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Environmental Change Monitoring with GIS in the Four Thousand Islands region, Laos

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1. INTRODUCTION

Recently, the global climate is changing; in general, it is getting warmer. Humans are known to be drivers of climate change through the release of aerosols and greenhouse effect. Others include activities such as cutting down of trees, use of fuel to run machines, burning trees and transportation (Field et al., n.d.).

Furthermore, new research indicates that human activities and climate change have a significant impact on changes in the flow of the world's major rivers (Xu, Taylor, and Xu, 2011). The Climate changes has resulted in an increase of air temperature, sea level rise, rainfall circulation, extent of sea ice and mountain ice caps, and season length (Samuel & Victor, 2011).

The world's most precious natural resources include wetlands, which are vital habitats for both flora and wildlife and play a significant role in water storage, filtration, and supply, flood control, and toxin retention (Mwakaje, 2009). Increase in population has direct impact on increased pressure on wetland as result of the need for more land for agriculture, also climate change has had impact on wetland ecosystems. In wetland distribution, size, and dynamics must be managed for maintaining wetland resources. Wetland maps and inventories can offer vital information for managing, restoring, and conserving wetlands. For mapping and monitoring wetland resources, Geographic Information Systems (GIS) and Remote Sensing (RS) technologies have shown to be helpful. Currently, it is possible to obtain quality images through advance in geospatial technology (Salimi et al., 2021; Wu, 2013; Yang et al., 2016).

Laos is a landlocked country which is rich in natural and environmental resources for instance, rivers, waterfalls, tropical forests, wetlands, plateaus, mountains etc. Laos borders with Thailand, Vietnam, Cambodia, China, and Myanmar. The population is 7,3 million in 2023 and the total area is 230,800 km^2 (Worldometer, 2023).

The unspoiled wetlands, woodland, rapids, and the deep pools of the Mekong provide an important ecosystem service for millions of people who live along the lower sections of the river many of which are dependent on it with their livelihoods. One of the biggest threats to the availability of natural resources is non-sustainable fishery, which is worsened through the expansion of hydropower as well as through the impacts of climate change. Without immediate intervention the unspoiled wetlands run in danger of being destroyed within the next ten years. Consequently, the basis of the population´s life threatened, and plant and animal species are at risk of becoming extinct (WWF, 2012).

In southern part of Laos has the world widest waterfall average width 10,783 meters and maximum width 12,954 meters (World Waterfall Database, 2017). This waterfall called Khonephapheng waterfall is in Four thousand Islands (Siphandone). In Four thousand islands the population is about 100,000 and area 1718 km^2 (NRO, 2020).

In the South of Siphandone, the Mekong crosses the national border of Cambodia, where it forms a river landscape which represents a mosaic of diverse natural habitats. Through the special hydrology of the water system, river basins which are up to 70 meters deep have been created on the Cambodian side of the river. These serve as retreat areas for many different fish species, especially during periods of low water.

The climate of the region is determined by the monsoon cycle, which represents an impressive change of the wind and weather conditions. Between the end of May and October, the region is marked by the prevalence of heavy rain falls, which is due to the influence of humidity and warm south-westerly air flows. The annual average rainfall of the region is approximately 1,750 mm. In contrast to that, the weather conditions are determined by dry air streams which are of continental origin from November onwards until the beginning of May. The transitions between these two general weather conditions are very short and they have a profound influence on the run-off behavior of the Mekong. The river-runoff shows seasonal variation, during the dry season it is 1060 m^3/sec and during the rainy season it is about 57800 m^3/sec. They result in a change of the water level of up to five meters (NRO, 2020; WWF, 2012).

1.1 Problem statement

Climate change and sea level rise (SLR) have threatened and posed major threats to coastal populations all over the world. This movement is likely to gain speed in the future. Based on IPPC report on the Intergovernmental Panel on Climate Change, coastal systems are affected by rise in sea level, rise in pH of ocean, increase in ocean temperatures. According to IPPC, human displacement is expected due to land loss as a result of flooding along the coastline by the year 2100 (Field et al., n.d.)

According to the initial report of the Climate Change Vulnerability Assessment developed under the IUCN's Mekong WET project. The use of wetland in the Four Thousand Islands by community for sources of income such as rice production, tourism, fishery, and livestock keeping. Also, society's welfare has been affected by droughts and floods in the Four Thousand Islands. Climate change-related hazards such as coastal flooding, erosion and inundation, land submergence, and water contamination are becoming a major concerned in the Four Thousand Islands area (IUCN, 2021).

Due to droughts, and floods, water regime changes occurred in the Mekong River over the past two years. The circumstances have had a significant impact on local livelihoods. Due to water restrictions, agricultural outputs were extremely low. Low fish catches were caused by migratory fish not moving across the river as they normally would, particularly during the dry season. Climate extremes have also had an impact on ecotourism, since fewer monkeys, birds, pangolins, and other animals are visiting the wetland due to lower water levels. Freshwater fisheries around the Four Thousand Islands are similarly affected by the decline in biodiversity, which has an impact on livelihoods in many different levels. Low water levels have affected the waterfalls, the primary attractions in the villages, which has diminished tourism in the area (IUCN, 2021).

The Mekong River's tributaries and other smaller water bodies provide the Lao PDR with abundant water resources. Due to their significant contribution to the macroeconomic growth of the nation and the means of subsistence for local inhabitants, the Mekong River tributaries are crucial for the nation. Although there is still a low per-person water demand, water resources have recently become more important because of the growing importance of agriculture and hydropower. The Mekong River is currently being dammed, which will affect the river's hydrological profile and ecology. The hydrology of the Mekong River Basin is anticipated to be far more affected by these changes than the anticipated trends in climate change. All these changes have significant effects on the region's water resource management issues, for instance through changing the processes of sediment erosion and deposition (The World Bank Group and the Asian Development Bank., 2021).

The effects of climate change will be manifested through an increase in extreme weather events (Qu et al., 2023). According to prognoses, extreme precipitation events and long-term droughts will occur more frequently in the future (Phi Hoang et al., 2016). Particularly, the population groups living below the poverty line and not having any economic buffer will be hit by the consequences of climate change. In most cases, their basic living conditions, such as food, water and construction material depend on the natural resources provided by the wetlands.

Dolphins in the rivers serve as crucial markers of the health of the waterways. Only in the Cheuteal trans-boundary pool between southern Laos and northern Cambodia can we discover the Mekong River Dolphins (also known as Irrawaddy Dolphins) in Laos. The fact that there are fewer of these river dolphins an iconic species associated with the Four Thousand Islands (Siphandone) especially considering the two that have been discovered dead in recent months underscores the need for increasing our conservation efforts and continue collaborating with local authorities and communities to safeguard these and other crucial freshwater species (WWF-Laos, 2021). Climate change is a worldwide challenge and the Mekong River ecosystem cannot be isolated, meaning that water level changes are experiences in both wet and dry seasons. These seasonal changes in water level require regular and accurate monitoring using the current available technologies and integrating the data obtained from this measurement to make inform data in addressing environmental changes. The data obtain as a result of this study can be used by the government of Laos to prepare for the inevitable changes associated with climate changes and also applied control or management measures as a result of climate changes.

1.2 Justification of the study

There is a limited literature on the impact of climate change and changes in water level and vegetation diversity based on the available data from GIS. Hence, there is a need to study the impact of climate change on the Four Thousand Islands and document the findings in this study.

1.3 Objective of the study

General objective

To determine environmental changes between 2010-2020 in the Four Thousand Islands (Siphandone) region in Laos, by using geoinformation techniques.

Specific objectives

- To determine the effects of the change of the water level in the dry and wet seasons of selected years.
- To quantify the dynamics of the changes in vegetation/ bareland/ water cover in the dry and wet seasons of the selected years.
- To evaluate how geoinformation technology and satellite images supported the environmental change analysis.

2. LITERATURE REVIEW

Droughts and floods represent the climatic extremes, affecting the water availability for agriculture. Droughts have three kinds of effects: economic, environmental, and societal. Aside from forest fires, water supply reduction, the need for new water supply sources. Economic repercussions are related to the affected industries such as agriculture, dairy production, animal rearing, and leisure activities. During the flood season, soil erosion can increase the concentration of silt in the runoff and excess floodwater. Environmental consequences include damage to species and habitats, worsening of water quality, and disease spread. We cover the findings from NDVI images of environmental changes in the Four Thousand Islands. In this progress satellite images (Landsat 5 & 8) imported to QGIS to determine water area, vegetation cover and bare land in dry/wet season by using the Raster Calculation function and Raster layer unique value report.

2.1 GIS technique

GIS is a set of information technology tools and equipment, utilized in the administration and organization of geographic data. Computerized storage, processing, and retrieval systems with hardware and software specifically created to deal with geographically related spatial data, and the accompanying informative attribute are referred to as GIS. Layers of spatial data are frequently used to represent topography or other environmental factors. GIS technology is increasingly being used to create models that simulate the interactions of complex natural systems by fusing diverse map and satellite information sources. Not only maps but also illustrations, animations, and other cartographic products can be created using GIS (Bettinger et al., 2017).

To assist maintain a sustainable water and food supply in accordance with the environmental potential, technologies like GIS must be applied due to the spatial aspects of the increased pressure on land resources brought on by the expanding global population. The idea of "sustainable rural development" envisions a landscape that is managed holistically with the exploitation of natural resources, including climate, at its core (Maracchi et al., 2000).

There are countless GIS applications that can be used both nationally and locally. For instance, integrating information on soils, elevation, and rainfall to calculate the size and location of biologically acceptable areas, agricultural planners may use geographical data to choose the optimum zones for crops, determine water area, vegetation covers and land covers, etc.

Each information layer in a GIS gives the user the option to consider its role in the processes. Besides the simple overlay of the various themes, the link between numerous levels can be reconstructed using either straightforward formulas or intricate models. Graphical representations or descriptive indexes are used to retrieve the final results (Sivakumar et al., 2003).

2.2 GIS in monitoring environmental change

Recently, fresh water sources are a major problem for the population in the world because all human activities require fresh water, for instance, drinking, cooking, washing. Furthermore, industry requires a big amount of fresh water. Thus, we must monitor and plan to solve this problem. Geospatial technology has become a particularly useful tool in assessing, monitoring, and conserving water resources due to its data integration and analysis functions. Remote sensing provides data covering huge and inaccessible areas in a short time. Extensive research has been conducted on the use of Remote Sensing (RS) and Geographic Information System (GIS) techniques for mapping water resources in various regions of the world (Dar et al., 2010).

Annually, various natural and hydrometeorological catastrophes such as floods, flash floods, droughts, hurricanes, typhoons, earthquakes, and landslides cause considerable damage to human lives and property around the world. Global warming and climate change significantly affect the hydrological cycle, changing the local dry/wet seasons having severe consequences to, among others, agriculture, and lifestyle (Du et al., 2013). The modified runoff accelerates riverbed and soil erosion influencing the surrounding environment, including soil, and ground cover, as well as their interactions. GIS technology has a significant potential for supporting erosion inventory, assessment, and modelling (Sivakumar et al., 2003).

2.3 Water level change

The movement of plant seedlings, animal migration, and the transit of physical materials in and by water helps to connect ecosystems. Besides these natural processes, the movement of water from catchments to coast poses numerous issues for the management of human activities that may have an impact on the supply of ecosystem services (Alvarez-Romero et al. 2011).

Riparian communities have been forced to adapt to enormous swings in water levels, which are far more significant than those in marine systems. This has brought attention to the necessity of incorporating climate change-induced water level changes into water level management. In the past, catastrophes have been caused by high water levels on rivers, while coastal bluff erosion is triggered by low and variable water levels (Kayastha et al. 2022; Gronewold et al. 2013).

2.4 Wetland

Wetlands are areas that are rich in diversity and covered with water in a seasonal or permanent period. Wetlands can provide habitat for both aquatic and terrestrial organisms. The presence of water for an extended period provides conditions that favor the growth of specially adapted plants (hydrophytes) and the creation of characteristic wetland (hydric) soils (EPA, 2022). Hydrologic processes govern the creation, persistence, size, and function of wetlands. Geology, topography, and climate are the primary drivers of the distribution and changes in wetland type, vegetation composition, and soil type. Variations are also caused by the circulation of water through or within the wetland, the quality of the water, and the degree of natural or human-induced disturbance (EPA, 2002).

River basin systems and related wetlands are an example of ecosystems which suffered greatly because of human activity. Globally, 69 -71% of wetlands have been lost since 1900 AD. Wetland loss has been faster throughout the twentieth and early twenty-first centuries than before. Inland natural wetlands have suffered greater and faster losses than coastal natural wetlands (Avis, Weaver, and Meissner, 2011; Davidson, 2014).

2.5 Climate change

In Southeast Asia, homes, infrastructure, crops, and fisheries are already being destroyed by rising temperatures, changing rainfall patterns, river flows, floods, and droughts. As a result, food shortages and reduced livelihoods affect vulnerable people. The following changes are anticipated in the upcoming decades, according to the Mekong River Commission (MRC). 16-17% decrease in rainfall by 2060; higher temperatures throughout the basin and across seasons; decreased agricultural yields that, in turn, force changes in agricultural practices, irrigation, and technological advancements; declining hydropower production; decreased navigation during the dry season, particularly in the upper Mekong; more frequent washouts and landslides that harm roads and other infrastructure; disappearing plant and animal species; and soil erosion. Since 2000, Lao PDR has experienced a considerable loss of forest cover, which has had a negative effect on the nation's greenhouse gas emission data. Lao PDR continues to contribute very little to the world's greenhouse gas emissions. Because it is obvious how climate change is affecting Laos, Vientiane has made the decision to help reverse global trends. The Lao PDR government has committed to increasing the country's forest cover to 70%, improving the resilience of agriculture, and preserving and restoring priceless terrestrial and freshwater ecosystems. Reversing deforestation, forest degradation, and loss of biodiversity are national priorities. Meanwhile, some areas will need to receive special care. Communities in some areas of Savannakhet and Champassak, for instance, depend on wetlands for their way of life and cultural practices. Flood and drought cycles that alter wetlands, reduce biodiversity, and block off some towns from access to wetlands are being exacerbated by climate change (Center for Excellence in Disaster Management, 2021).

3. MATERIAL AND METHOD

The character, spreading and change of water bodies, land, and vegetation, can be analyzed by Geographic Information Systems (GIS) using satellite images. QGIS is an open-source software, which processes data precisely and efficiently. Changes in surface water are essential indicators of environmental, climatic, and anthropogenic processes. Throughout the last four decades, satellites, such as Landsat, have been providing data that may be used to extract land cover types such as forest and water (Sivakumar et al., 2003).

First, Landsat images must be preprocessed, since they are given as raw values, before calculating the necessary indices to generate variation maps. We used the QGIS software to analyze NDVI maps after we downloaded them online. We created NDVI water, land, and vegetation cover maps by using raster calculation tool in the QGIS software. We used image slicing to separate water, land, and vegetation in this study.

3.1 Study Site

Siphandone (translated from Laotian as "Four Thousand Islands"), located in southern of Laos. 14° 3'31.91"N 105°53'33.59"E (Fig.2). It is an important ecological area of the Mekong River. The country's biggest concentration of fish consumption occurs in this area, which is also the habitat of the critically endangered Irrawaddy River dolphin. It covers a section of the Mekong River beginning from the Don Khong Island to Cambodia´s international border. The total land area is 1718 km^2 (NRO, 2020). This area is composed of a multitude of islands, whose banks are surrounded by alluvial forests and gallery forests, when the river exceeds the high-water mark. In this area, which is characterized by many waterfalls and rapids water flow, the Mekong overcomes a height difference of 30 meters. For this reason, it is not possible to pass through the river by ship. The shores of the river and the most important islands are covered by steep slopes, many of which are used to a limited extent for the cultivation of agricultural products. On the biggest islands, rice is cultivated during the dry seasons. Usually, smaller islands are overgrown by natural vegetation, which is seasonally flooded. Some smaller islands are therefore characterized by grassland and vast sandy beaches. At the rapids, the river landscape is marked by rock faces which are overgrown with bushes (WWF 2012; NRO 2020).

Mekong River connects countries in south Asia hence it's an important river in terms of social economic point of view (Fig.1). It also surrounds about 70 million people. Its average annual discharge is about 475 cubic kilometers. Its length is about 4900 km that flows through 6 countries such as Myanmar, China, Laos, Thailand, Vietnam and Cambodia, its basin encompasses several temperature zones and is vulnerable to changes in the global climate (MRC, 2023; Pearse-Smith, 2012).

Four Thousand Islands is a unique region, where a large number of islands are surrounded by riparian forests. The flow of water dynamically forms the islands and the waterfalls. Based on the information collected through interviews, the main activities in four thousand islands are Fishery, agriculture, and livestock. In the 2020s this area was affected by climate change which is shown in extreme hot weather and flash floods that have a negative impact on huge areas of crops. Other sources of income are from the tourism industry.

Kang, (2019) reported that in 2019. The southern part of Laos was desolated by significant floods after the region was hit by two tropical storms. Floods caused by tropical depressions Podul and Kajiki are still being addressed by disaster relief activities in Lao PDR and Thailand. In Lao, where the government is conducting a National Joint Needs Assessment in the provinces hit by the floods of Champasak, Saravan, Sekong, Savannakhet, Attapeu, and Khammouan, at least 40,000 people have been displaced (OCHA, 2019).

The provinces of Champasack, Salavanh, Sekong, Attapeu, and Savannakhet are among those that are impacted. Residents of these areas are desperately attempting to defend their houses, livestock, and crops because they have been severely devasted. In the Lao People's Democratic Republic (Lao PDR), drought is a pressing problem. For instance, the Mekong River reached its lowest level in 100 years in 2019 and the monsoon rains fell less frequently than usual. As a result, 18% of paddy crops were destroyed in the northern provinces where the drought was worst (UNDRR, 2022).

The 2019 wet season, which ran from May to October, Laos PDR was marked by drought conditions in the country's north and heavy, irregular rainfall in other regions. Widespread flooding brought on by a tropical cyclone in the southern region of Lao PDR affected an estimated 765,000 people in six provinces and cost an estimated USD 164 million in damages. The 2019 floods exacerbated the effects of the 2018 floods, resulting in extensive livelihood destruction, disruption of economic activity, and degradation of social conditions, all of which elevated the dangers of food insecurity (AHA Centre, 2019).

Impact from Climate Change result in seasonal shift (Graph 2) below shown that the length of floods period was shorter in 2019. It was held only 47 days from 15th of August 2019 to 1st of October 2019 and after that was a drought season. That means, drought took longer period in

2019 than other year, in addition we made comparable from 1998 to 2020 drought period was increasing relate to floods or high-water level period decrease.

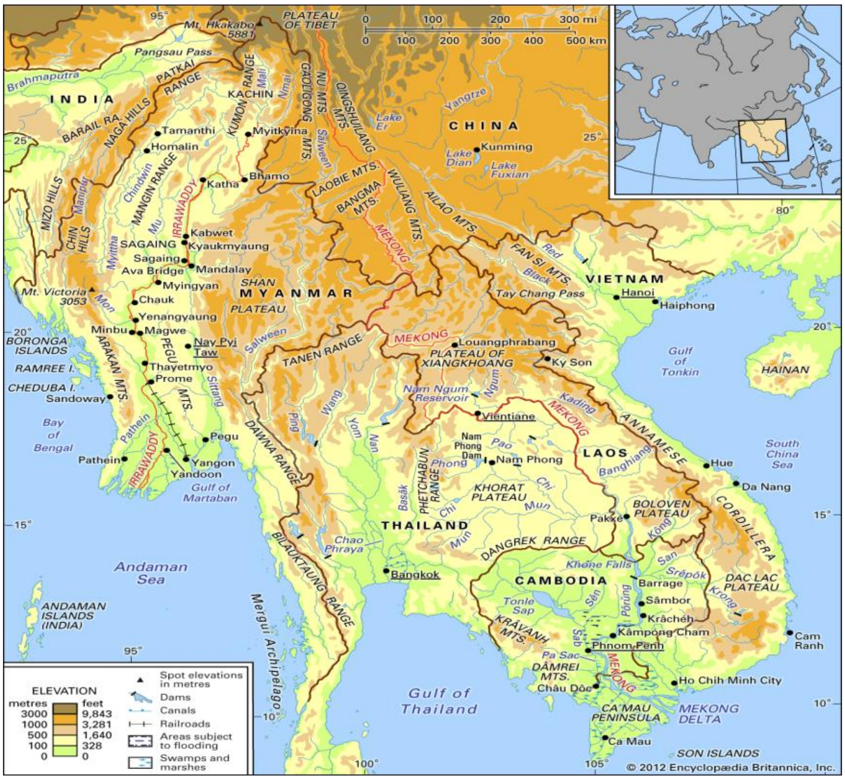


Figure 1: Mekong River Map. Source (Gilbert F. White et al., 2023).

Figure 2: Satellite image of Four Thousand Islands (Google Earth, 2023).

3.2 Methodology

The NDVI images were copied file's name from https://earthexplorer.usgs.gov/, and create a list of Landsat file's name in Notepad, we used Landsat 5 for the year 2011 and Landsat 8 for the year 2015, 2019 and 2020 (both OLI and TIRS data) (Fig.3). Furthermore, we ordered NDVI index maps from https://espa.cr.usgs.gov/index/, by entered the Landsat file's name. We accessed the data by QGIS 3.30 to determine water, land and vegetation cover using the Raster Calculation function.

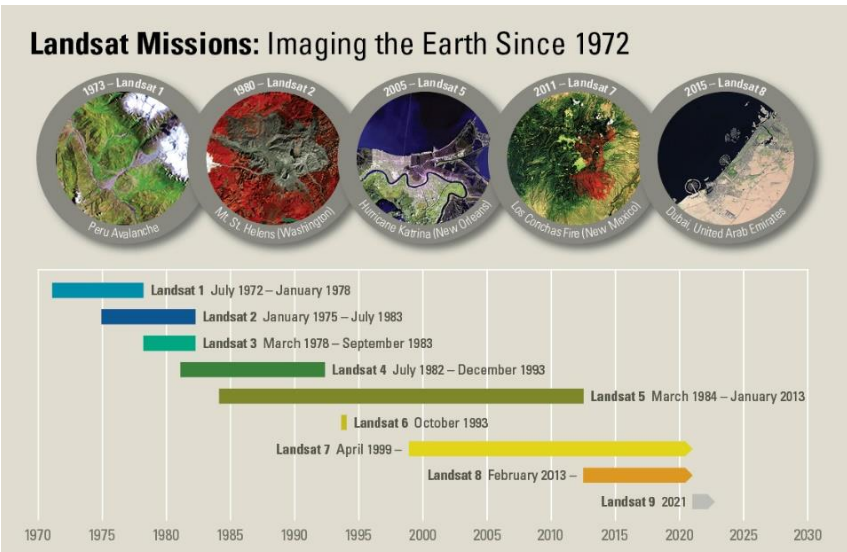
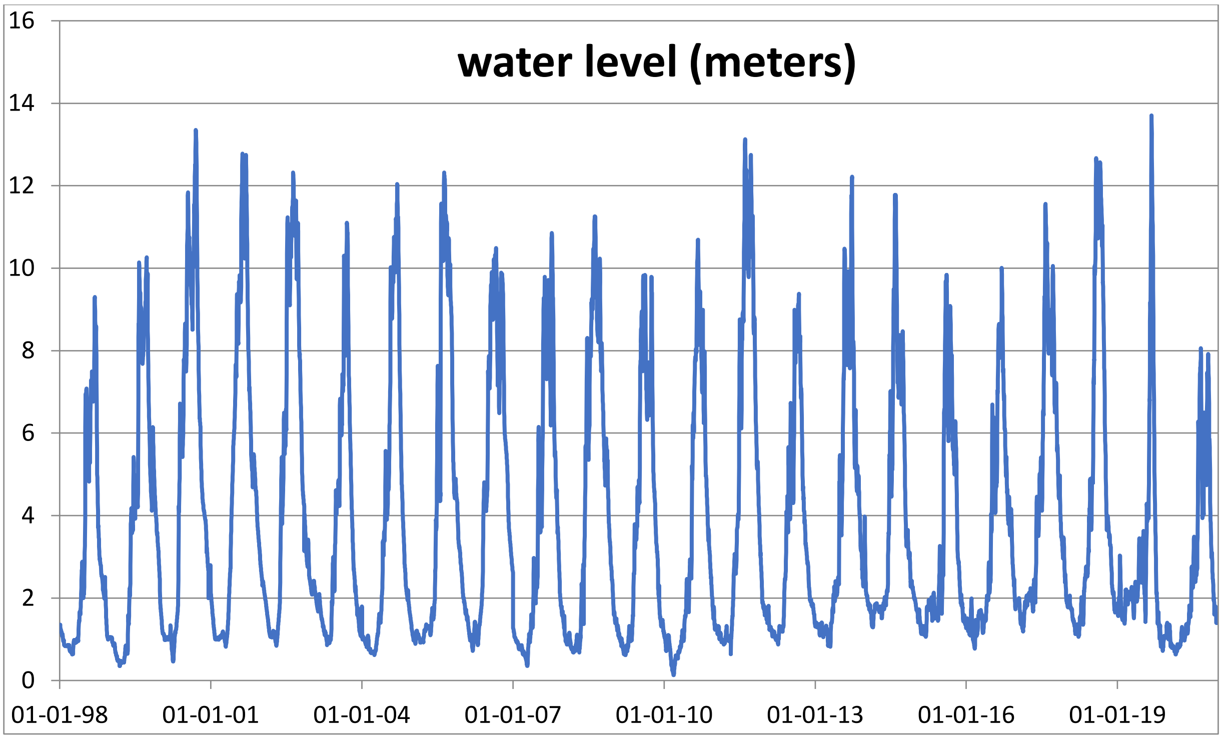


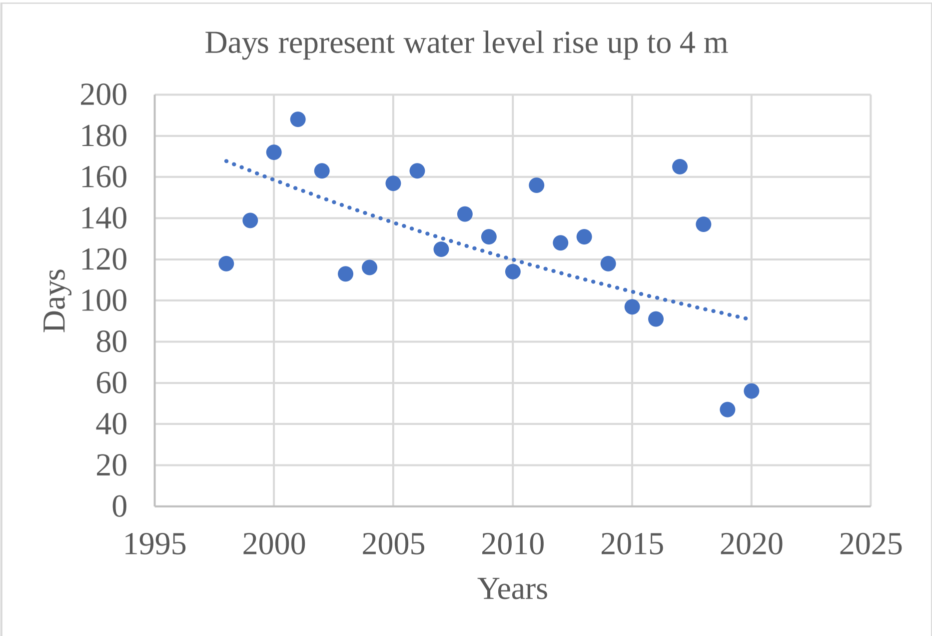
Figure 3: Demonstrates the availability of the Landsat images (Landsat Mission, 2021).

3.3 Water level data.

We used time series of water level data from 1998–2020 (Meteorological Department, 1998), to set a goal for getting data (Graph 1).



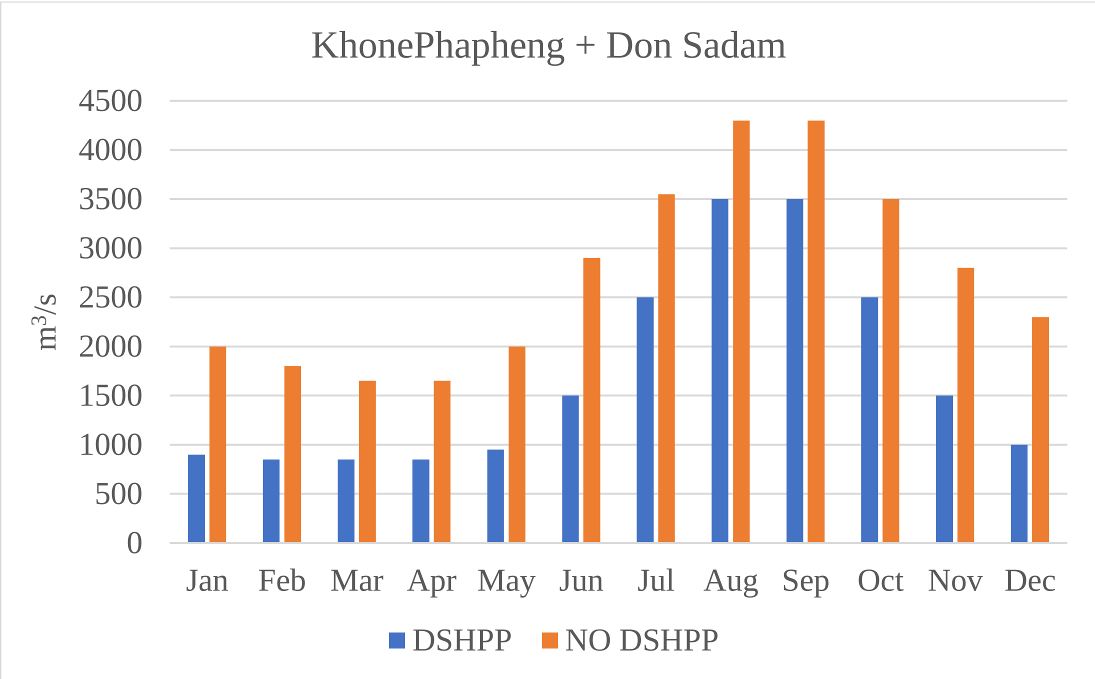
Graph 1: Time series of Mekong River water level from 1998 – 2020 (Meteorological Department, 1998).



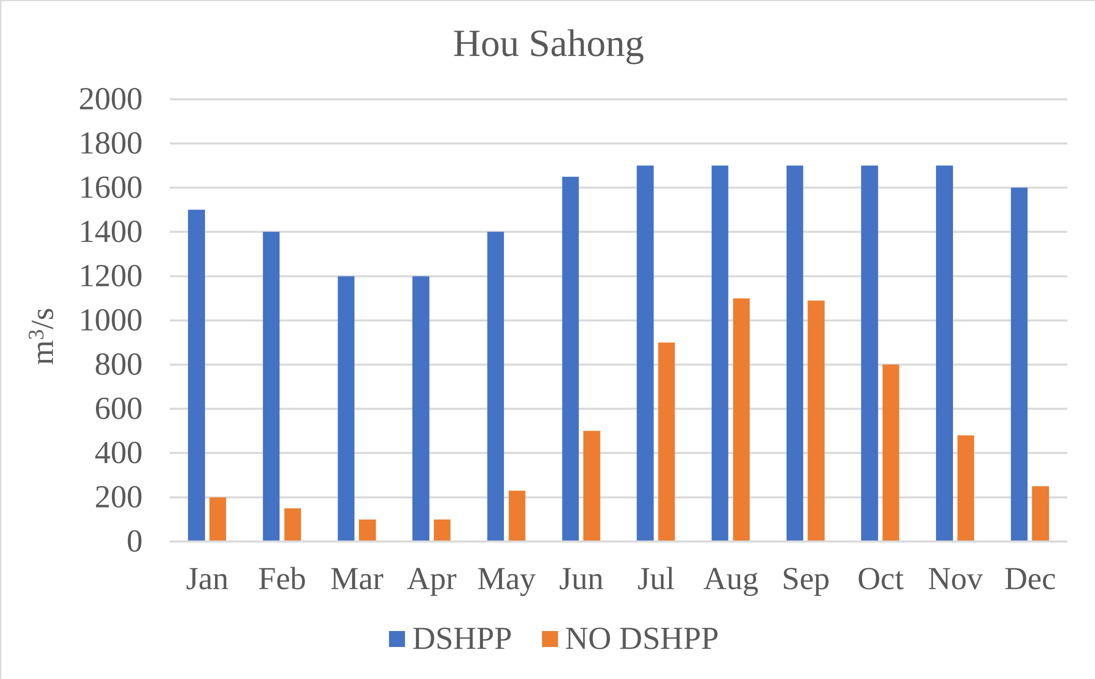
Graph 2: Comparison length of floods period from 1998-2010.

3.4 Water flow changes in Siphandone area.

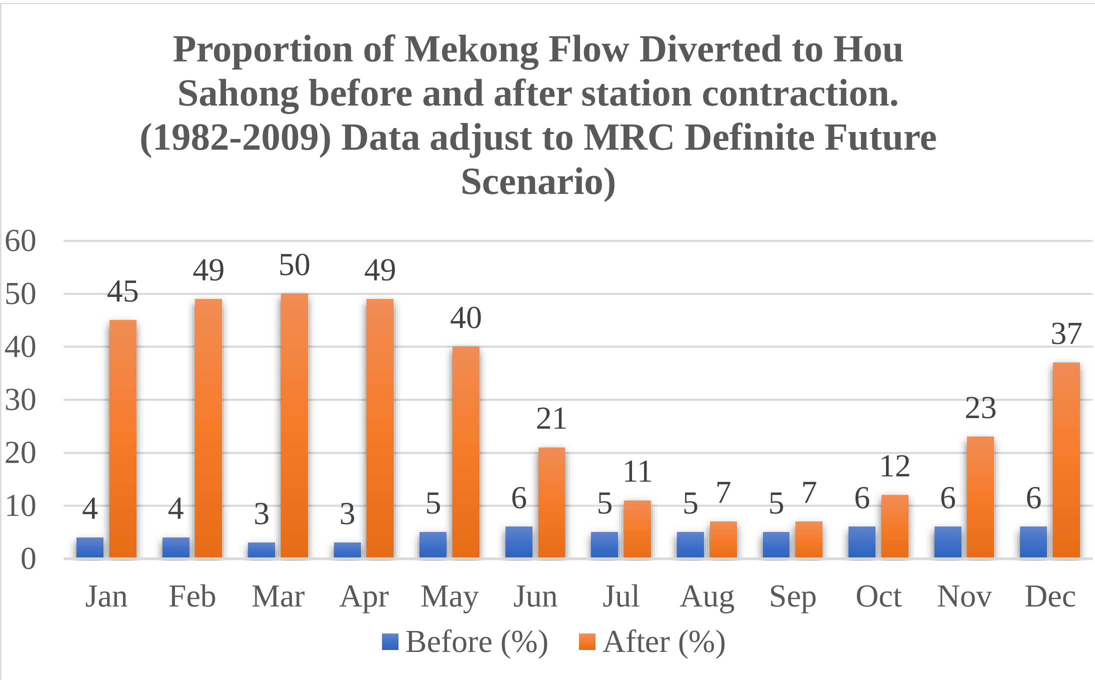
The true major factors that effected Mekong river water levels based on 2013 National consulting company as a secondary data was, water level before construction Don Sa Hong Power Plant (DSHPP) and after its construction based on monthly water flow rate data in KhonePhapeng + Don Sadam (Graph 3) during this construction the water ways ground was modified leading to changes in water flow rate where by the flow rate before construction was significantly low in all the month of the year after modification the flow rate was high (Graph 4). This is also confirmed by the data obtain between 1982-2009 as a percentage flow rate due to the presence of water way obstacle (dam) (Graph 5). These water level changes characteristic can be used to determine changes of water level difference water way's location by comparing to the secondary data.



Graph 3 : DSHPP's impact on maximum flow at Khonephapheng waterfall. Source: (National Consulting Company, 2013)



Graph 4: DSHPP's impact on maximum flow at Hou Sahong. Source: (National Consulting Company, 2013)



Graph 5: Proportion of Mekong flow before and after DSHPP. Source: (National Consulting Company, 2013)

3.4 Landsat images

Between July 1982 and May 2012, the Landsat Thematic Mapper (TM) sensor, which had a 16-day repeating cycle and was referenced to the Worldwide Reference System-2 (Table 1 and Table 2), was carried onboard by Landsat 4 and 5. In the period from November 2011 to December 2012, very few cloud-free images were taken. Decommissioning of the satellites started in January 2013 (Earth Resources Observation and Science (EROS) Center, 2018).

Landsat data products stored in the USGS databases, can be searched, and downloaded for free from several data sources. Many Landsat-related tools and services are available to assist users, maybe the most frequently used one is the Earth Explorer (https://earthexplorer.usgs.gov). We use Landsat 5 for 2011 and Landsat 8-9 images for 2015 – 2020 to determine water and vegetation cover in the Four Thousand Islands region.

Landsat 4-5	**Wavelength (Micrometers)**	**Resolution (meters)**	**Advantage of use**
Band 1 – Blue	0.45-0.52	30	"Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation"
Band 2 – Green	0.52-0.60	30	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 3 – Red	0.63-0.69	30	Discriminates vegetation slopes
Band 4 – Near Infrared (NIR)	0.76-0.90	30	Emphasizes biomass content and shorelines
Band 5 – Near Infrared (NIR)	1.55-1.75	30	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 6 – Thermal	10.40-12.50	120 (resampled to 30)	Thermal mapping and estimated soil moisture

Band 7 – Shortwave Infrared (SWIR)	2.08-2.35	30	Hydrothermally altered rocks associated with mineral deposits

Table 1: Landsat 4-5 wavelength and advantages of use. (USGS, no date).

Bands 8-9	**Wavelength (Micrometers)**	**Resolution (meters)**	**Advantage of use**
Bands 1 – Coastal aerosol	0.43-0.45	30	Coastal and aerosol Studies
Band 2 – Blue	0.45-0.51	30	Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
Band 3 – Green	0.53-0.59	30	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4 – Red	0.64-0.67	30	Discriminates vegetation slopes
Band 5 – Near Infrared (NIR)	0.85-0.88	30	Emphasizes biomass content and shorelines
Band 6 - Shortwave Infrared (SWIR) 1	1.57-1.65	30	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 7 – Shortwave Infrared (SWIR) 2	2.11-2.29	30	Improved moisture content of soil and vegetation; penetrates thin clouds
Band 8 – Panchromatic	0.50-0.68	15	15-meter resolution, sharper image definition
Band 9 – Cirrus	1.36-1.38	30	Improved detection of cirrus cloud contamination
Band 10 – Thermal Infrared (TIR) 1	10.6-11.19	100	100-meter resolution, thermal mapping, and estimated soil moisture

Band 11 – Thermal Infrared (TIRS) 2	11.50-12.51	100	100-meter resolution, improved thermal mapping and estimated soil moisture

Table 2: Landsat 8-9 Wavelength and Advantage of use. (USGS, n.d.).

3.5 Quantum Geographical Information System

QGIS is a geographic information system that is open source. QGIS aims to be user-friendly with comprehensive capabilities and features. The project's primary purpose was to develop a data viewer. By the time, QGIS has progressed to the point where it is widely utilized for daily GIS data handling and analysis. QGIS is compatible with a variety of raster and vector data formats (Ohri, Mishra, and Prakash Maurya, 2015; Dipali et al., 2019). QGIS is free to use and can have its performance enhanced by a broad variety of third-party plugins created by its large community. Recently, many QGIS plugins have been created to serve environmental purposes, such as the prediction of evapotranspiration, mapping of near-surface air temperatures, support of the mitigation of climate change, and evaluation of aquatic ecosystems (Ellsäßer et al., 2020; Lindberg et al., 2018a, 2018b; Touati et al., 2020).

3.6 Raster files

Raster images are matrices composed of pixels (picture elements). Each of them has at least one assorted attribute, e.g., color or intensity data. The spatial resolution of the raster images is defined as the size of the rectangular area represented by one pixel. The larger the pixel size, the more integrated the information is over a broader region, making the image appear less sharo (University of Michigan Library, 2022).

3.7 Normalized Difference Vegetation Index

NDVI indicates chlorophyll activity. It is frequently used to identify major land cover categories, like vegetation, water, and bare land. It is used for monitoring vegetation condition, since the index value is proportional to the vegetation density and photosynthesis intensity. Limited moisture and nutrient availability is expressed by a NDVI value close to the possible minimum for vegetation (approximately 0.1 and full coverage with healthy vegetation is expressed by the maximum value (usually close to 1) (Pettorelli et al. 2005; Walter-Shea, Viña, and Hayes, n.d.).

The spectral absorption characteristics of water in the visible and NIR bands, as well as normalized indices, such as NDVI are utilized to extract water features from satellite images and to aid in water feature classification (Zhongshi et al., n.d.; Mc Feeters 2014).

Several satellite sensors detect red and near-infrared light waves reflected by terrestrial surfaces. Scientists use mathematical procedures (algorithms) to convert raw satellite data on these light waves into vegetation indexes. A vegetation index is an algorithm that rates each pixel in a satellite image's greenness, or the relative density and health of vegetation (USGS, 1972).

There are various vegetation indices, the Normalized Difference Vegetation Index is one of the most extensively utilized (NDVI). The NDVI scale runs from +1.0 to -1.0. NDVI readings are typically low in areas of barren rock, sand, or snow (for example, 0.1 or less). Moderate NDVI values may occur from vegetation cover, including bushes and grasslands, or from vegetative parts (about 0.2 to 0.5). High NDVI values (about 0.6 to 0.9) indicate thick vegetation, such as that found in temperate and tropical rainforests, or crops in their peak development stage (Fig.4) (Brown, 2018).

As sunlight strikes an object, certain wavelengths are absorbed while others are reflected. Chlorophyll, a pigment found in plant leaves, absorbs visible light strongly (from 0.4 to 0.7 µm) for use in photosynthesis. In contrast, the cell structure of the leaves substantially reflects near-infrared light (from 0.7 to 1.1 µm). The more leaves a plant has, the more of these light wavelengths are influenced (Fig.5) (John weier and David Herring, 2000).

NDVI Formula:

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

$$NDVI = \frac{(Band\ 4 - Band\ 3)}{(Band\ 4 + Band\ 3)}$$

$$NDVI = \frac{(Band5 - Band4)}{(Band\ 5 + Band\ 4)}$$

Figure 4: NDVI formular for Landsat (4-9)(Landsat Mission, n.d.)

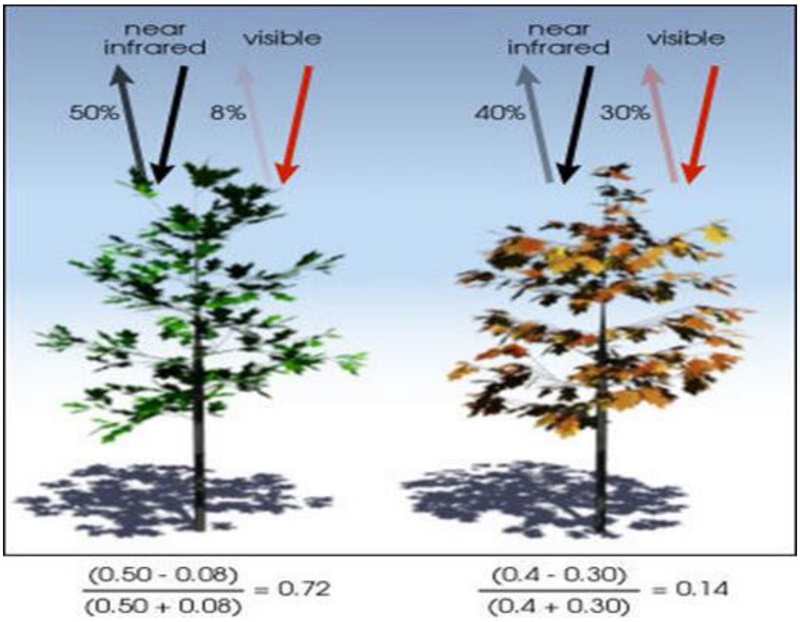


Figure 5: Representing healthy vegetation reflectance. (GIS Geography, 2022).

NDVI is commonly used to identify vegetation and measure their health and vitality. The NDVI has been positively correlated to measures such as Leaf Are Index and projective cover. The spectral signature of the vegetation with wavelength on the X axis and reflectance on the Y axis, displays a sudden increase in reflectance between the red and the NIR wavelengths (Figure 6), which is due to Chlorophyll activity, i.e., photosynthesis. Light is absorbed in the red region of the spectrum while internal cellular structure of the vegetation can affect the near infrared region. In general, healthy and /or dense vegetation reflects much of the near infrared light, but the red is absorbed. When the vegetation is sparce or not so healthy, we can see a decrease in the near infrared reflectance and otherwise in the red reflectance, as there is less chlorophyll to absorb the red light. The NDVI combines the data of the red and near infrared bands in a single representative value. The reflectance of the red band is subtracted from that of the near infrared band and divided by the sum of the two to ensure that the number falls always between -1 and +1. Furthermore, it can be used to identify other features in an image too. Water has very distinctive values of NDVI as almost all near infrared light is absorbed by the water and the red reflectance value is higher than the near infrared. Resultingly, this number will become negative (Solgi, Ahmadi and Seidel, 2023).

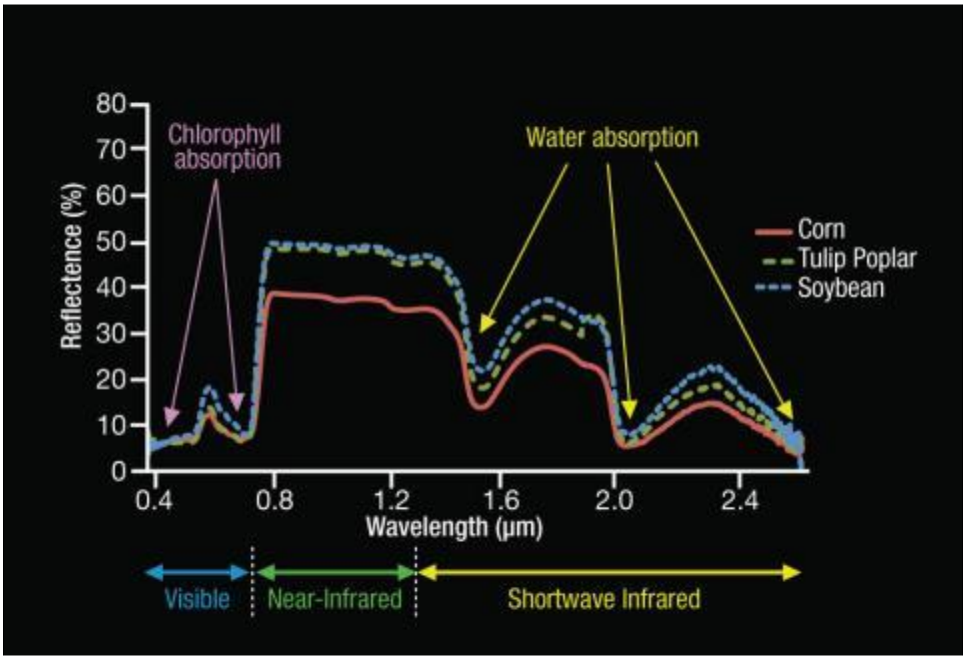


Figure 6: A graph of the amount of reflection in wavelength. (National Aeronautics and Space Administration, 2010).

3.8 Water occurrence map

To obtain Water Occurrence map the following site was use https://global-surface-water.appspot.com/map. Si phan don, Laos was entered and water occurrence between 1984-2021 was selected. The result generated data showing water occurrence in different grades (level). Based on color code, the following scale color codes were obtained, where blue represent 100% water occurrence between pink through purple where water occurrence is considered sometime (0% < occurrence < 100%) NB, paler shade indicates areas where occurrence of water is less frequent.

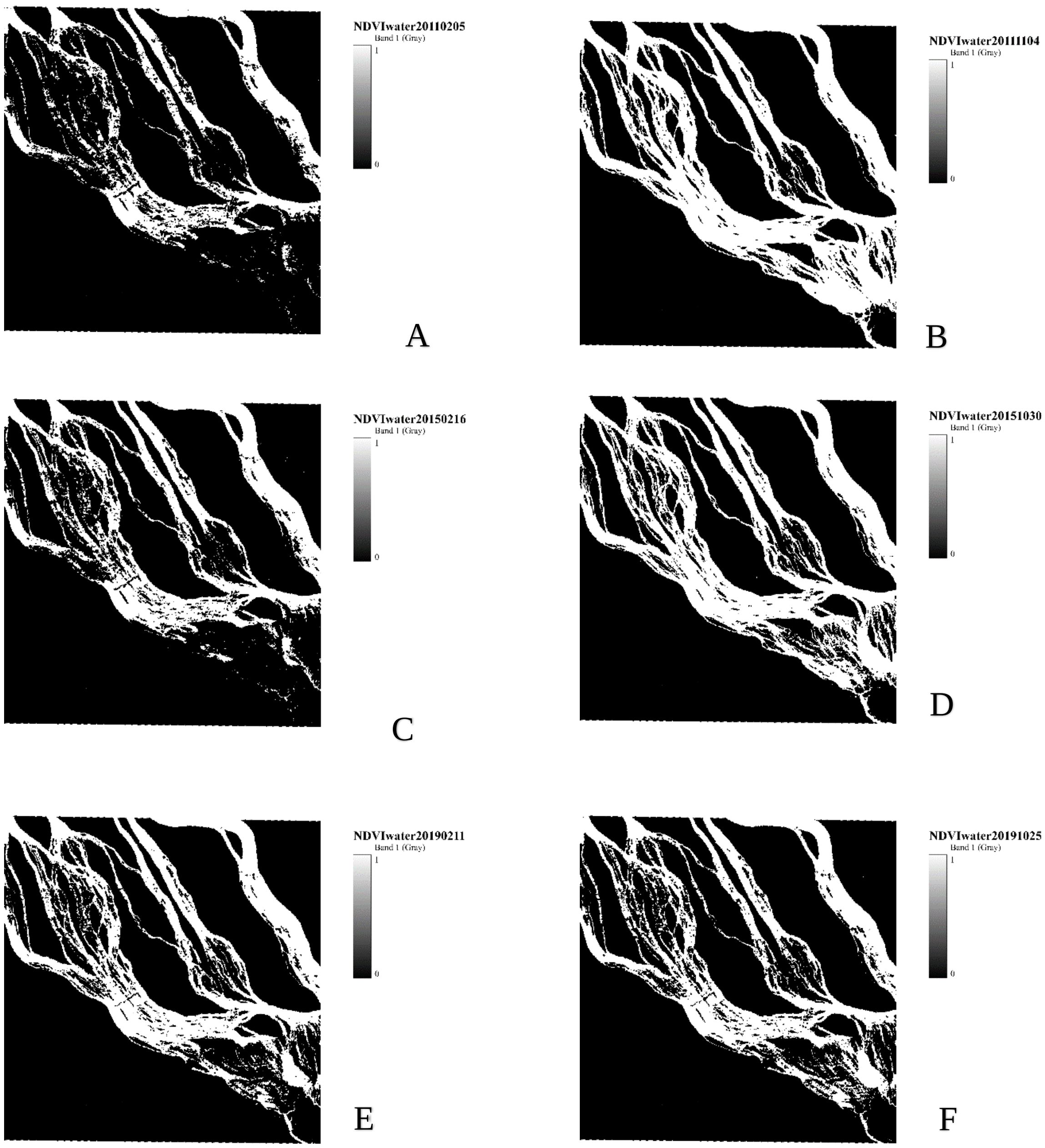
The image was download from https://global-surface-water.appspot.com/#features by selecting the coordinated 20-30N, 100-110E and files were download from symbology under data set QGIS and display in desktop GIS tools by use of the symbology used in the Global Surface Explore. In order to get the NDVI images, the link https://espa.cr.usgs.gov/index/ was used to order the NDVI images from year 2011, 2015, 2019 and 2020 to do this, account was create and order made under "new order" icon, the date to be download was insert and request submitted. The images were sent to the email address used to create account from the link that is used to access the images, the images were used to calculate the water, land and vegetation area as follows.

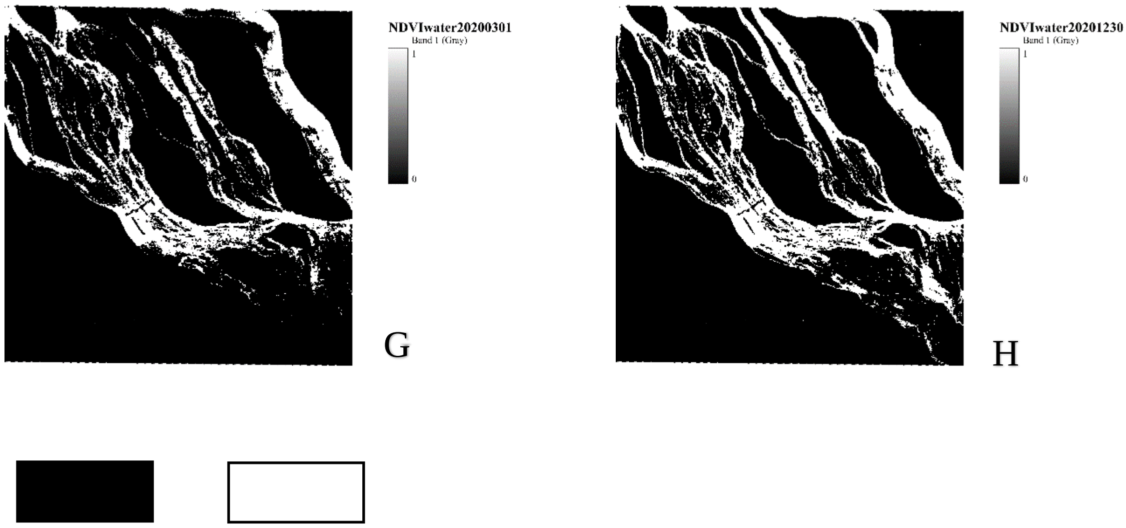
The NDVI images have scale (+1.0 to -1.0) value less than 0.1 clarify as water cover, 0.2-0.5 clarify as bare land and more than 0.6 to 1.0 classified as thick vegetation. The image is open in QGIS and Raster Calculation Function is open and a command (‘If NDVI image < 0.1,1,0’) to get the NDVI water map and to calculate the area. The Raster layer unique value report is selected, and the intended month selected and saved to a temporally files and thereafter run the program. The analyzed file is displayed, and area determine in m^2 (This is repeated for the years 2011, 2015, 2019, 2020). The images in surface water occurrence are compared with the images of NDVI in different seasons (Pekel et al., 2016).

4. RESULTS

The aim of analysis NDVI images is to make accurate in NDVI of interested area maps by using Geographic Information System technique, information will be including Landsat images of dry and wet season, monitoring change of water levels, change of settlement of soil and vegetation changes in four thousand islands (Siphandone).

4.1 NDVI image analysis to determine the inundated areas.



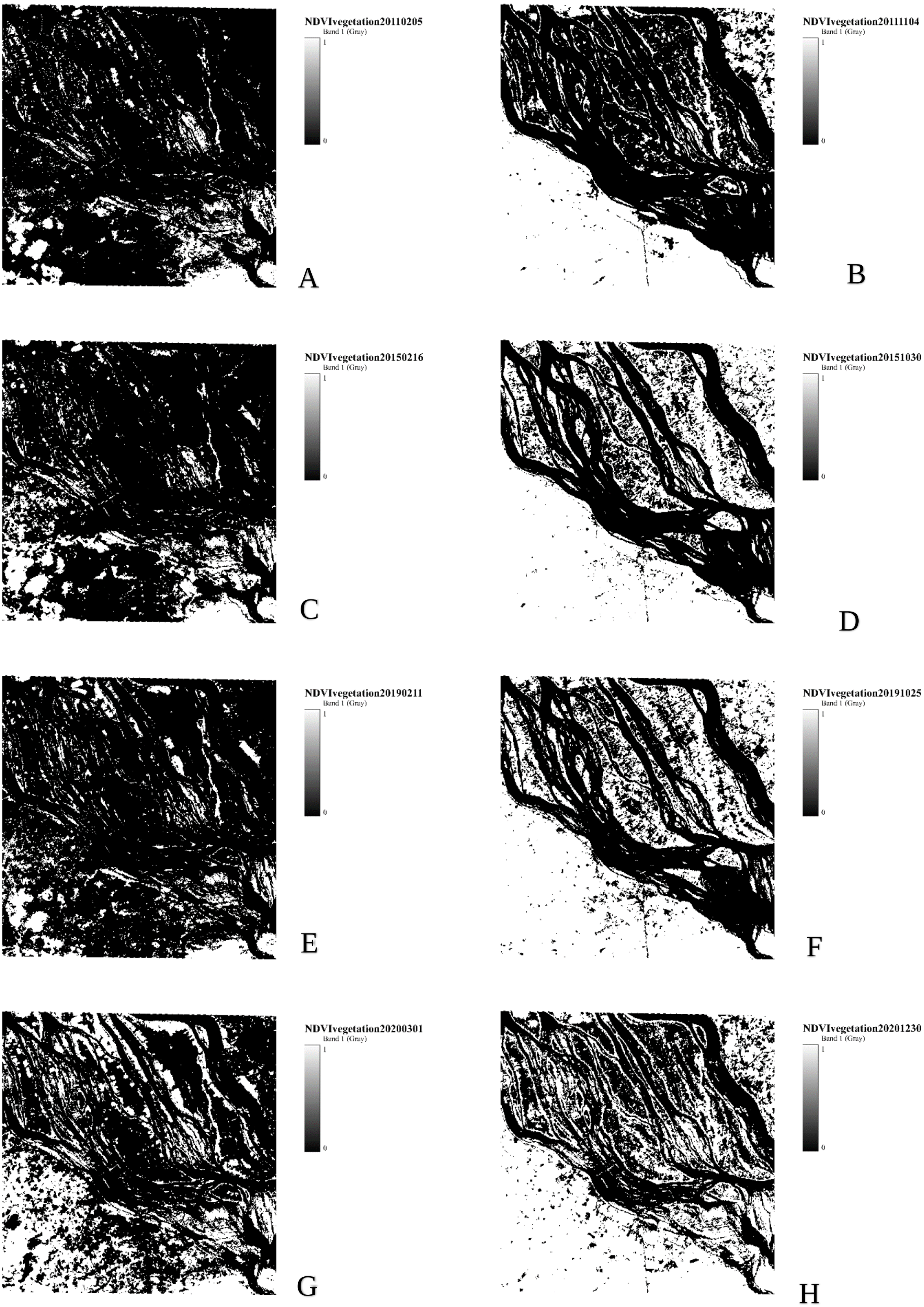


Non-water Water

Figure 7: NDVI-based water cover maps of the dry and wet seasons.

In (fig.7) NDVI value below 0.1 define as water cover areas illustrate in white color (value 1) while value higher than 0.1 indicate as non-water cover area represent in black color (value 0). In the months of October, November, and December are defined as wet season, in this season the water cover areas in the Four Thousand Islands were increased, whereas the water cover area in dry season was decreased. A detailed observation of the NDVI based water cover and water level data in (Graph 1) shows specifically for the water level in The Mekong River rising that have relative to water cover area increasing in the Four Thousand Islands.

4.2 NDVI image analysis to determine vegetation-covered areas.

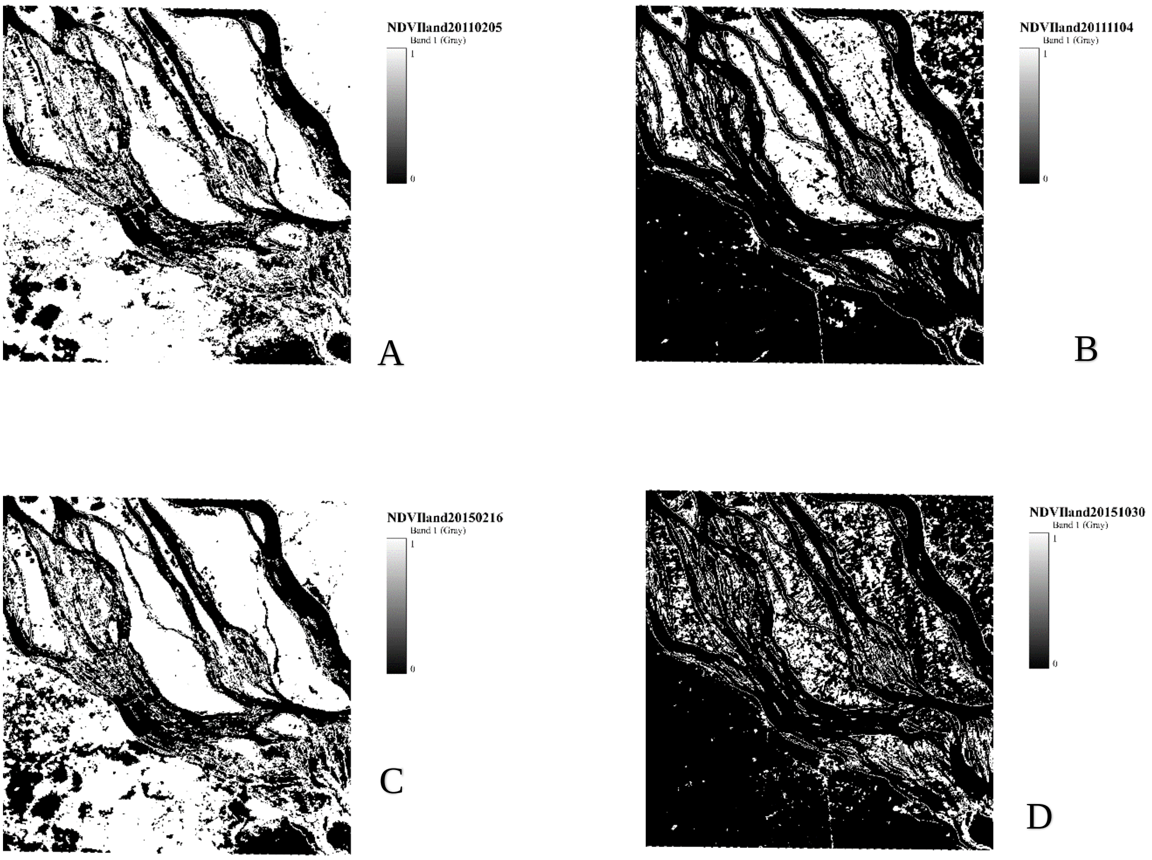


Non-Vegetation Vegetation

Figure 8: NDVI-based vegetation cover maps of the dry and wet seasons.

From (Fig.8) during October and November, NDVI based vegetation cover maps is define from more than 0.5 in NDVI value represent in white color (value 1 increasing in vegetation cover maps, while dry season result in vegetation reduction by less white color represent in vegetation cover maps. The results of time series can be compared between two seasons. The results show that the rainy season between October/November and December is the time when communities in the villages cultivate rice. The vegetated area is higher in the wet season than in the dry season, due to the crop harvest in December and January. However, bare land, land cover and rocks are showing low values in NDVI in February to May. This is because this is a period of the dry season with the following characteristics i.e., no agriculture activities, lack of water and less vegetation.

4.3 NDVI image analysis to determine bare surfaces.



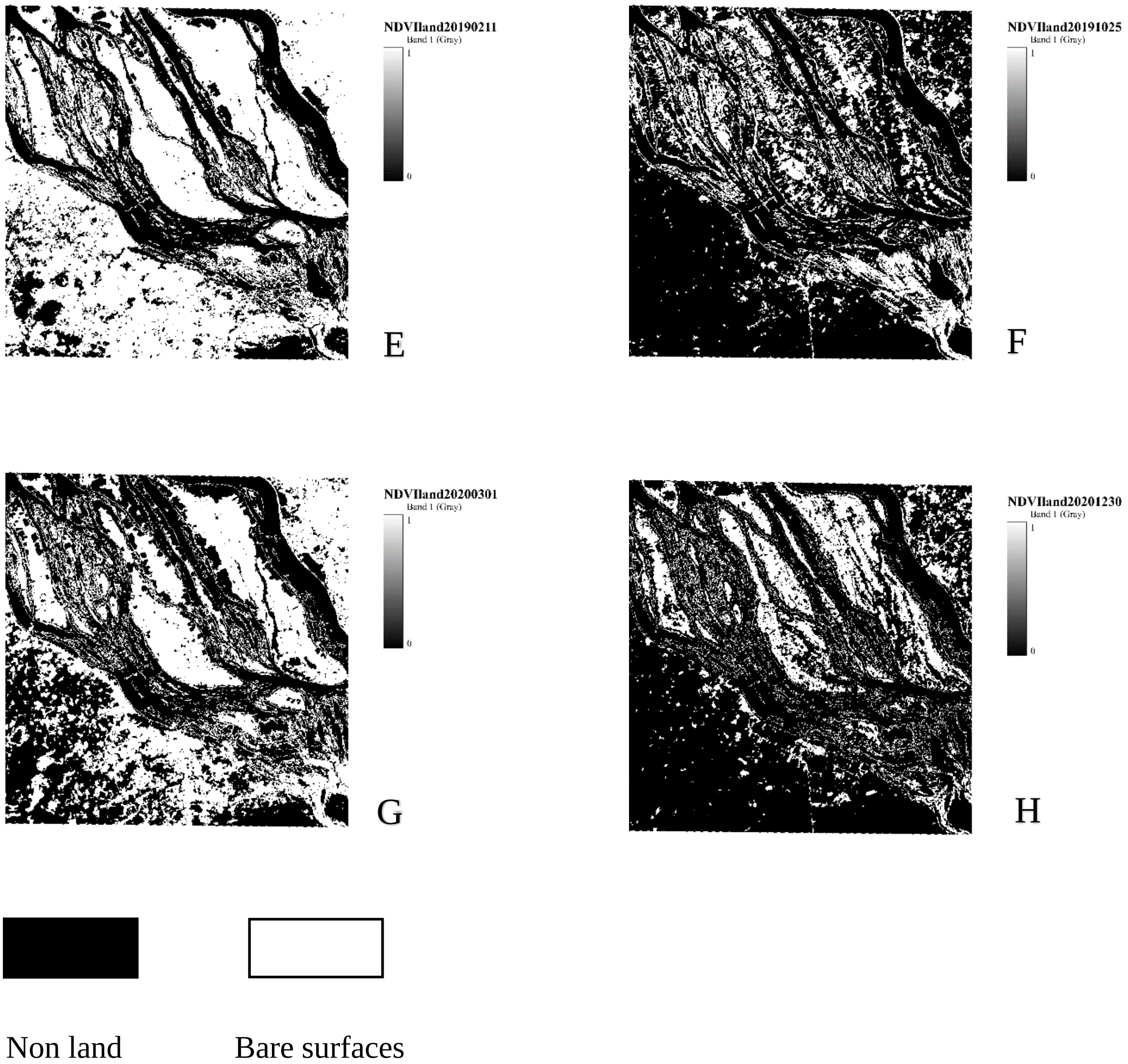


Figure 9: NDVI-based bare land maps of the dry and wet seasons.

The results, show value 1 which is white color is mean we sensor for the land or something below 0.12 we used the theoretical from NDVI value to made this classification that is the reason in the dry season the NDVI of Land map showing more white color than the rainny season.

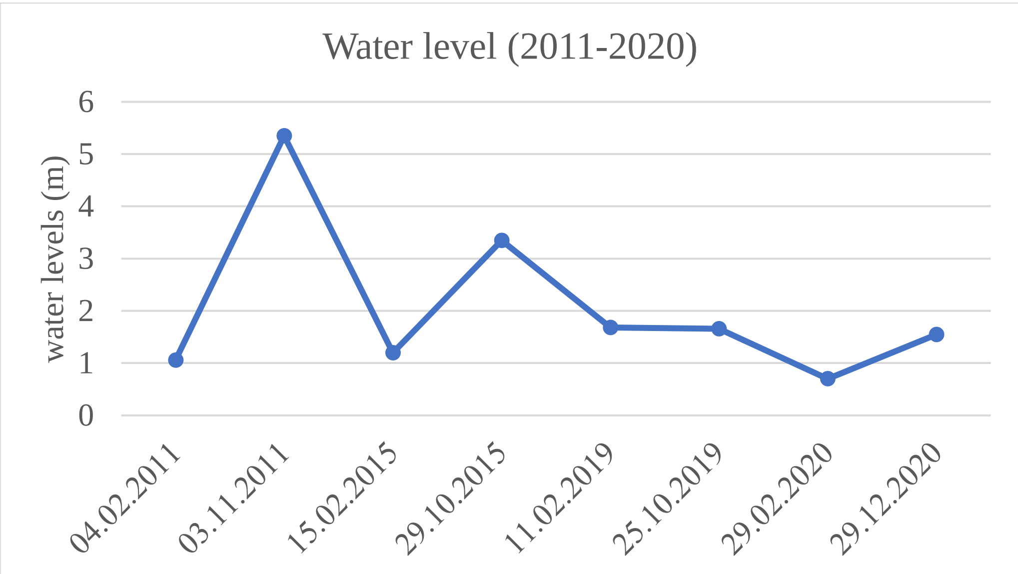
Bare surfaces are shown in white color in (Fig.9). From these maps, we can identify that bare lands reach their maximum extent in January, February and March because in this season, a lot of small islands occur due to the low water levels in the river and lack of vegetation.

4.4 River stages at the time of the image acquisitions

The data in (Table 3) and (Graph 6) represent the water levels in the Mekong at the Pakse station, which is approximately 100 km upstream from the Four Thousand Islands. It takes about 24h for the water to arrive to the monitored region.

Date	water level(m)	Date	water level (m)
03.02.2011	1.12	02.11.2011	5.6
04.02.2011	1.06	03.11.2011	5.35
05.02.2011	1.02	04.11.2011	5.23
14.02.2015	1.21	28.10.2015	3.5
15.02.2015	1.2	29.10.2015	3.35
16.02.2015	1.14	30.10.2015	3.17
10.02.2019	1.61	24.10.2019	1.65
11.02.2019	1.68	25.10.2019	1.66
12.02.2019	1.75	26.10.2019	1.62
28.02.2020	0.63	28.12.2020	1.47
29.02.2020	0.7	29.12.2020	1.55
01.03.2020	0.7	30.12.2020	1.53

Table 3: Water levels on and around the Landsat image acquisition dates (highlighted with blue).



Graph 6: Water levels at the Pakse station (Meteorological Department, 1998).

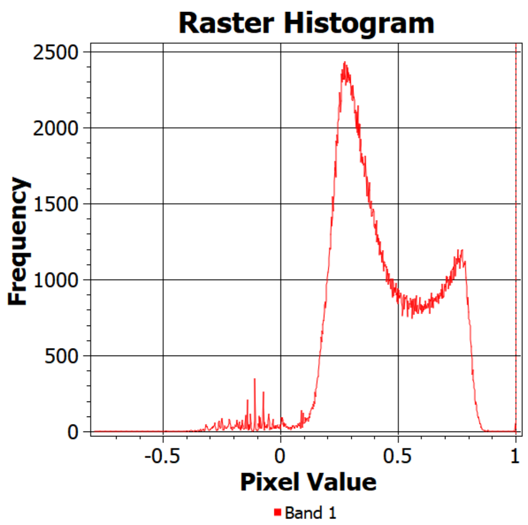
4.5 NDVI images analysis

The NDVI maps were used to determine water, land and vegetation covered areas in different seasons in the Four Thousand Islands region, which is surrounded by the Mekong river.
In the rainny seasons, water levels are appriximately 10 m higher at the Pakse station than in the dry seasons. Unfortunately, cloud-free sattlite images are not available during the peak of thehigh-water periods (August-September, Graph 1). The first images suitable for interpretation occur usually around November-December. The highest water was captured in the beginning of November 2011 (Graph 6). As the graph shows, the other images, which were acqired in high-water situations were captured at significantly lower water stages. Comparison on the bare lands in the dry and wet seasons shows, that there is less of it in rainy seasons than in thr dry season, which means that some land is inundated by flooding of the wet season.

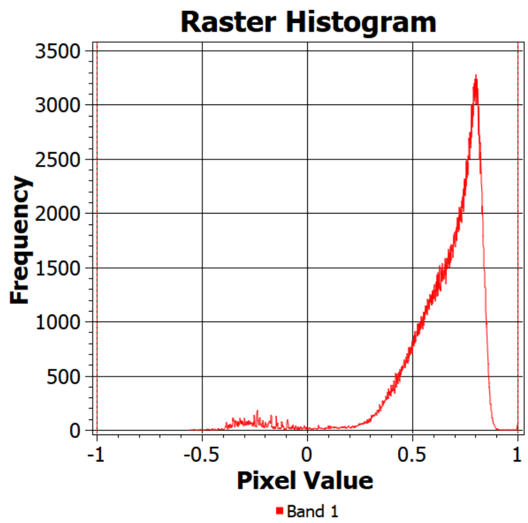
4.5.1 Histograms of the NDVI maps

Maps obtain from NDVI data can br futher be transfrom in to histogram that shows the year and month, pixel value and frequentcy for example, during the month of November 2011 as indecated in histogram (fig.10), the frequentcy between -0.5 to 0.4 was low indicating presence of water between 0.3 with frequency of about 700 indicate bareland, the pixel value increased from 0.4 with maximum frequentcy about 3000 with the pixel value of 0.8 indicating a dense vegetation. This can be seem in other year (2015, 2019, and 2020) based on the folowing scale. (-0.5 to -0.4 (water), 0 to 0.2 (bareland), 0.5 to 0.9 (dense vegetation)).

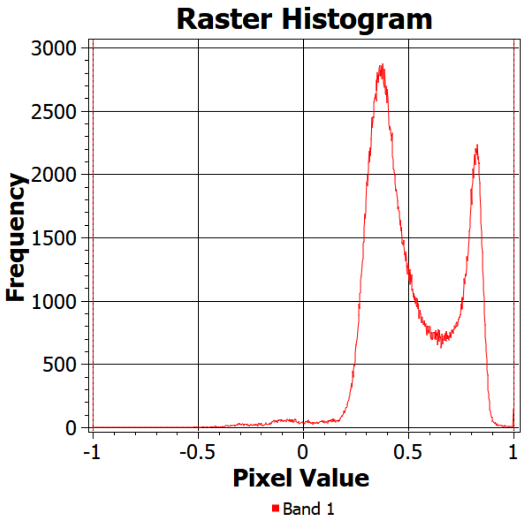
2011.02.05



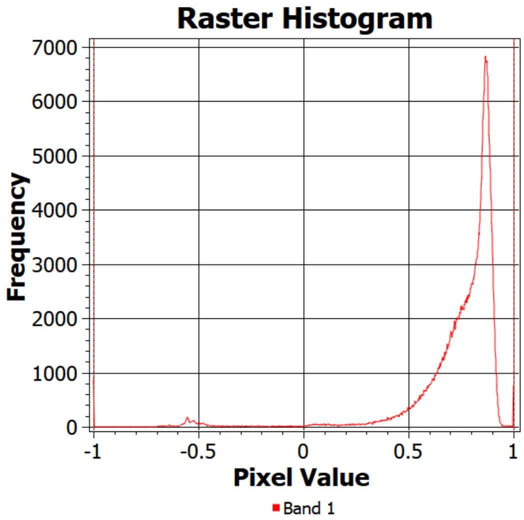
2011.11.04



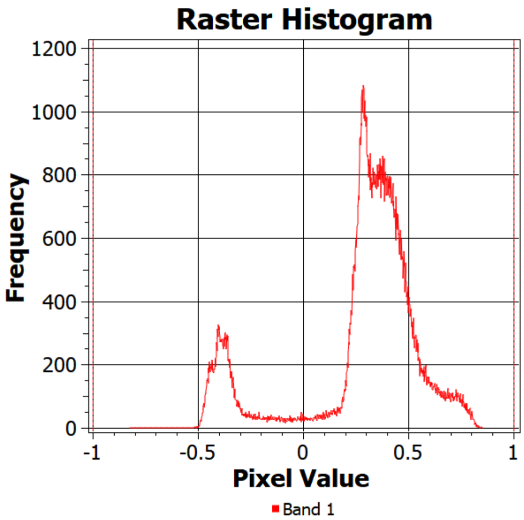
2015.02.16



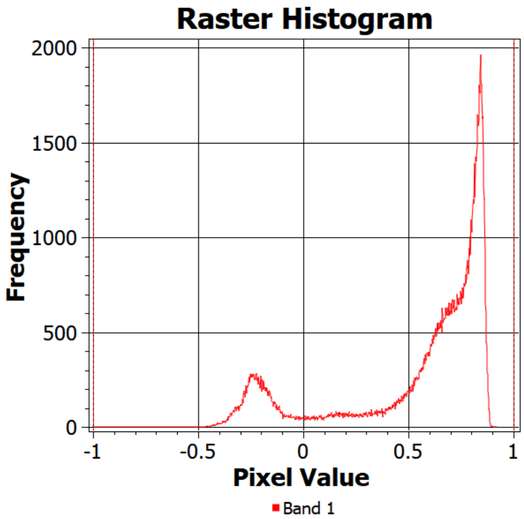
2015.10.30



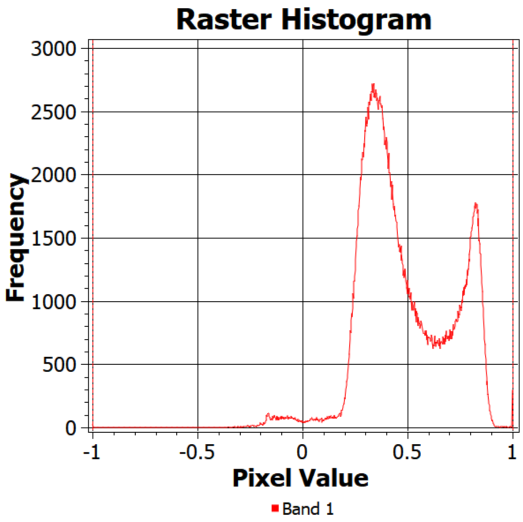
2019.02.11



2019.10.25



2020.03.01



2020.12.30

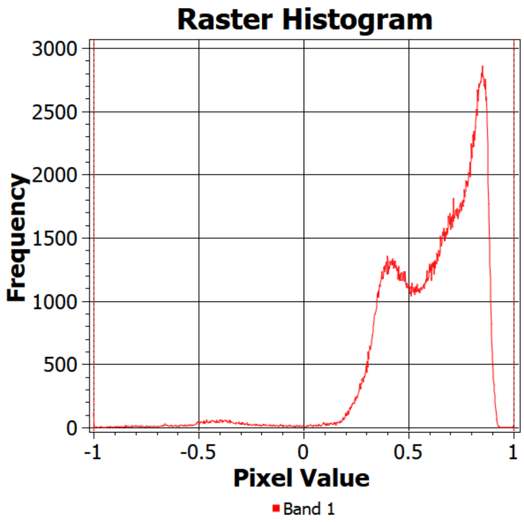


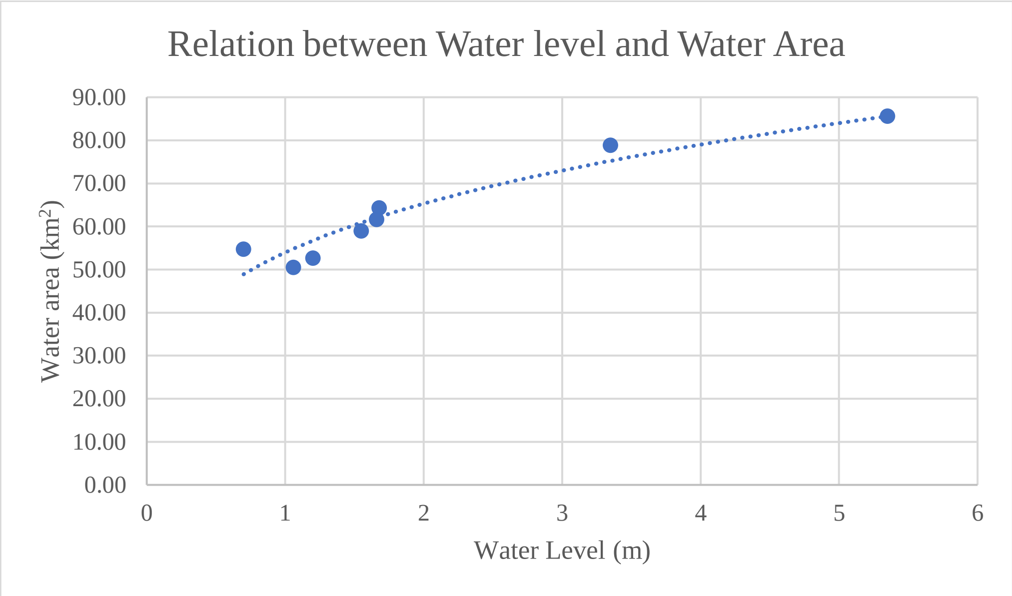
Figure 10: Histograms computed from the NDVI maps.

To compare area of water, land and vegetation cover for the four-different years, the average area in km^2 was calculated. For example, in the year 2019 Feb. the vegetation cover was 56.18 km^2 compared to 2019 Oct. with an area of 244.20 km^2 vegetation cover. This shows that the images can be used to compare the images, area and water, land, and vegetation cover (Table 4 and Graph 8).

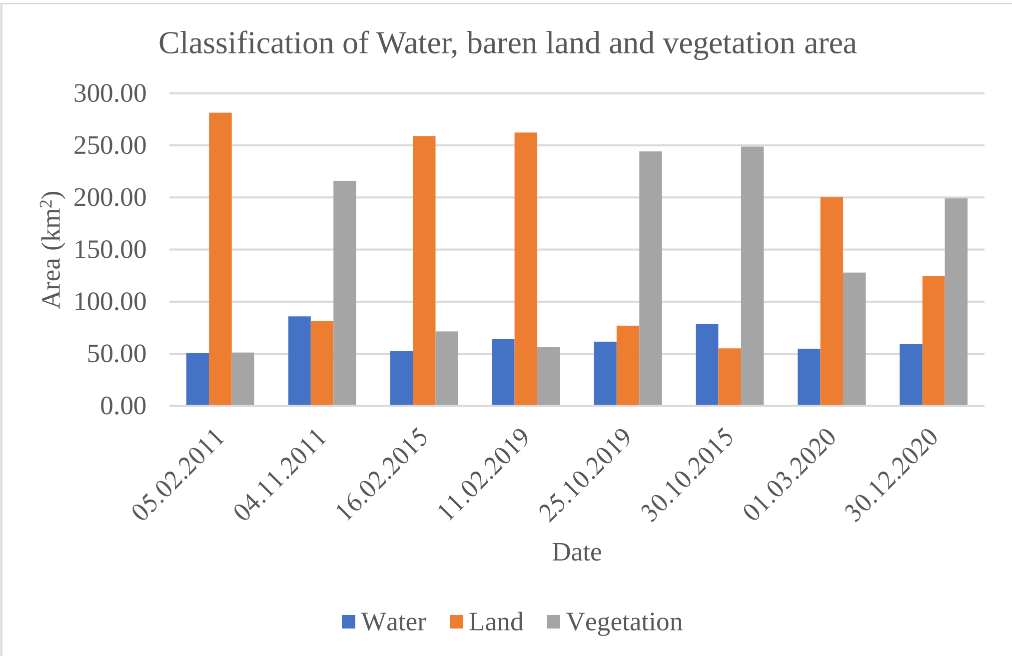
Date	Area(km^2)			Total
	Water	Land	Vegetation	
05.02.2011	50.52	281.34	51.03	382.89
04.11.2011	85.65	81.37	215.88	382.89
16.02.2015	52.64	258.89	71.36	382.89
30.10.2015	78.84	55.17	248.88	382.89
11.02.2019	64.30	262.40	56.18	382.89
25.10.2019	61.66	77.04	244.20	382.89
01.03.2020	54.73	200.45	127.71	382.89
30.12.2020	58.99	124.68	199.22	382.89

Table 4: Use of NDVI image pixel to calculate area of water, land, and vegetation between dry/wet seasons.

The relationship between the water level in Mekong River and area of water in the Four Thousand Islands was directly proportional. An increase in water level has a direct proportional increase in water area as shown in graph 7.



Graph 7: Relation between Water level and water area from 2011-2020.



Graph 8: Paragraph of area changes by seasonal.

Date	water %	Land %	Vegetation%
05.02.2011	13.195	73.478	13.327
04.11.2011	22.369	21.25	56.381
Change	▲9.17	▽52.23	▲43.05
16.02.2015	13.749	67.613	18.638
30.10.2015	20.592	14.408	65
Change	▲6.84	▽53.21	▲46.36
11.02.2019	16.79	68.53	14.67
25.10.2019	16.10	20.12	63.78
Change	▽0.69	▽48.41	▲49.10
01.03.2020	14.295	52.35	33.355
30.12.2020	15.407	32.563	52.031
Change	▲1.11	▽19.79	▲18.68

Table 5: Change of area between dry/wet season

The use of pixel count in QGIS to calculate NDVI maps was used to determine change in area between dry and wet season. Removed of vegetation during harvesting season indicates low water level. Increase in vegetation is related to the beginning of monsoon as this a season of planting vegetation (Table 5).

4.5.2 Comparison between water occurrence data and NDVI water map image

Permanent water surfaces (100% occurrence over 38 years) shown in blue (fig. 11) (fig.12), while areas where water occasionally occurs are shown in pink through purple. The paler colors represent areas where water occurs less frequently.

Moreover, using water occurrence images from 1984-2021 and NDVI water images from March 2020 which is the lowest water level and November 2011 which is the highest water level from Landsat images to compare areas with different water levels. Hence there is an indication that in the year 2020 four thousand islands were facing extreme drought and lack of water directly from climate change and human activities.

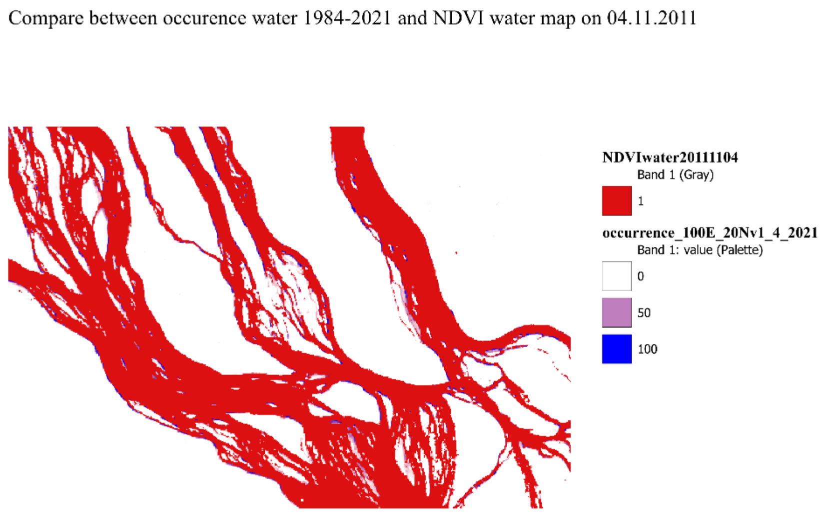


Figure 11: Water occurrences image and NDVI water map on 2011.11.04. (Global surface water, 2020)

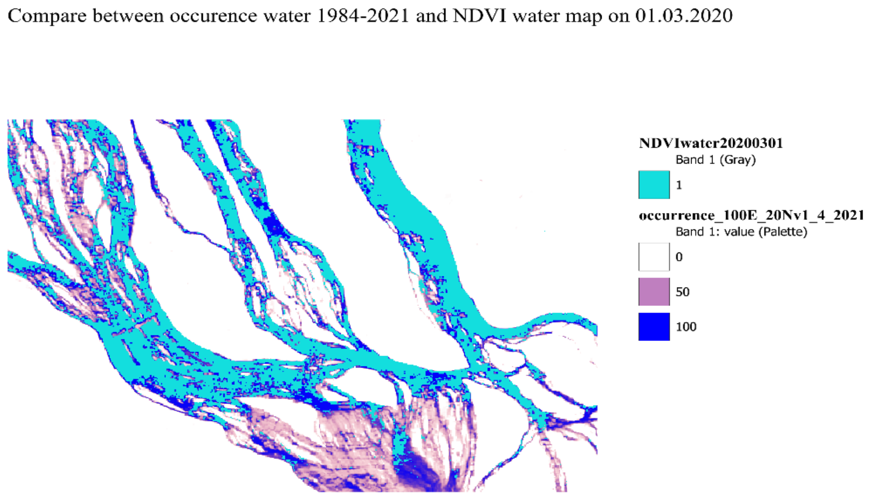


Figure 12: Water occurrences image and NDVI water map on 2020.03.01 (Global surface water, 2020).

4.5.3 Comparison between Occurrence water map and NDVI vegetation map image

In (Fig.13) NDVI vegetation cover map and occurrence water map used to create a comparison between dry and wet seasons. Dark green color defines as vegetation cover map in October 2015 and light green color represents vegetation cover map in February 2015.

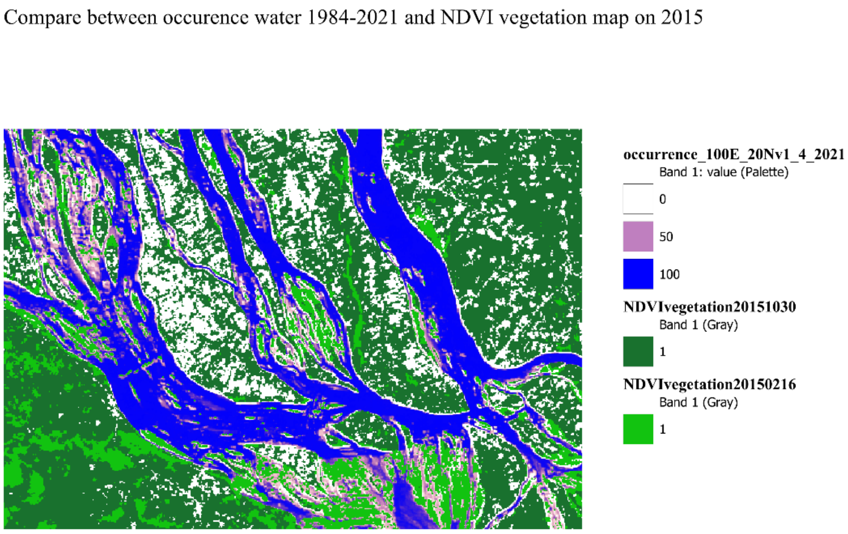


Figure 13: NDVI vegetation map in 2015 and occurrence water data 1984-2021 (Global surface water, 2020).

4.5.4 Comparison between Occurrence water map and NDVI Land map image

In (Fig.14) NDVI bare land map and water occurrence map used to compare bare land cover map between dry and wet seasons, orange color defines as bare land cover in February 2011 and yellow color represent as bare land cover in November 2011.

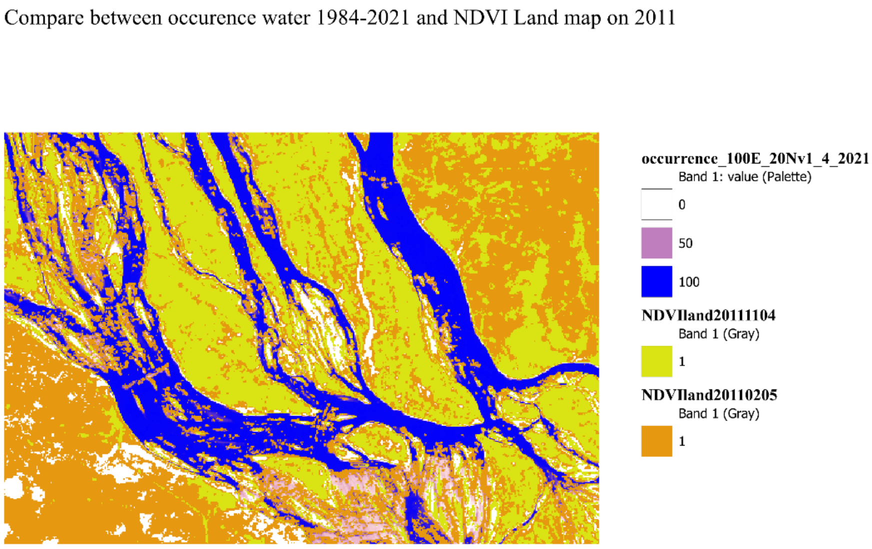


Figure 14: NDVI bare land map in 2011 and water occurrence data 1984-2021. (Global surface water, 2020).

4.6 Human activities that influence water dynamics along Mekong River

This important waterway is currently in danger, in large part because of a string of Chinese mega-dams constructed close to the Tibetan Plateau's border, just before the river enters Southeast Asia. A total of 21,300 megawatts (MW) of energy can be produced by the 11 dams that are now in use (fig.15), which is more than the installed hydroelectric capacity of all the nations that are downstream put together. And they are destabilizing geopolitical, economic, and environmental systems.

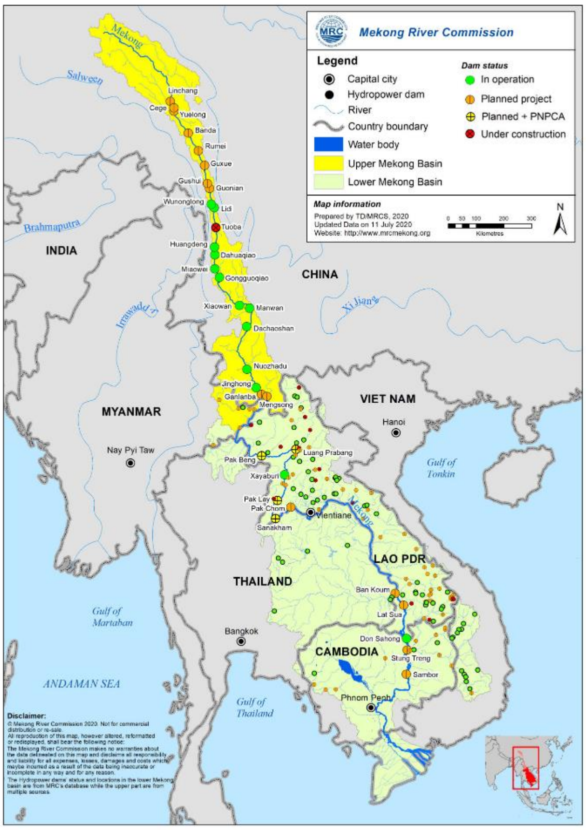


Figure 15: Sub-basins, significant rivers, and a Chinese appraisal of the UMB. (Mekong River Commission, 2023)

Additionally, a Mekong River Commission study found that through 2040, hydropower development, which includes three additional Chinese mega-dams that are being built or planned, will cause a 40–80% loss in fish stocks (measured by biomass). Much of the basin's migratory fish population, which currently ranks second only to the Amazon in terms of fish species variety, would vanish (MRC, 2017).

China then used Mekong water to refill the Jinghong Dam. Due to a 40% reduction in monsoon rains in June and July 2019, water shortage circumstances were made worse by the decline in downstream water levels shown in (Graph1). The Mekong River Commission claims that rather than overflowing throughout the summer, the river reached record-low levels, reducing fish populations, and slowing rice production (MRC, 2019).

Although the Xayaburi Dam is in northern of Laos the dam's commercial operation began in October 2019 it has already had an impact. The flow of the Mekong tributaries in downstream Thailand has been impacted by its filling and test run alone, worsening the drought there. The impact is so severe that Lao has been urged to halt its test run until the drought subsides by the Thai government, which has promised to buy 95% of the electricity the dam produces (MRC, 2020).

Over the past two decades, hydropower dams have had a significant impact on the Mekong River, causing unseasonal flooding and droughts, low water levels during the dry season shows in water level downstream the Mekong River (Graph 1), and decreases in the quantity of silt the river carries. These changes have had a significant negative impact on biodiversity and fisheries. The cumulative effects of major dams pose a threat to the forests, mangroves, and fisheries that depend on the waters of the Mekong, which are exacerbated by climate change and a lack of cross-border communication. The Lower Mekong experienced some of its lowest river levels ever over the most of 2019, which was one of the biggest effects. There was above-average natural flow coming from the Upper Mekong when natural flow is predicted using the wetness index. Flow during the wet season was severely constrained because of the Lower Mekong receiving record low amounts of rainfall during the wet season, as seen by the residuals, which show excess flow during the dry season, likely to enhance electrical output in early 2019. The severe restriction of water flow from the upper Mekong during the 2019 wet season played a significant role in the severe lack of water in the Lower Mekong (Basist & Williams, 2020).

5. CONCLUSION

This study focused on determining the effects of changes in water level on the land cover in the two main seasons, i.e., the dry (November-May) and wet (June-October) seasons. The wet season brings a rise in water levels of the Mekong, that triggers changes in the land cover of the Four Thousand Islands region. These changes were calculated using pixels count from NDVI images (Graph 8 and Table 4).

During the month of February to March the main activities conducted in the study area is harvesting this mean that the vegetation has lost its green color and therefore the images obtain by use of NDVI images correlates with results that shown no vegetation cover and reduce water level (Fig 8A and Table 5). There is an inverse relationship of bare and vegetation land cover type, during the dry season the bare land is increased while water cover area is decreased. In the wet season bare land decreased as a result of increased water cover area. As indicated in Table 5.

In other studies, on the use of GIS to monitor climate change (Than et al., 2019). The meteorology data and GIS images showed a correlation in differences season and year this result is show some level of similarity on the data obtained and hence agree with this finding. According to the studies by (Du et al., 2013) other methods suggested such as SPI methods to determine wet and dry season has been use and therefore such data can be used to validate or standardize data from QGIS in other and future studies. The results of the present study showed that satellite images-based technologies and QGIS were able to determine vegetation cover and water cover and open land that correlate with the calculation. The quality of NDVI images obtain vary due to the effect of environmental factors such as cloud cover. This study therefore, strongly suggest a more suitable improvement of technology in obtaining clear images to make a detailed analysis and report on NDVI images, this is because the challenges that cause the environmental changes have been fully manage and therefore the needs to get accurate and reliable images in environmental changes analysis.

5.1 Recommendations

1. QGIS can be used to analysis the Landsat images and NDVI maps to do determine climate change by using pixels count to calculate the changes in area and other environmental changes.

2. Government of Lao can use this technique in other wetland ecosystem to determine changes in water and vegetation cover caused by climate change or human interventions, to conserve natural environment

3. The limitation of getting land cover information using optical (e.g., Landsat) images is frequent cloud cover. For increasing the frequency of land cover information from the Four Thousand Islands, a method for fusing optical and radar images should be worked out.

6. SUMMARY

Four Thousand islands are one of the most valuable islands in the southern part of Laos, it's containing Waterfalls, Wetland, water channels and settlements for humans and biodiversity. This study focused on changes in environment such as: water, bare land, and vegetation cover area in wet/dry seasons because of climate change and human activities. This study aimed to determine the impact of the changes in water levels in dry and wet seasons in different years. The study also aimed at determining if there were changes in vegetation cover during different dry and wet seasons in different years and determine if the size of the islands change as due to changes in water levels. To be able to achieve the above objectives the following methods were applied. QGIS software version 3.30 was used to analysis NDVI images, used NDVI images to create and classification water, barren land, and vegetation cover map areas. To be able to determine area of water, Land, and vegetation cover between year 2010 – 2020 at Four Thousand Islands and determine water area change, bare surface and vegetation change by rapid water flow and climate change, the Raster Calculation function was used for the Calculation of pixels on NDVI maps. Results from this study showed that barren land increased in the dry season while vegetation and water areas decreased. Additionally, water cover areas are decreasing related to reduction of water level at Mekong River based on Seasonal shifting caused by climate change because of long drought period and short period of monsoon. A significant effect associated with climate change was noted in the month of November that showed increased vegetation cover area of 43% with a decrease in island size (52.23%), the possible cause for this could be due to increase of water level and end of monsoon season. NDVI maps and water occurrence maps showed that in the year 2020 there was extreme drought and lack of water due to climate change and human activities. The GIS technique is a precise and convenient tool to get calculated pixels data on NDVI maps. The result of this study can be used by the government of Laos to determine change in water level and vegetation cover in other ecological area of interest in assessing the impact of climate change in the environment and inform policy maker in decision making on issues affected by climate change, for the purpose of detecting and analyzing the impact of drought in the future NDVI is easy technique and effective tool that can be linked to other environmental monitoring. The findings of this study can be used to decide before implementing the conservation measures of the Four Thousand Islands.

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