ANALYSING LAND USE CHANGE EFFECTS ON DISCHARGE OF THE PAWAN RIVER

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In collaboration with Witteveen+Bos

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Preface

This Bachelor thesis project marks the end to my time studying at the University of Twente. These past 4 years have been an incredible journey full of meeting new friends, having new experiences, and most importantly learning at a higher level of education. None of this would be possible without God strengthening me and providing guidance and wisdom throughout this whole process. Along with my parents and family, who have only given their never-ending and unconditional love and support. Also, thank you to my girlfriend Celine, who has been a dependable support system.

I would like to take this opportunity to express gratitude to several people who have made this Bachelor thesis project an enlightening and educational experience as a final assessment for my BSc in Civil Engineering. Firstly, I want to thank Pieter Roos for being an exceptional supervisor and for always lifting my spirits. Unfortunately, our weekly coffee meetings were cut short due to going back to Indonesia. Secondly, for the external supervisor, Joost Noordemeer who welcomed me, made this whole project possible, and provided a different perspective when it came to this study. Additionally, Daan te Witt from Witteveen+Bos who helped with the modelling section of this study. Other notable mentions from Witteveen+Bos Indonesia are Weny Sihombing who accompanied and supervised me during the site visit to Ketapang, and Antonio Dewabrata who helped with modelling in the Python language. I also want to thank AidEnvironment for welcoming us during our site visit to Ketapang. They also made it possible for me to interview several governmental agencies which was vital for this study's success. Lastly, for my study advisor Judith Roos, who has helped me countless times during my studies.

Summary

Introduction and Research Context

Indonesia regularly experiences floods due to numerous factors. Ketapang, West Kalimantan is an area that is significantly exposed to flood risk. AidEnvironment staff members who resided in the study area experienced a flood disaster that devastated their homes. With the support of the government of Ketapang, AidEnvironment is tasked to figure out methods to mitigate floods in Ketapang. They reached out to Witteveen+Bos who prompted the beginning of this Bachelor thesis project.

The Ketapang region has a large catchment area called the Pawan Catchment. This catchment area collects rainfall water that flows into the Pawan River. The catchment area is observed to have experienced significant land use changes from forests to palm oil plantations. Currently, the land use of the catchment is dominated by palm oil plantations.

Research Objective

The goal of this thesis project is to discover how land use has changed in the Pawan catchment and to understand the effects of land use change on the discharge of the Pawan River. Then, the study aims to identify an intervention that can be implemented on Ketapang through a qualitative and quantitative analysis.

Methodology

The methodology of this study contains two types of analyses, qualitative and quantitative analysis. The quantitative analysis utilized a hydrological model called Wflow. Meanwhile, the qualitative analysis underwent a site visit to Ketapang, where unstructured interviews with stakeholders took place. The site visit was intended for data collection that was necessary for model validation.

Conclusion

This study shows how plantation areas increased drastically from 1990-2020. Discharge has also increased in correlation to plantation areas. Therefore, the intervention scenario was a reforestation strategy. It was found that when reforested, discharge was decreased, although the results were relatively small. This coincides with the increase in discharge due to plantation areas, which were also relatively small.

Recommendation

Discharge measurements gathered from the Ketapang government was insufficient to calibrate and validate the model. This could explain why the change in discharge was relatively small, as the Wflow may not simulate Ketapang conditions to an accurate degree. Therefore, for future use of the model, it should be calibrated and validated, provided data is available.

For a more effective mitigation strategy, several interventions must be implemented. The use of a hydraulic model may be suitable to test different interventions directed to the Pawan River. In combination with land use interventions, the effect may be compounded and be more apparent in the analysis.

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1 Introduction

1.1 Background

Rivers have played an important role in the growth of human civilizations. Since ancient times, rivers have been used for agriculture and economical purposes. Nowadays, many cities are built near river systems for their water resources. These cities can innovate and develop with the help of water resources from the river systems (Jinxin, Deshan, Ijaz, & Mei, 2015).

With building cities near bodies of water comes the risk of flooding. Flooding can occur due to many different factors. Natural driving factors of flooding can be divided into pluvial, fluvial, and coastal flooding (https://www.floodinfo.ie/). Pluvial floods occur due to extreme rainfall events which may exceed the soil infiltration and storage capacity of a catchment. Fluvial floods stem from water exceeding the capacity of a river, causing water to overflow from the riverbanks. This can also be due to blockage or high tides that prevent water from flowing into the sea. Coastal flooding is induced through sea level rise and occurs when sea levels are higher than the level of land, overtopping the coast. Additionally, storm surges and extreme weather conditions may play a role in worsening these effects. In many cases, floods are a combination of two or all these driving factors. This case study will be dominated by factors of fluvial floods.

Floods in Indonesia can be explained by several factors being from intense rain, land conversion, poor river management, and coastal inundation (Nugraheni, Suyatna, Setiawan, & Abdurrahman, 2022). According to the National Board for Disaster Management (Badan Nasional Penanggulan Bencana, BNPB) (2023), during 2014-2023, Indonesia has suffered from a staggering 8067 flood disasters. One area particularly sensitive to flood disasters is West Kalimantan, Indonesia (Figure 1), which boasts a population of 5.069 million people. BNPB (2023) recorded 223 accounts of flood disasters in the West Kalimantan region from 2014-2023. AidEnvironment (2023) reports that an approximate 50% of the population in West Kalimantan are exposed to significant flood risk. Considering these issues, the prevalence rate of floods in West Kalimantan is a truly dire situation when taken into account its population.

In October 2022, a staff member of AidEnvironment who resides in Ketapang, Kalimantan experienced a flood event that devastated their residential house. This led to one of the governmental heads of Ketapang approaching AidEnvironment to discuss ways of solving inundation problems in Ketapang. Consequently, Witteveen+Bos was brought into the project as a consultant, who made this project available as a bachelor thesis.

1.2 Involved Parties

This project was commissioned and supervised by the engineering consultancy company Witteveen+Bos. Witteveen+Bos was informed and brought into this project by AidEnvironment. AidEnvironment is a non-governmental organization (NGO), with the focus of conservation of nature. This NGO has done work in the region of West Kalimantan on the conservation of orangutans. Provided this study produces promising results, funding may be granted by the Netherlands Enterprise Agency (RVO) to AidEnvironment with the aid of Witteveen+Bos as a consultant. The outcome of this study should benefit the city of Ketapang, in applying sustainable construction methods, in line with the government's plan to build with its surrounding nature. Furthermore, the outcome of this project is vital for stakeholders in the area, who depend on land use and the river for economical purposes (e.g., palm oil plantations, fishermen).

2 Research Context

2.1 Study Area

Figure 1 - Map of Indonesia with West Kalimantan highlighted in red

Kalimantan is part of the large island of Borneo, located in the north of Indonesia, shown in Figure 1. The province of West Kalimantan, highlighted by red in Figure 1, has an area of 14.73 million hectares, with 0.83% of it used as urban areas. The Ketapang region is the third largest settlement in the province. The regency of Ketapang is shown by the white outlined area in Figure 2. Blue highlighted areas are the parts of the city prone to flooding. The most notable area is the Delta Pawan also known as Ketapang City. Preliminary observations made from AidEnvironment identified heavy rainfall and sea tides as two of the main causes of flooding in Ketapang City. Due to increasing levels of precipitation and sea levels induced by climate change, this study will investigate the land use of the Ketapang region and its effects towards discharge of the Pawan River.

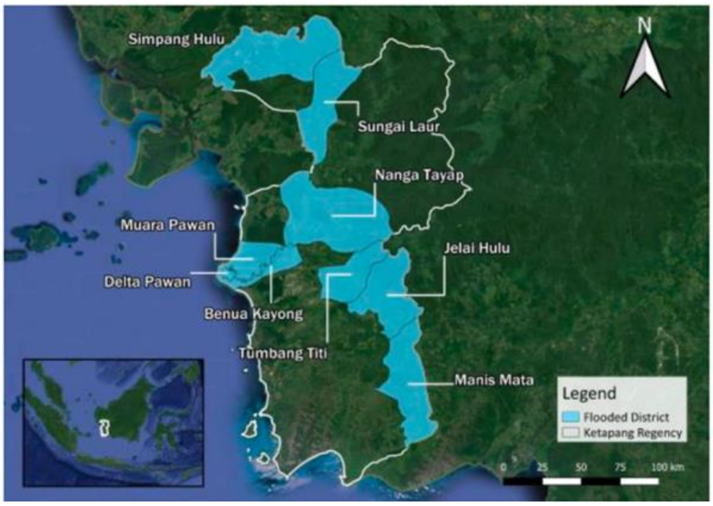

Figure 2 - Ketapang region shown in the white outlined area, with blue highlighted areas being prone to flooding (AidEnvironment, 2023)

Figure 3 - Overview of the Pawan River system surrounding Ketapang city (AidEnvironment, 2023)

Figure 3 depicts the geographical characteristics of the Pawan River that runs through the region of Ketapang. The river is 197 kilometres long, splitting the region between Ketapang city and the Karimata Strait (https://kalbarprov.go.id/page/geografis). The Pawan River has an estimated average discharge of 1,215 m^3/s (Wikipedia, 2023). Kendang Kerbau River is a tributary of the Pawan River, which surrounds Ketapang City; hence, this area is called Delta Pawan. The local population depends on the river for freshwater, transportation of goods, fish, agriculture, and economic development (Harfiyanto, Nurhayati, & Masrudi, 2020).

2.2 Catchment Area

To analyse the hydrological conditions of the study area, a catchment will be studied. Figure 4 shows the catchment area this project will focus on. The catchment is called the Pawan catchment, which is the area where precipitation is collected in the Ketapang region. This catchment consists of urban areas and concession dominated lands. Delta Pawan or Ketapang city is located at the bottom left corner of the Pawan catchment. The land use of the Pawan catchment is observed to have experienced significant conversion from rainforests into palm plantations. This will be discussed in section 3.

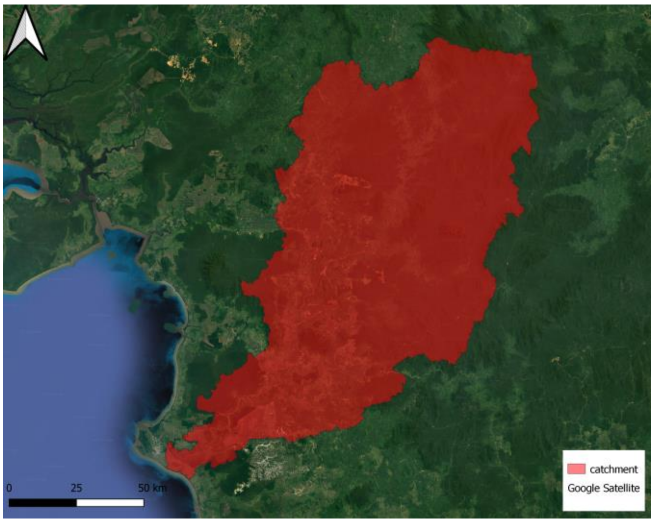

Figure 4 - Pawan Catchment of the Ketapang region

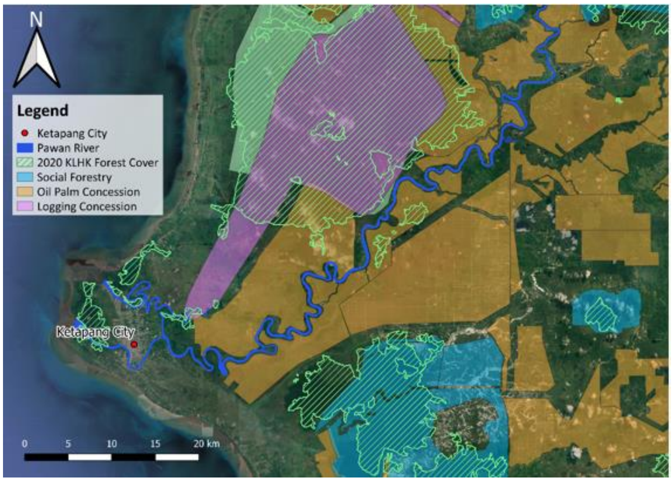

Figure 5 - Land use of the Pawan catchment, shown mostly dominated by concessions (AidEnvironment, 2023)

Figure 5 depicts the land use within the Pawan catchment. It can be concluded that most of the land use is dominated by a palm oil concession and timber concessions in the area. This means that over the years, this area has experienced significant land use conversions that may have an impact on the river downstream. AidEnvironment has formed good relations with a palm oil concession in the area called PT Aartu Energy Resources and believes they may give up their land for conversion with the purpose of mitigation of floods. The discussion of the changes in land use throughout the years will be in the results section, as well as the effectiveness of converting the concession area of PT Aartu on decreasing discharge into the Pawan River.

Furthermore, there exists several villages within the Pawan catchment. Figure 6 depicts the locations of Tanjung Pura and Mayak village, located on the banks of the Pawan River. Villagers believe that floods are worse because of the combined effects high sea tides and heavy precipitation upstream. In addition, the effects of deforestation due to forest clearing and fires is believed to play a significant role. These villages rely on fishing as their primary economic activity, which is hindered due to flood events. The head of Tanjung Pura village mentioned the worst floods occurred during the October 2022 and March 2023. In both instances, all 300 families living in the Tanjung Pura village were affected by the flood event. The impact of floods on these villages further magnifies the magnitude of the flooding problem imposed to the region of Ketapang.

Figure 6 - Location and boundaries of Tanjung Pura and Mayak Village in relation to the Pawan River

2.3 Literature Review on possible factors worsening inundation

Flood dynamics in West Kalimantan, Indonesia, particularly in the Ketapang region, are influenced by different factors. These include deforestation, changing land use, sea level rise, and land subsidence. This literature review aims to understand these factors with their impacts to allow for a formulation of mitigation strategy for the Ketapang region.

With West Kalimantan being mostly forest, it faces the reoccurring issue of deforestation. Koyuncu and Yilmaz (2008) states that Indonesia has the world's second highest rate of deforestation. This is caused by factors of population growth, agriculture, and economic growth attributed to production forests (e.g., palm oil & timber), and mining activities (Medrilzam et al., 2017 & Yamamoto, 2023). These deforested areas experience land use change into production forests, urban areas, etc. Subsequently, Indonesia highly depends on crude oil production for economic growth (Brehm & Brehm, 2022). Consequently, the expansion of palm oil plantations has caused conversions of mangrove forests in the Kalimantan islands. It was estimated that 48,000 ha of mangrove was lost between 2000 and 2012 (Yamamoto, 2023). Additionally, loss of mangrove regions induces a decrease in fish yield for fishermen, further decreasing the income and quality of living in the region (Yamamoto, 2023).

Impacts of deforestation towards inundation is not a new subject. The significance of deforestation on flood effects was studied by Bruijnzeel (2004), focusing on the difference between untouched forests and deforested regions. The study discovered severe effects on soil that may contribute to flood, specifically due to rainfall. A change in land use due to forest clearing reduces infiltration capabilities as well as the retention ability of the soil. Resulting in degradation of soil which causes higher discharge into a river, further worsening flood risk. However, the effects of land topography on sediment yield are not well-studied in tropical places. Tropical regions are often characterized by complex terrain, making it difficult to conduct accurate measurements. However, a main indicator of sediment transport is discharge. Steeper and uneven geographical conditions can increase fluvial erosion by inducing higher discharge (Das et al., 2023). This is evident in Figure 8, depicting the eroded riverbank of Tanjung Pura village.

The paper by Bruijnzeel (2004) found that overall land use change in a forest can increase sediment yield by 10-20 times in comparison to an undisturbed forest. A change in land use may increase sediment transported downstream of the river, inducing an increase in sediment transport. This is not desirable as it may increase in sediment build up in the river, which may increase the height of the riverbed and narrow the width of the river, thus decreasing total capacity of the river. The increase in sediment yield is particularly significant for this case study, where the upstream catchment in the Pawan River experienced land use changes. AidEnvironment found evidence of sediment build-up in the form of sand deposits, which reduces the capacity of the river and induces a risk of flooding.

Furthermore, many illegal mines, may it be for gold or other minerals, exists within the forest. Their activities are often unknown and can lead to further deforestation. Since these are illegal mines, the waste product of sediments is discarded without regulation, possibly into the river system. Subsequently, the sediments transported downstream from these mining activities may induce further damage in the river system (conservationists of a palm oil plantation, pers. comm).

The Indonesian Climate Change Sectoral Roadmap (ICCSR) projected an increase of rainfall in the Kalimantan region due to climate change. Moreover, sea level rise remains to be a prevalent issue in the world and is projected to worsen in the future due to the melting of glacier ice caps (Suroso, Hadi, & Salim, 2009). As shown in Figure 2, the Ketapang region has the Pawan River that connects to the sea. The flood risk from this situation are the backwater effects that may take place in the event of high tides (Phillips, 2018). With increasing sea levels each year, measures must be implemented to prevent risks from coastal inundation. The combination of the decreased river capacity from sediment build-up and backwater effects in the Pawan River can lead to additional flooding to Ketapang City.

Land subsidence is another issue Indonesia has faced. Batubara et al. (2023) studied land subsidence in Jakarta, the capital city of Indonesia. Land subsidence is induced by two anthropogenic factors, being weight of the buildings and groundwater extraction. Subsiding land increases the vulnerability of an area against floods. Triana and Wahyudi (2020) studied the relation between sea level rise and land subsidence, finding a positive correlation. With the increasing volume of groundwater extraction and overall development, land in Indonesia is subsiding slowly. With increasing sea levels, when combined with subsiding land may further worsen floods.

Unfortunately, drainage conditions in Ketapang are quite poor. Many drainage channels are disconnected, clogged, and are often blocked. It can be blocked by roads or structures that were built by civilians in the area (PUTR-SDA, pers. comm). Nugraheni et al. (2022) conducted a study on different regions in Indonesia in need of water defences. This study compared different regions in Indonesia using measures from a CLEAR model, focusing on community participation, and a CLUES model, focusing on the conversion of land use. Findings of the study suggested that the combination of both measures will be most effective. This conclusion was proven in Pesawaran, Lampung, Indonesia, where members of the community participated in drainage cleaning to mitigate floods. For this research project, it can be suggested that a land use conversion from one of the concessions dominating the upstream area (Figure 4) may be an effective solution when combined with effective improvements on the drainage system in Ketapang.

From the knowledge above, we now know that the cause of flooding in Ketapang cannot be solely blamed on a singular factor. Deforestation contributes to soil degradation while causing further damage by increasing sediment transport downstream. Moreover, factors of sea level rise and urban drainage must be addressed to fully understand the extent of Ketapang's ongoing flood problems. Only then will it be possible to formulate strategies that may mitigate inundation in Ketapang, Kalimantan, Indonesia. This case study will focus on the factor of land use change from deforestation for a mitigating solution.

3 Research Dimensions

3.1 Problem Statement

The region of Ketapang regularly experiences flood events, devastating its population and hindering further developments in the region. In recent decades there has been extreme land use changes due to the expansion of palm plantations. In combination with climate change and sea level rise, it is unknown which factor directly contributes to worsened inundation. It is therefore imperative that new water management solutions be developed to ensure the safety of its population from flood risks.

3.2 Research Objective

The research objective is (1) to discover the contributing factors inducing a change in land use of the Ketapang region; (2) to understand how land use change affects discharge of the Pawan River; and (3) to identify an intervention for Ketapang, through a combination of qualitative and quantitative analysis.

3.3 Research Questions

The main research questions addressed in this study are listed below.

1. How has land use changed from the past and present situation in Ketapang?
2. How does land use change affect discharge of the Pawan River?
3. What type of intervention may mitigate floods in Ketapang when modelled in Wflow?

The first research question aims to identify the main factor inducing land use changes in Ketapang. The second research question pertains to modelling past and present situations of Ketapang. Peak discharges will then be compared to see how discharge was affected. The third research question relates to identifying an intervention that can be applied to Ketapang, analysed through the Wflow model.

This project involves a series of quantitative and qualitative analyses, including a site visit to the Ketapang region. The utilization of a model is necessary to predict discharge conditions of the Pawan River. This report will detail the accounts of acquiring discharge data from governmental agencies. One thing to be aware of is that Indonesian government data underestimates the impact of flooding on its population by 10-100 times less than other reports (Wells, et al., 2016). With West Kalimantan undergoing land use changes in recent decades, the use of a model may simulate its existing conditions and provide insight that may not be possible due to incomplete measurements in the region, while enabling the simulation of interventions that may be suitable for Ketapang.

4 Methodology and Theoretical Framework

The combination of quantitative and qualitative analysis will be presented in this section. This study is carried out with the usage of a model, which will utilize the Wflow open-source model. In this section, the method of modelling and analysing different scenarios of land use against its effects on discharge of the Pawan River will be elaborated.

4.1 Model Structure

Wflow is a hydrological modelling framework that can simulate water balance and flow at a catchment scale. This tool is valuable for this research as it can aid in understanding factors that cause peak discharges. It is important to note that Wflow is not a hydraulic model; therefore, it produces discharge as a main output and is not able to predict water levels and overflowing from a river.

4.1.1 Supporting Theory

The advantage of being an open-source model is that Wflow has many modules applicable to various scenarios with different characteristics such as topography, climatology, and meteorology. The module utilized for this project is the wflow_sbm module. This is based on the bucket model theory, as depicted in Figure 7. The catchment of the Pawan River will act as the bucket where it collects precipitation that falls into the catchment. Water then flows through the catchment and into the river. Within the catchment, there are various layers through which water flows. This includes different characteristics of soils, amount of trees, and the general topography of the environment (e.g., slope & roughness).

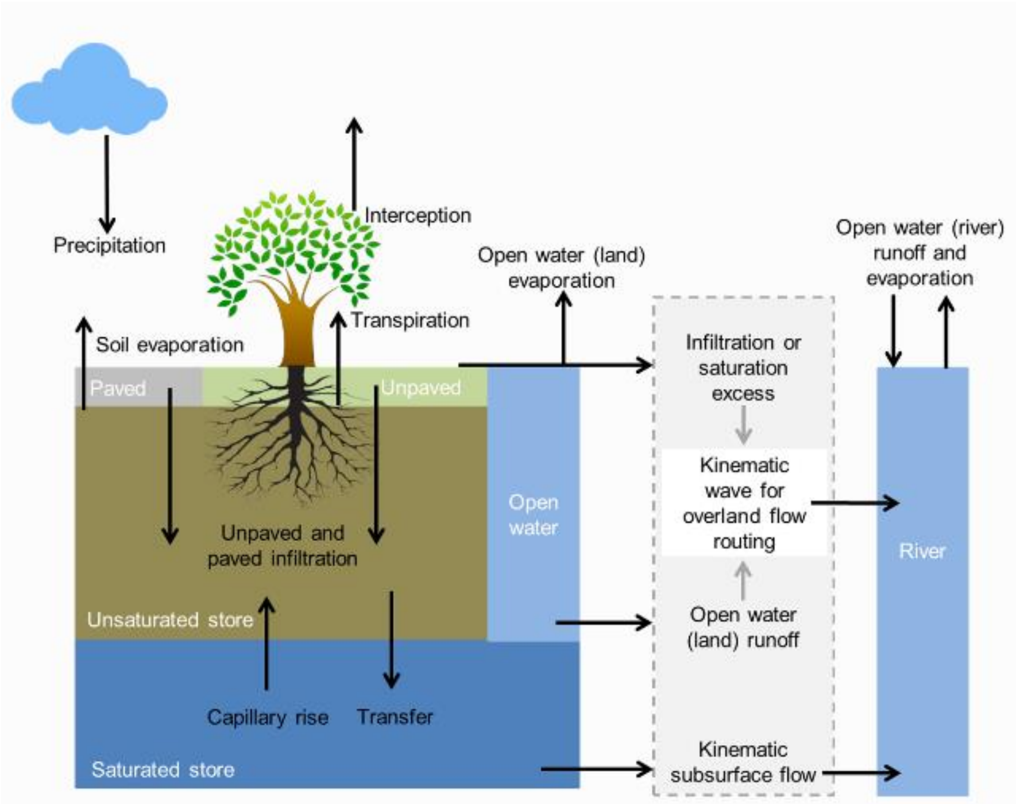

Figure 7 - Hydrological processes (Bucket model) simulated by Wflow (https://wflow.readthedocs.io/en/latest/wflow_sbm_old.html)

Precipitation infiltrates the soil which acts as the bucket. From there, some of the water is absorbed into the soil, inducing an increased soil water storage and soil runoff. This process is calculated by Vertessy and Elsenbeer (1999), where the module topog_sbm is created to calculate soil water storage and runoff within saturated and unsaturated soils, while considering hydraulic conductivity, soil depth and slope. The output of topog_sbm is the soil water storage and soil runoff generation. On the other hand, water is also intercepted before reaching the soil by plants. The interception process in this model relates to the evapotranspiration that induces water loss regarding land use and soil water content. This process is calculated using the Gash model (Gash, Lloyd, & Lachaud, 1995).

With the aid of the modules above, Wflow can model the flow of water from the catchment while considering the various processes that may take place in the hydrological process. In the data requirements section below, the different types of data required for the model to function will be explained. With the elaboration of data required by Wflow, the different processes that takes place in Wflow can be understood.

4.2 Data Requirements

4.2.1 Types of data and its relation to Wflow

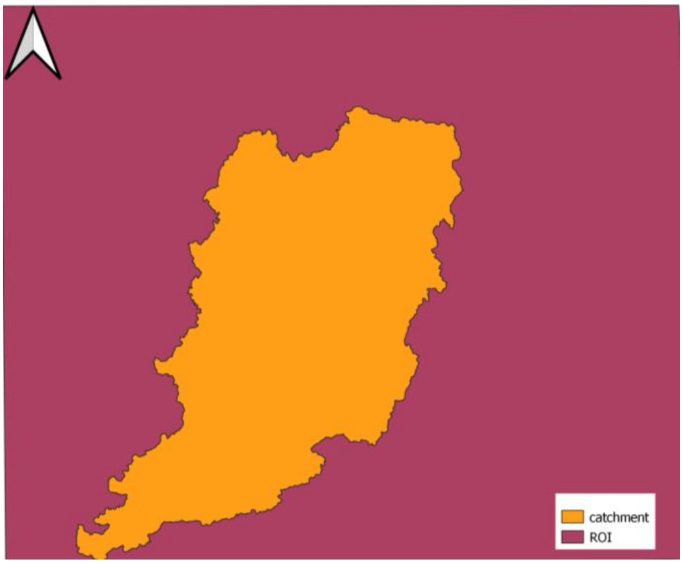

Figure 8 - Pawan Catchment clipped onto ROI

Figure 8 depicts the Pawan catchment highlighted in yellow, clipped onto a region of interest (ROI). An ROI is a rectangular polygon that surrounds the catchment area. Since Wflow is a hydrological model, it requires a catchment area that acts as the bucket in this model. This area will be studied for its land use and its effects on discharge in the Pawan River. The orange highlighted area in Figure 8 will serve as a base reference for the location of the study area, allowing for data collection specifically in the region of interest. Collection of datasets is explained in section 4.2.2.

Wflow requires information on topography, river geometry, climatology, and meteorology to construct the study areas geographical conditions. The information of topography defines the elevation which relates to how the water will flow according to the topographical conditions of the land. Additionally, soil characteristics should be considered as it defines the retention and storage capacity. Further, a land cover map is useful to classify the land use in the region. Different land usage causes different water retaining capabilities, impacting the flow of water in the catchment. River geometry will define the river characteristics, flow direction of the water in the river and the river width. Climatology information is used for temperature and evapotranspiration in the region. Lastly, meteorology defines the inflow into the region of interest, in the form of precipitation.

4.2.2 Data Collection and Justification

As mentioned above, the Wflow model requires a variety of datasets to construct a model scenario. Collecting these various datasets can be tedious due to the large quantity of data. As a result, Peter van Tol of Witteveen+Bos made HydroMT available to simplify the process of compiling and preparing these datasets for use in Wflow. In addition, Peter van Tol made the HydroMT data downloader which is a plugin for QGIS to download several datasets required by Wflow. Therefore, the data requirements of Wflow must first be run through HydroMT, which produces command and data forcing files for the Wflow model to operate (Houwelingen & Witt, 2022). The process to collect the datasets is elaborated below.

4.2.2.1 Topography and River Characteristics

Firstly, a digital elevation model (DEM) of the study area must be derived. For the DEM, there are two options, a multi-error-removed improved-terrain (MERIT DEM) or a forest and buildings removed (FABDEM) will be used. The difference between the two is that FABDEM depicts an area with less noise, meaning the depiction will be more centralized and accurate in a modelling context (https://www.fathom.global/). The FABDEM is a newly developed system, and as such, it may not yet be as reliable as more established systems. Since Wflow models hydrological systems and not hydraulic systems, a MERIT DEM is sufficient as it depicts the flow of water in a river system. The MERIT DEM will be taken from MERIT Hydro dataset which is available at http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/. The MERIT Hydro dataset contains various hydrography data, including flow direction, flow accumulation, hydrologically adjusted elevation, and river channel width. These datasets will all be taken into account by Wflow as an input to model the hydrological and topographical characteristics of the region.

4.2.2.2 Soil Characteristics

The next step is to gather soil data. With the aid of the HydroMT data downloader, an ROI is used as an input location. The output will provide data on the contents and condition of the soil in the catchment area. Clay, sand, and silt content, soil thickness, soil bulk density (oven dry), soil organic carbon content, and soil pH levels are some of the various data that are downloaded and required for Wflow. This information is useful for calculations within the topog_sbm module by Vertessy and Elsenbeer (1999). The output file of the soil datasets is in a raster format, which need to be aligned to ensure consistent cell sizes for usage in HydroMT and Wflow. The soil data is in a fixed timestep, meaning it is constant throughout the period for which the model runs.

4.2.2.3 Land Cover Map

A land cover map must be used to define land use in the region of interest. Wflow supports three different sources of land cover maps by having available indexes in its database to categorize land use. Namely, Globcover, Vito, and Corine are the three land cover maps. This model will use Vito, as it released its latest version for 2019. Corine has land cover maps up to 2018 while Globcover only had a map for 2009. Vito is derived using the satellite PROBA-V which is developed by the European Space Agency (ESA). The map contains tiles of 110x110 kilometres area with a 100-metre resolution. With the Sentinel-2 program by the ESA, the land cover map can be continuously developed with new observations (https://lcviewer.vito.be/about). The Vito land cover map is downloaded from https://lcviewer.vito.be/download. Figure 9 depicts the land cover map in relation to the ROI. Further, the legend lists the land use codes for the Vito land use map which are elaborated in Table 6, Appendix B. This land cover map can also be altered with its corresponding land use codes, allowing for the design of interventions which will be discussed in section 5.3.

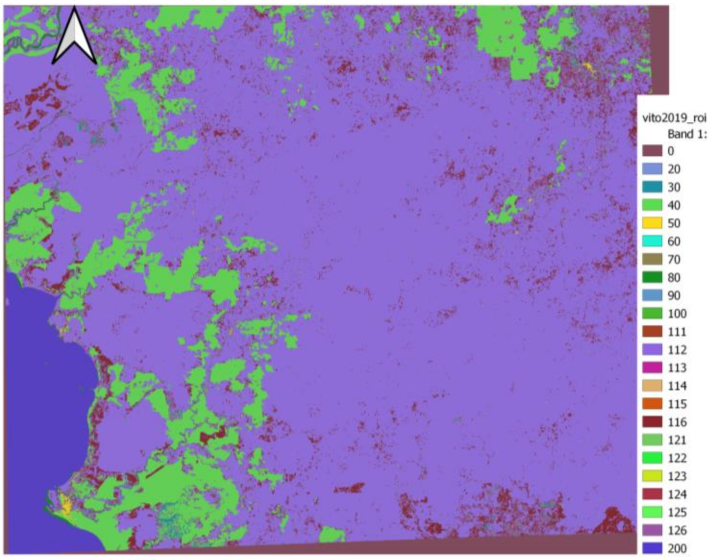

Figure 9 - Vito land cover map clipped onto the ROI

4.2.2.4 Meteorology

Meteorological data for the Ketapang region will utilize the ERA5 model, available at https://climate.copernicus.eu. ERA5 is a climate estimation model containing estimates on precipitation, temperature, potential evaporation, mean sea level pressure, and solar radiation. Gathering these variables allow for a construction of the meteorological conditions of this environment. The ERA5 dataset has 320 cells in the ROI, where the dataset provides different estimates of measurements for each corresponding cell location (Figure 10). Precipitation estimates for 9 out of 320 cell locations can be seen in Figure 21, Appendix A. These 9 cells were selected at random to display how precipitation estimates are different in each cell location. The ERA5 dataset was downloaded with a period from 01/01/2003 to 31/12/2022.

One drawback of using ERA5 is that it tends to underestimate the precipitation values in tropical regions. Alternatively, two different precipitation datasets are also available for download, namely Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) and Tropical Rainfall Measuring Mission (TRMM). The CHIRPS dataset taken from https://data.chc.ucsb.edu/products/CHIRPS-2.0 while the TRMM dataset is available at https://disc2.gesdisc.eosdis.nasa.gov. It is believed that estimates of precipitation will be best done with the TRMM dataset. Unfortunately, during the duration of this project there was an issue with the TRMM server, rendering it unable to be downloaded. Therefore, it was only possible to choose between the ERA5 estimation and CHIRPS.

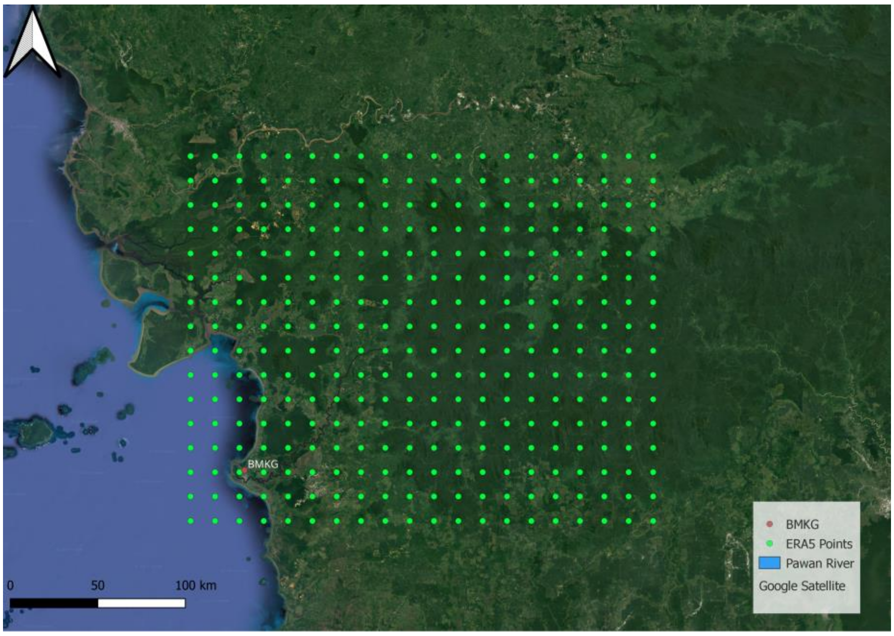

Figure 10 - ERA5 cells (green) with BMKG measurement point (red)

Measurements of precipitation in the region are available from BMKG, the meteorology agency of Indonesia. The measurement from BMKG is conducted at the Rahadi Oesman Airport in Ketapang, depicted by the red point in Figure 10. Precipitation estimates from ERA5 and CHIRPS were taken at the closest point to the BMKG measurement point. The method of comparison is by using a Pearson correlation graph. A Pearson r-value between 0 and 1 indicates a positive correlation between the datasets, while a value between -1 and 0 indicates a negative correlation. The closer the Pearson r-value is to one or negative one, the stronger the correlation is.

As depicted in Figure 11, there are 3 different subplots for each dataset, being daily, monthly, and yearly. The daily plots include daily measurements plotted against daily BMKG measurements. Monthly and yearly are much larger as they are the total sum of monthly or yearly precipitation values. This is done to depict the differences between the datasets with more clarity. The plots show that ERA5 is better suited to estimate precipitation measurements compared to CHIRPS. In addition, the Pearson r-values indicate a positive correlation for daily, monthly, and yearly precipitation values. Monthly and yearly comparisons of ERA5 against BMKG show a strong positive correlation.

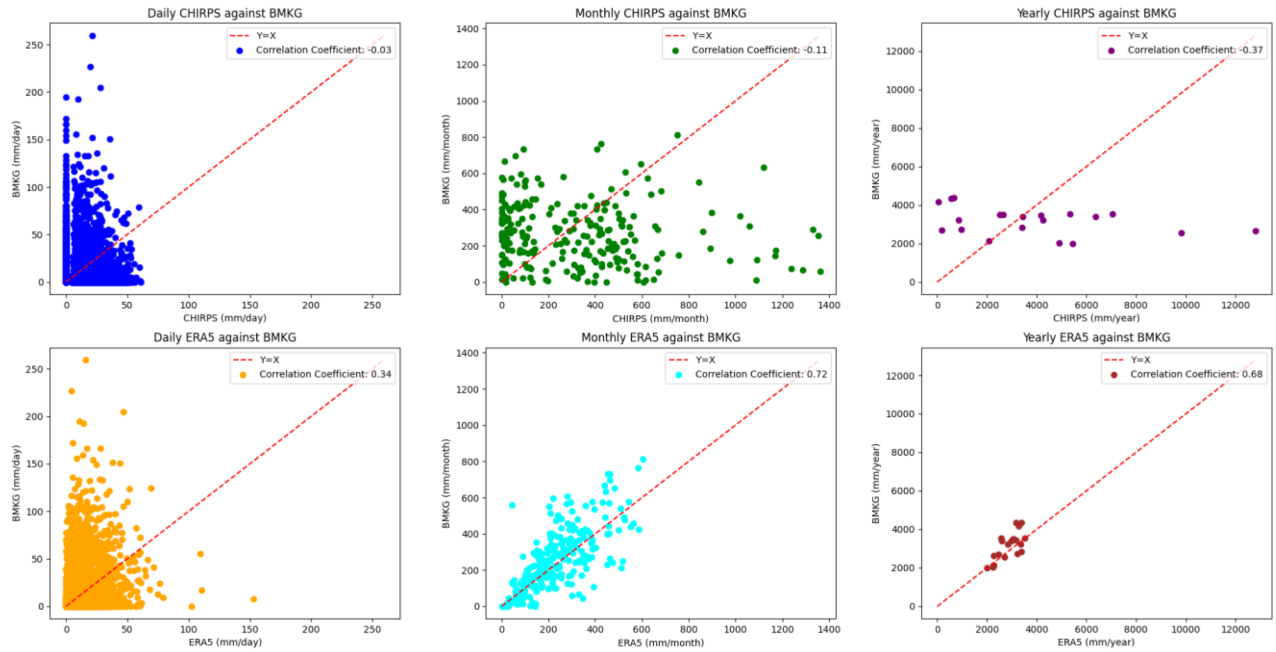

Figure 11 - ERA5 and CHIRPS against BMKG, Pearson correlation graphs

4.2.2.5 Climatology

Additionally, climatology is required for a model simulation in Wflow. This is accomplished using the form of Modis LAI, which is derived from the Moderate Resolution Imaging Spectroradiometer (Modis) on NASA satellites. A leaf area index (LAI) depicts the surface of leaves in a cell or area. Climatology is depicted by the amount of leaves per cell, with more leaves appearing in warmer temperatures and fewer leaves appearing in colder temperatures. In a tropical region, the climatology is assumed to be relatively stable, with no significant changes from one season to another. Modis LAI can be downloaded via the HydroMT tool, which is available in the Earthdata | Earthdata (nasa.gov) website. The LAI dataset is in a daily timestep for the allocated period which is then averaged to show changes in climatology over time. For this project, Modis LAI was downloaded from 2013 up to 2023. A period of ten years allows for a sufficient depiction of climatology in the area. The more time downloaded for the Modis LAI period, climatology of the area is depicted with more clarity. It is also best to download LAI in accordance with the period used by the model. However, this is not always possible due to the availability of LAI data.

4.2.3 Time Series

The Wflow simulations employ a daily time step. Time series for the model depends on the period of which precipitation estimates are utilized. Since ERA5 was downloaded from 2003-2022, the time series of the simulation this model performs is from 01/01/2003 up to 31/12/2022.

4.3 Qualitative Analysis

This section will discuss the steps taken to conduct a qualitative analysis. This analysis involves a site visit to Ketapang, as well as stakeholder interviews.

4.3.1 Identification of Stakeholders

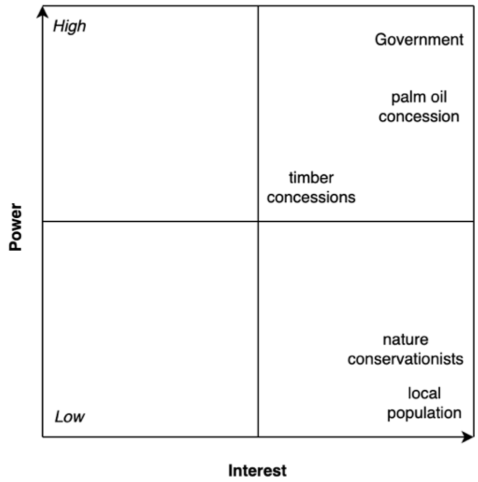

Figure 12 - Power - interest matrix of Stakeholders (Júnior et al., 2015)

Figure 12 depicts a concise power-interest matrix that indicates the importance of each stakeholder. This method was derived from Júnior et al. (2015), to understand each stakeholder and apply an appropriate strategy for the stakeholder analysis. The analysis denotes the government as the ones with the most power and the local population with the least despite a shared level of interest. Power can be defined by the amount of influence one has over the decision-making process. The government has the most power due to its influence on policy changes and possible improvements in the region. Government defines several governmental agencies in charge of different aspects in Ketapang and West Kalimantan. Further, the palm oil and timber concessions have a considerable amount of power, as they currently dominated the land use near the upper catchment (Figure 5).

Meanwhile, interest can be defined by how much a stakeholder can be affected by the decisions made. Nature conservationists and the local population share the same end goal, which is to prevent further flooding. Locals fear harm to their homes if floods are not mitigated in the future. Additionally, nature conservationists fear harm to the wildlife. The government wishes to address all these factors and demands, putting them as the top contender for interest.

Table 1 below lists all stakeholders with the names being anonymized due to no direct consent from stakeholders. For the governmental agencies, a translation in English is provided. Further, the palm oil concession requests full anonymity. This is not PT Aartu Energy Resources, whom unfortunately were not available to be interviewed. Although, this palm oil concession is relatively close to the location of the concession owned by PT Aartu Energy Resources. With respect to their wishes to be anonymous, they will only be referred to as the palm oil concession. Most of the interviewees originate from or has lived in Ketapang for a while. Therefore, these interviewees were considered a reliable source.

Table 1 - List of Stakeholders

No	Stakeholders	Translation in English
1	Badan Pengendalian Pencemaran dan Pemeliharaan Lingkungan Hidup Kabupaten Ketapang (BPP-PLH)	Agency for the control of pollution and Maintenance of the Environment in the region of Ketapang
2	Dinas Pekerjaan Umum dan Tata Ruang bagian Sumber Daya Air Kabupaten Ketapang (PUTR)	Department of Public Works and Spatial Planning, division of Water Resources in the region of Ketapang
3	Dinas Pekerjaan Umum dan Tata Ruang bagian Tata Ruang Kabupaten Ketapang (PUTR)	Department of Public Works and Spatial Planning, division of Spatial Planning in the region of Ketapang
4	Dinas Pekerjaan Umum dan Penataan Ruang Provinsi Kalimantan Barat (PUPR)	Department of Public Works and Spatial Planning in the province of West Kalimantan
5	Balai Pengelolaan Daerah Aliran Sungai Provinsi Kalimantan Barat (BPDAS)	Department River Basin Management in the province of West Kalimantan
6	Desa Tanjung Pura, Kepala dan Sekteratis Desa	Tanjung Pura village, Head and Secretary of village
7	Desa Mayak, Kepala Desa	Mayak village, Head of village
8	AidEnvironment	AidEnvironment
9	Palm oil concession	

4.3.2 Site visit and Interviews

Method of qualitative analysis will undergo a site visit to Ketapang, Kalimantan. The site visit is intended for interviews, through which missing data for model validation is to be gathered. AidEnvironment guided us through the visit, connecting us to different governmental agencies, a palm oil concession, and the local population.

Table 2 - List of Questions for Stakeholder Interviews

1	How many times does flood in Ketapang occur every year?
2	When did flooding worsen in its effects?
3	Which areas experience the worst floods?
4	When did the concessions form and start to develop?
5	How has the land use changed throughout the years?
6	What factors do you think contribute to flooding?
7	Are there any plans on mitigation of floods? If so, what are they?

Interviews with the stakeholders were conducted in an unstructured manner, with the questions listed in Table 2 acting as a general guide for topics that should be discussed throughout the interview. Through the method of an unstructured interview, more information was able to be gathered as the questions were not limited to those listed in Table 2. Having the interviews unstructured allows for expansion of answers through supporting questions for elaboration. The interviewer must not ask direct or biased questions since it may produce biased answers from the interviewee. It is also the responsibility of the interviewer to keep the response of the interviewee related to the topic at hand (Zhang and Wildemuth, n.d.). In section 5.1, answers of the stakeholder interviews will be discussed and analysed. Along with that, the interview notes are in Appendix C with Figure 22 to prove that interviews were conducted.

5 Results

5.1 Interview Results

In this section, interview notes from Appendix C are discussed and analysed. Stakeholders generally share similar sentiment on the conditions of Ketapang, with interview notes located in Appendix C. Ketapang can flood 3-5 times every year and floods have worsened in the past 3-5 years. It was observed that once the city of Ketapang floods, time taken for dissipation of floods is 1-2 days. Meanwhile, for the villages of Tanjung Pura and Mayak, the fastest time taken for a flood to dissipate was one month. The villagers claim that 1-2 days of heavy rainfall leads to an overflowed Pawan River. Unfortunately, the government has no plans for mitigation, and has only started taking measurements of flood depth during March 2023 (stakeholders no. 6 &7, Table 1). This is evident in Figure 13, where the image depicts a government official conducting measurements of flood depth in the Tanjung Pura village, accompanied by the head of the village.

Figure 13 - Head of Tanjung Pura village and government official conducting measurements of water height during flood of March 2023

Figure 14 - River bank of Tanjung Pura village

Government aid for the affected villages were in the form of food and clothing, however, did not reach the point of evacuation of locals. Villagers receive additional help from nearby palm concessions as well. Another worrying factor is the riverbank of these villages that has slowly receded through the years (Figure 14). Villagers claim that it has receded by 2-3 meters (stakeholder no. 7, Table 1). In light of these claims, no mitigation plans have been formulated. Villages have suggested several mitigating solutions such as building a wall or planting trees along the riverbank to prevent further erosion. However, the government did not agree due to budget issues.

One government official does not believe that inundation is solely a result of an increase in plantation areas. Other factors mainly addressing the Pawan River is of concern. The government has plans for mitigation aimed at the Pawan River system. The plan is to normalise the river. This entails cleaning the riverbed from sediment build-up. Despite this, due to governmental processes and the system in place, the governing body in the region of Ketapang is not able to freely conduct these plans. They require approval from the office of the West Kalimantan region. Therefore, currently the only rivers able to be normalised are the small tributaries that exist in the Pawan River system (stakeholder no. 2, Table 1).

Plantations have existed since the 1990s and around 2010 it started to develop and expand. Coincidentally, floods have worsened in a similar time frame. Factors of inundation according to the stakeholders are generally due to climate change and most importantly deforestation, may it be caused by plantations or forest fires. The plantation concession interviewed experienced a forest fire in their high conservation value (HCV) forest in 2019. Every plantation area must have 7% of their land maintained as an HCV forest. Due to an internal dispute of an employee, the HCV forest was burnt as an act of retaliation (stakeholder no. 9, Table 1). Villages of Tanjung Pura and Mayak also experienced forest fires nearby, where it was caused by a lit cigarette being thrown irresponsibly (stakeholder no. 6, Table 1). These are examples of how forest fires are still a reoccurring issue.

High conservation value forests are forests containing endangered species, rare eco-systems, etc. AidEnvironment is mostly interested in the conservation of these forests and other untouched forests. They have done some work in Kalimantan specifically for the conservation of orangutans. In the past, plantation concessions have resorted to shooting orangutans to protect their crops. This practice is illegal and cruel, and it has contributed to the decline of orangutan populations in Indonesia. The HCV area of the plantation concession interviewed has no more signs of orangutans (stakeholder no. 9, Table1).

Most stakeholders believe inundation is worsened due to deforestation, may it be due to concessions or human faults. Figure 15 below depicts the change in plantation concessions against the Pawan catchment from 1990 until 2020. Plantation areas are highlighted in blue, with the catchment highlighted in yellow as the background. As shown in Figure 15, plantation concessions have increased significantly since 1990. This finding supports the stakeholder interviews, allowing for better dependency on the results of the stakeholder interview.

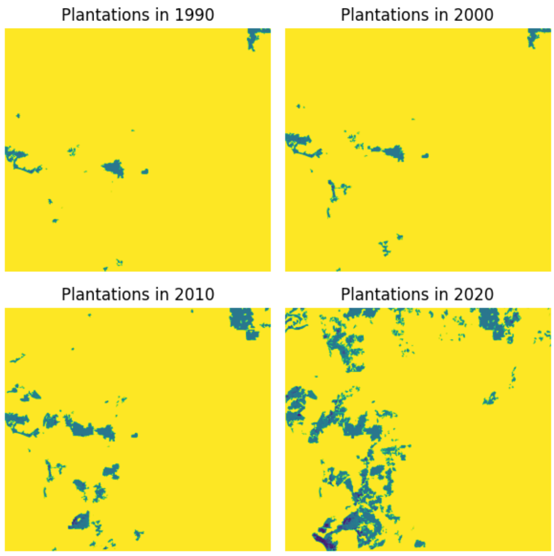

Figure 15 - Plantation concessions (in blue) against the catchment (in yellow) from 1990 up to 2020 (KLHK)

5.2 Model Validation

In this section, the model is validated with discharge measurements of the Pawan River. Therefore, a main goal for the site visit was to collect discharge data of the Pawan

River. Due to the nature and working system of the government agencies, most agencies existing in the region of Ketapang did not have the discharge measurements. We were essentially redirected between various agencies in search of the data until we were required to travel to Pontianak, where the agencies responsible for the whole province of West Kalimantan possibly had the data. On a positive note, we had the opportunity to interview various governmental agencies and were able to retrieve discharge data for the validation of the model.

Before utilizing the model for analysis, the Wflow model must be calibrated and validated to ensure it simulates the Ketapang region with sufficient accuracy. The main method of validation is through comparison of discharge, as it is the main output of Wflow. Data availability was scarce and after requesting data from multiple governmental agencies, discharge measurements was available from the Department of River Basin Management (Balai Pengelolaan Daerah Aliran Sungai, BPDAS). Discharge data from BPDAS was in the format of average discharge over the past 4 years. Likewise, to validate the discharge data simulated by the model, the results of the past 4 years were averaged. Figure 16 depicts the location for which BPDAS conducted the discharge measurements, highlighted in the blue point. The three red points are where the model measurements are derived, with the two points on the right being the location of the villages Tanjung Pura and Mayak.

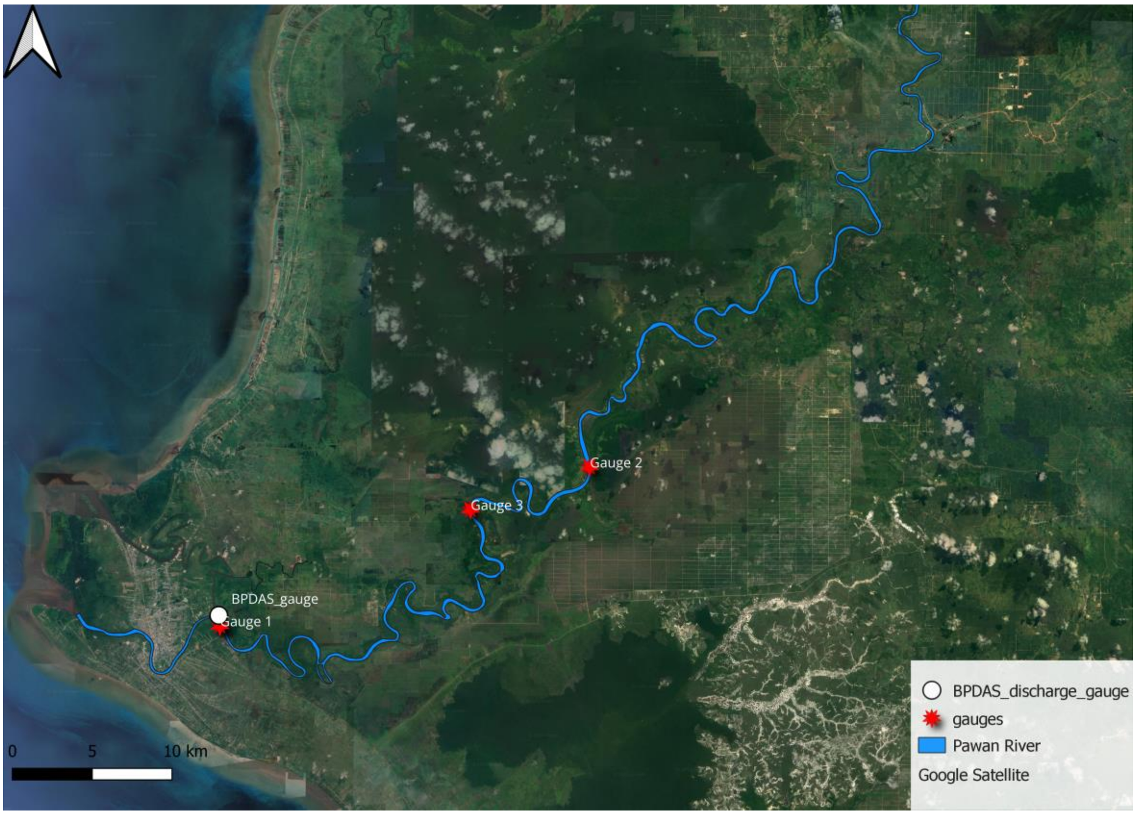

Figure 16 - Gauge locations of Wflow model and BPDAS measurement in the Pawan River

The average discharge value from Wflow in the past 4 years is 776.27 m^3/s. Meanwhile, the average discharge by BPDAS is measured at 761.04 m^3/s. There is a difference of roughly 2% in the simulation of the Wflow model on the real-world situation. This method of validation indicates that the model estimates discharge properly with correct estimates of meteorology, climatology, and land usage of the Ketapang region.

However, this validation is not conclusive. One issue with the available measurements is that it is not comprehensive as it only contains an average of 4 years. Measurements of a daily timestep throughout several years will be more accurate to properly calibrate and validate the model. Another issue is that the measurements are located at a singular point. The singular measurement point is located near gauge 1 (Figure 16). Therefore, it is not possible to validate the discharge output from gauges 2 and 3 (Figure 16). Hence, for future use of this model, it must first be calibrated and validated to discharge measurements, provided the data is available.

5.3 Design of Interventions

With the results from the stakeholder interviews, the intervention for changing land use would be reforesting the Pawan catchment in the Ketapang region. Additionally, through literature review we were able to understand the effects of deforestation and how it can cause various factors leading to inundation. Hence, for the intervention scenarios, three scenarios were designed. Firstly, a reforestation event where all plantation areas are converted into forests. Secondly, a scenario where half of the plantation areas are converted into forests will also be included in this analysis. Thirdly, an extreme scenario where the whole Pawan catchment is covered by forests will be simulated.

Furthermore, AidEnvironment requested a land use change analysis on one of the palm oil concessions in the area. PT Aartu Energy Resources is a palm oil plantation made up of peat land. Their issue is that the area always floods, causing them to replant palm trees. These palm tree stalks can never grow due to the flood that occurs every year. Therefore, AidEnvironment has requested that the land use of that area be changed and what its effects towards discharge would be. Therefore, another scenario of an intervention is to see what will happen if only this plantation is reforested.

Figure 17 below depicts the location of the concession area owned by PT Aartu in relation to the plantation areas of 2020 and the Vito land cover map as the background. The concession area is relatively small compared to the other plantation areas. This will be a realistic intervention that is likely to be in implemented. With the extreme reforestation scenarios, the results can demonstrate the effect of land use change towards discharge on a larger scale.

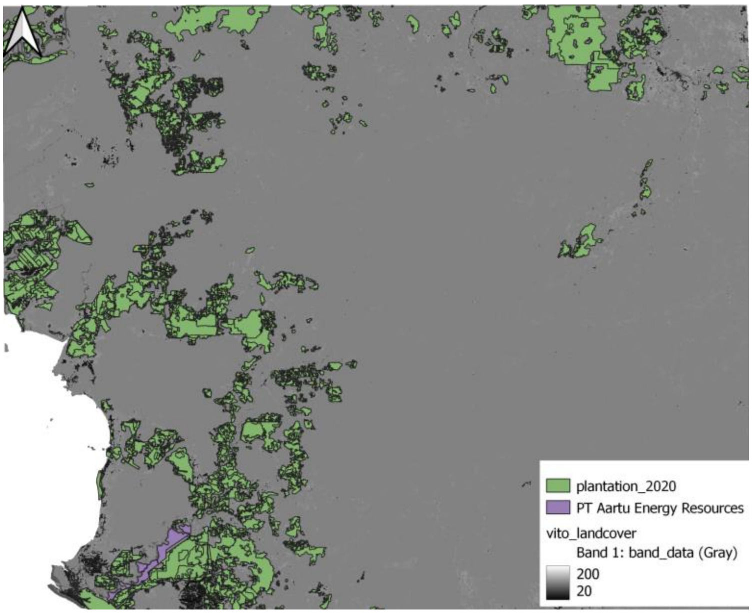

Figure 17 - Plantation area of PT Aartu in relation to plantation concessions in 2020

5.4 Analysis of Results

As explained in the design of the interventions, three different scenarios of model simulation, being a full reforestation of plantation areas, half plantation areas reforested, the plantation area of PT Aartu being reforested, and the whole catchment covered by forests. These intervention scenarios will be referred to as the future model simulation. In addition, simulations of past and present situations of plantation areas in the Pawan catchment is modelled, ranging from 1990 up to 2020.

5.4.1 Difference between Model Scenarios

With the interventions determined, land use of the Vito land cover map is altered according to the plantations map provided by KLHK. This was done utilizing Python to change the desired land use classes with plantations. For plantations, the classification index is 40, while for forests the classification index is 112. Table 3 below lists the percentage of plantations in the catchment area for each model scenario.

Table 3 - Percentage of plantations within the Pawan Catchment for each modelled scenario

Scenario	1990	2000	2010	2020	PT Aartu Reforestation	50% Reforested	100% Reforested	Extreme Reforestation
% of land use (40)	2.49	2.7	5.55	15.17	14.13	8.92	0	0

Table 3 depicts the increase in plantation areas from the past (1990) and the present (2020). Plantation areas increased by nearly 13% in three decades. Meanwhile, the reforestation scenarios show a decrease in plantation areas, which is desired when modelling these scenarios. The difference between the 100% plantations reforested and the extreme reforestation is that in the extreme reforestation, all areas are converted into forests and not only plantation areas.

5.4.2 Comparison of Peak Discharge

Table 4 below lists the peak discharge values of the past, present, and future model simulations of the Pawan catchment in the Ketapang region. The peak discharge values are labelled as 'Q_{peak}' and uses two significant figures. Difference of each peak discharge values labelled 'ΔQ_{peak}' is used to depict the impact of each intervention and the change between the past and present situations. Peak discharge for all model simulations occurs on June 25, 2010.

Table 4 - Peak discharge values of past, present and interventions by model simulation

Model Simulation	Q_{peak} (m^3/s)	ΔQ_{peak} compared to 2020 (%)
Past - 1990	10.30×10^3	-0.98
Present - 2020	10.40×10^3	0
PT Aartu reforestation	10.41×10^3	$+0.02$
Half Plantations Reforested	10.34×10^3	-0.62
All Plantations Reforested	10.23×10^3	-1.75
All Forested Areas in the Catchment	10.19×10^3	-2.06

According to the Wflow model, difference in peak discharge values between the past and present situation is 0.98%. Oddly enough, a reforestation scenario for PT Aartu induces an increase of peak discharge. This is unexpected as a reforestation scenario should increase retention capabilities and not lead to further discharge downstream. On the other hand, the model simulation where half and all of the plantation areas in the catchment are reforested shows a decrease in peak discharge values. This discovery is in accordance with the literature review and the results of the stakeholder interviews that entails a region covered with forests will induce lower peak discharges downstream. In addition, the scenario where the extreme reforestation intervention is implemented shows a decrease of 2%. This is acceptable as most of the catchment is covered with forests. Therefore, the change will not be significantly larger than a scenario where all plantations are reforested as the land use of the catchment is mostly forests to begin with.

5.4.3 Comparison of Hydrographs

This section will depict the hydrographs of each model simulation to demonstrate the difference between each scenario. The hydrographs in Figure 18 are made for the period 2008-2012, to highlight the characteristics of the Pawan River and its discharge around the period for which peak discharge was identified.

There is a slight difference in the overall height and peak of the hydrographs, with reforestation simulations having a lower peak and overall hydrograph. The 2020 simulation presents the highest peak while the simulation where the whole catchment is reforested has the lowest peak and overall height of the hydrograph. The differences of hydrographs are in the height of the curves and not discharge characteristics.

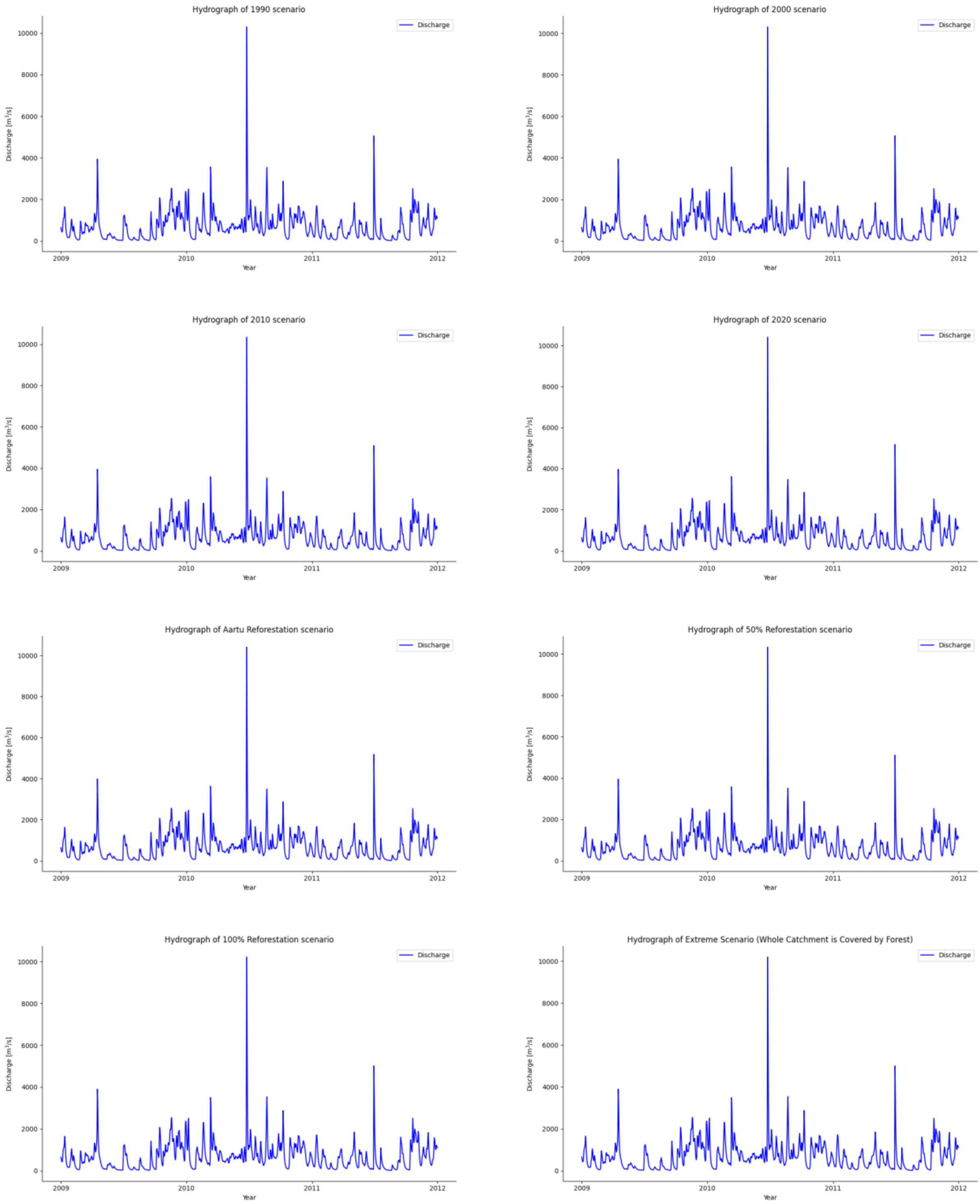

Figure 18 - Hydrographs of each model simulation (see title of graph)

5.5 Sensitivity Analysis

To understand how sensitive the Wflow model is to a change in land use, a sensitivity analysis is conducted. This is done by simulating another, fourth scenario where forests in the catchment are converted into plantation areas. The alteration resulted in 87.4% of the catchment area being converted into plantation areas. Table 5 below depicts the peak discharge values of each sensitivity model simulation. The whole catchment being covered by plantation areas increases peak discharge by 10.60%.

Table 5 - Sensitivity Analysis of Peak Discharge

Model Simulation	Q_{peak} (m^3/s)	Δ Q_{peak} compared to 2020 (%)
All Plantation Areas in the catchment	11.64×10^3	$+10.60$

6 Discussion

6.1 Model Components

The model cannot be calibrated due to incomplete or lack of data measurements of the real-world situation. Data provided by BPDAS is in the format of averages of every 4 years. Therefore, it is not conclusive that the Wflow model is valid and accurate to model the Ketapang region for its hydrological processes. Ideally, data measurements in a daily timestep would be better suited to calibrate and validate the model, since the model provides an output of discharge in a daily timestep. Additionally, more points of discharge measurements must be obtained to validate the model output from different gauges as in Figure 16. Hence, for future use of this model, it must first be calibrated and validated, provided discharge measurement data is available.

Design discharge of the Pawan River is also not known. Design discharge is the limiting value before the river overflows. This information may be useful to determine when the Pawan River overflows with each model scenario. By having this information, we can also determine the frequency at which the Pawan River overflows.

The ERA5 precipitation dataset itself is not considered an accurate estimation of the precipitation in the region. An extreme value analysis was conducted to the datasets of ERA5 and BMKG. This analysis was conducted to investigate whether the ERA5 estimation estimates precipitation similarly to the BMKG measurements, in an extreme rainfall scenario. By doing so, it can be confirmed if the estimates of ERA5 are suitable for modelling the Ketapang region against the precipitation measurements by BMKG. The evaluation tool was made by Antonio Dewabrata, a member of Witteveen+Bos Indonesia. The extreme value analysis for ERA5 is depicted in Figure 19 and for BMKG is depicted in Figure 20. As shown in both figures, there are various distributions that are fit onto the datasets, with a return period of 100 years.

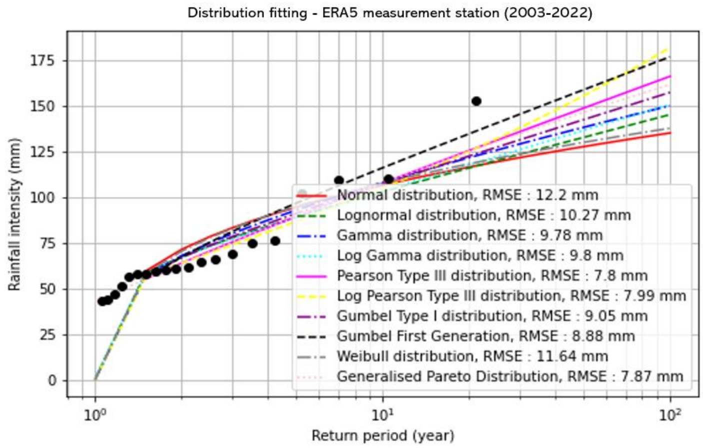

Figure 19 - ERA5 Extreme Value Analysis

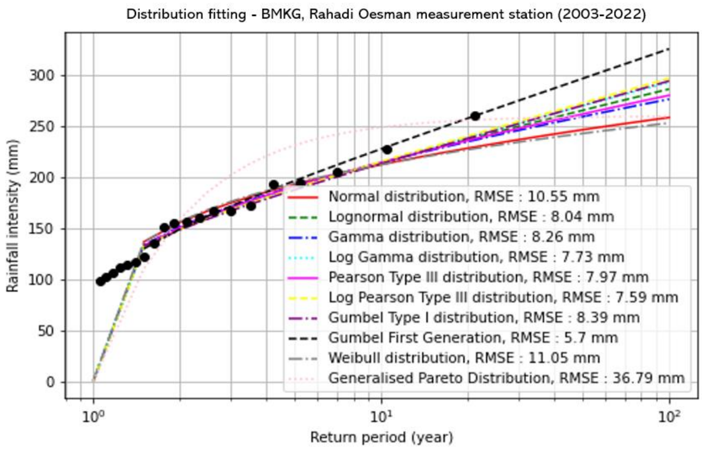

Figure 20 - BMKG Extreme Value Analysis

RMSE stands for root mean square error, which defines the difference between the distribution and the dataset. Ideally, the lowest RMSE will result in the best distribution. On the contrary, there is a possibility that a low RMSE does not define the best fit for a distribution. As an example, in Figure 18, the ERA5 dataset has the lowest RMSE for the Pearson type III distribution. This distribution curve underestimates two extreme data from the ERA5 datasets. For this project, it is considered that a distribution that overestimates will be better than a distribution that underestimates the datasets as this project utilizes extreme precipitation estimates for model simulations.

Therefore, for the ERA5 dataset, the Gumbel first generation distribution was chosen (Figure 19). Along with that discovery, the distribution that fits the BMKG data (Figure 20) is also the Gumbel First Generation distribution. This distribution has the lowest RMSE and estimates the dataset relatively similar. The Gumbel First Generation is the original approach by Gumbel, modified by Onen and Bagatur (2017), where the reduced mean and reduced standard deviation are divided by the number of data points (Dewabrata, 2021).

The ERA5 dataset is a valuable resource for climate modelling, but it is important to be aware of its limitations. Specifically, the ERA5 dataset has been shown to underestimate the intensity of extreme precipitation events. The extreme value of BMKG is 325 millimetres while the ERA5 has an extreme value of 175 millimetres. This means that the Wflow model when modelled with the ERA5 dataset may underestimate the risk of flooding associated with an extreme precipitation event.

6.2 Qualitative Analysis

The unstructured interview method proved to provide insightful information into the existing conditions in Ketapang, Kalimantan. Utilizing this method resulted in a flexible interview, where the interviewer does not follow a script but also interacts with the interviewee in a conversation. The unstructured interview also brought up several information topics that were not originally planned. For example, the discussion of deforestation experienced by both the villages and palm oil concession. Although, most of the interviewees were confused at the beginning and were afraid of the interview due to the data being used against or harm them. Once the interviewees were convinced that this was for a thesis study, they were open and willing to share information.

6.3 Interventions

Modelling past, present, and future scenarios in this study was done through the change of land use in the region. The reason why only land use was changed is because this study mainly intends to investigate land use change and its effects towards discharge. Therefore, to see the effects of only land use change, variables such as meteorology and climatology are kept constant.

In addition, the land cover classifications are not realistic. Vito uses the classification index '40' to classify managed agriculture and croplands. This would mean that the effects of a palm oil plantation are similar to the effects of a rice field. Which in reality is not the case. Furthermore, changing land use does not simultaneously alter the soil characteristics of the area. The soil characteristics is downloaded with a fixed timestep. Therefore, throughout the model simulations of different scenarios, soil characteristics stay constant. In reality, when altering a palm oil plantation to forests, soil contents change. PT Aartu is a peat covered plantation. When converting the area into a forest, the soil contents will be changed to ensure growth of the forest.

Furthermore, land subsidence is not taken into account in the Wflow model. Apparent in plantations, peatlands dominate the plantation areas. Subsidence in peatlands occurs due to compression, consolidation, and oxidation (Evans, et al., 2019). Floods will be worsened if land gets more shallow overtime. Therefore, it is important to note that the modelled discharge values are not absolute values. The model was made so it may depict the fluctuation of discharge in relation to a change in land use. To model absolute values in the corresponding years and future scenarios, different climatological and meteorological estimations must be used.

7 Conclusion

This study analyses the effects of land use change to discharge of the Pawan River in the Ketapang region with the Wflow model. While utilizing a qualitative analysis through the method of unstructured interviews. In this section, the research questions (RQ) will be answered.

RQ 1: How has land use changed from the past and present situation in Ketapang?

One of the factors of worsened inundation in Ketapang can be pointed at deforestation due to an increase in plantation areas. This is shown in the land cover map by KLHK (Figure 15) and Table 3 that depicts the plantation areas in the catchment. Plantations have been increasing since 1990 and the difference from 1990 and 2020 is quite staggering.

RQ 2: How does land use change affect discharge of the Pawan River.

Along with the discovery of the first research question, peak discharge is observed to have increase by 1% (Table 4). However, it is important to note that this is not the only factor. Factors such as land subsidence, degradation of the river system, and the poor quality of drainage system in the Ketapang regency may be at fault and should be studied to fully understand the extent of floods in Ketapang.

RQ 3: What type of intervention can be implemented in Ketapang when modelled in Wflow?

The qualitative analysis provides beneficial information into this project. Mainly, for the formulation of interventions that would be best suited with the Ketapang region, while focusing on land use change. The land cover map by KLHK supports the agreement of stakeholders that one of the factors of worsened inundation is the decreasing amount of forests throughout the years. Therefore, a reasonable and viable option on land use change in the catchment would be a reforestation intervention.

Findings of this study shows when land use is changed from a plantation to a forest, it results in a decrease in peak discharge values. Although the decrease in peak discharge was relatively small, this observation supports the preliminary theoretical framework that a change in land use from plantations to forests may improve hydrological conditions of the Pawan catchment. The relatively small change could be because the model was uncalibrated to properly simulate the hydrological conditions of the Pawan catchment. Therefore, the model may underestimate the effects of land use change on peak discharge as it employs an uncalibrated model.

8 Recommendation

To better depict the effects of interventions of the Ketapang region, a secondary model must be introduced into this study. As mentioned before, Wflow is a hydrological model. Hence, it is not able to model changes in the river system for mitigation plans of normalisation of the river. A combination of this intervention with land use change may induce a greater effect on the discharge of the Pawan River, since deforestation is not the only factor causing worsened inundation. Therefore, introducing a hydraulic model such as Sobek can enable the modelling of river interventions in combination with land use interventions. This allows for a variation in interventions that does not only focus on land use changes. A combination of river interventions and land use interventions may be a suitable strategy to mitigate floods in Ketapang. Output from Wflow which is discharge can act as input for a Sobek model. In addition, utilizing a hydraulic model can simulate overflowing of the river and the water depth of the inundation.

Data is also an issue for this study. A more complete dataset for discharge can be beneficial for the model. For one, having discharge measurements at a daily timestep allows for validation and calibration of the model. Allowing the model to accurately simulate real-world conditions of Ketapang, Kalimantan. Secondly, having a design discharge for the Pawan River enables us to identify the frequency at which water overflows from the Pawan River.

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10 Appendix A: ERA5 precipitation estimates in 9 out of 320 cells

These 9 cell locations were chosen at random for the purpose of demonstrating how the precipitation estimates differ at each point.

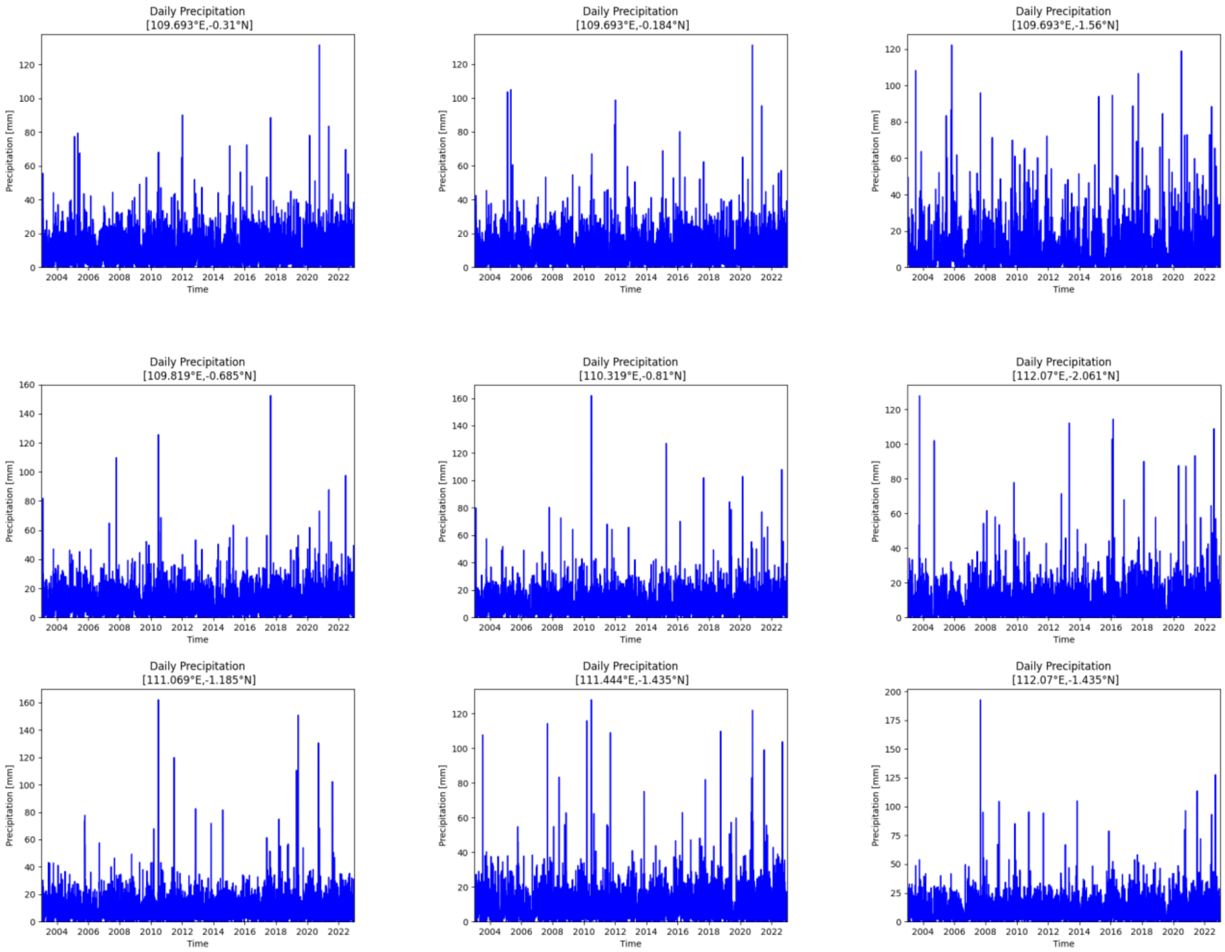

Figure 21 - ERA5 precipitation estimates in 9 out of 320 cell locations

11 Appendix B: Vito Land Use Classification Index

Table 6 below lists the classifications of the Vito land cover map. As mentioned before, land use code 40 is used for palm plantations while land use code 112 is used for forests.

Table 6 - Vito Land Use Classification Index

Land Use Code	Description
20	Shrubs
30	Herbaceous vegetation
40	Cultivated and managed vegetation/agriculture (cropland)
50	Urban/built up areas
60	Bare/sparse vegetation
70	Snow and ice
80	Permanent water bodies
90	Herbaceous wetland
100	Moss and lichen
111	Closed forest evergreen needle leaf
112	Closed forest evergreen broad leaf
113	Closed forest deciduous needle leaf
114	Closed forest deciduous broad leaf
115	Closed forest mixed
116	Closed forest unknown
121	Open forest evergreen needle leaf
122	Open forest evergreen broad leaf
123	Open forest deciduous needle leaf
124	Open forest deciduous broad leaf
125	Open forest mixed
126	Open forest unknown
200	Open sea
0	No data

12 Appendix C: Interview Notes

Here, the main points from each interview are listed.

BPP-PLH

1. One of the worst floods was 3 years ago in 2019 that caused Delta Pawan or Ketapang City to be submerged.
2. The upstream area of the villages of Tanjung Pura and Mayak experiences the worst aspects of the flood.
3. Intervention is normalisation of the river, but because of jurisdiction they cannot do anything without approval from the government of West Kalimantan. Ibu Sri believes the river must be normalized.
4. Ibu Sri handles the quality of water in the Pawan River.
5. Deforestation increased in recent years.

PUTR - SDA

1. Intervention is normalisation of the river by digging sediment/trash build up.
2. Cannot act freely and must get approval from provincial government board.
3. Floods worsened in the past 5 years.
4. Floods occur due to sea tides and precipitation from upstream area.
5. Drainage is also poor as some channels are not connected and is hard to improve due to urbanization.
6. Changing land use for concessions must have permission from government.

PUTR

1. Floods are due to sea tides and heavy rainfall.
2. Ketapang city floods can dissipate within a day.
3. Extreme land use changes due to palm concessions and illegal/legal mines.
4. No actual existing land use map.

Tanjung Pura village, Head of village

1. Floods occur 5 times in the year 2022. Every year floods will occur.
2. October 2022 was the worst flood, took 1 month to dissipate and 218 houses were submerged.
3. Floods occur mostly in wet seasons of October - May, due to runoff from the upstream area.
4. Government provides food and blankets during flood events.
5. River overflows quicker than in the past.
6. Factors could be climate change but most importantly deforestation due to concessions.
7. Riverbank erodes more and more every year. Has eroded by 3 metres.
8. No mitigation plans from government, even though village has suggested the construction of a wall or planting trees along the riverbank to prevent further erosion.
9. Deforestation occurred recently due to a cigarette thrown irresponsibly.
10. Last flood was March 2023.

11. Every time it floods, evacuate to houses that hasn’t been flooded.

Mayak village, Head of village

1. Every year it can flood 3-5 times.
2. This is because if it rains for 2 days, the river can overflow.
3. Floods can take months to dissipate due to runoff from upstream area and backwater effects from sea tides.
4. Used to be able to predict when floods would happen. But after 2010, could no longer predict and it became highly irregular.
5. Flood of October 2022 was the worst flood.
6. No plans on mitigation from government, only last flood they took flood depth measurements.
7. They receive help from a palm concession, where income from 6 hectares of their land is given to the village. The palm concession also gives food if a flood occurs.
8. All houses are submerged in the event of flood. The Mayak village evacuates to the Tanjung Pura village due to it being slightly more elevated than the Mayak village.

Palm oil concession, conservationist

1. They have 1000 ha of high conservation value (HCV) forests
2. Around 2008 floods started to occur. October 2022 it was also flooded.
3. Why orangutans are killed is because they eat the stalks of palm trees, causing a loss for the concession being unable to grow palm trees.
4. For plantation areas, land clearing can involve excavator or forest fires.
5. Their HCV was burnt in 2019, due to an employee dispute. The employee knew that if the HCV was burnt, the concession would be in more trouble compared to if the plantation area was burnt.
6. 56% of their plantation is made of peat.
7. Illegal mines also cause sediment transport, not only plantations.
8. Plans on construction of 2 water gates at the end of their river, to control discharge downstream.

DPUPR Provinsi Kalbar

1. Gathering discharge data.
2. Intervention is the normalisation of the river. (Only started with small tributaries)
3. Peat areas when dry is quite easy to experience forest fires.

BPDAS

1. Intervention is replanting and rehabilitation of forests. Focusing on mangrove forests
2. Additionally, construction of sediment traps
3. Gathering data on the Pawan Catchment

AidEnvironment

1. House was submerged during the flood of October 2022.
2. Approached by the head of PUTR to discuss floods and how to solve it.
3. Then this project was formulated.
4. Focus on conservation of orangutans in West Kalimantan.
5. However, they also want Ketapang's inundation problems to be mitigated.

Figure 22 - Image of interview being conducted