547	

123	Forestry	Shrubland	Forest	-7.2713	109.7549	
124	Forestry	Forest	Forest	-7.30968	109.7112