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Mangrove forests changes and responses to sea level rise based on remote sensing and GIS in PKWS, Cambodia

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ABSTRACT

Mangrove forests in Cambodia can be found along the coastline 435 km. Recently, mangroves have declined by anthropogenic activities and threatened to Sea level rise (SLR) caused by climate change. SLR was estimated to rise 40 to 60 cm in Koh Kong province by the end of the twenty-first century. Mangroves in Peam Krasop Wildlife Sanctuary (PKWS), Cambodia, will extract from 2015 to 2020 using sentinel-2 multi-temporal data with Random Forest classification. Moreover, the changes in mangroves also conducted using MOLUSCE. To predict the vulnerable mangroves area in 2020 due to future SLR based on Geospatial Model and SLR scenarios (40 cm, 60 cm, and 1 m). Mangroves in PKWS were estimated about 7157.90, 7495.21, 7337.47, 6436.26, 6761.66, and 7045.64 ha in 2015, 2016, 2017, 2018, 2019, and 2020. Furthermore, mangroves were increased by 337.31 ha during 2015-2016 but decreased about 157.74, 901.21 ha in 2017 and 2018. However, mangroves undertake to increased 325.40, 283.98 ha in 2019 and 2020. The total changes of mangroves were extremely decreased 112.26 ha from 2015 to 2020. When SLR by 40 and 60 cm, mangrove areas are projected to be inundated about 40.44 ha and reached 53.14 ha by 1 m, respectively.

1. INTRODUCTION

Mangrove forests can be found in the Southwestern part of Cambodia consists of four provinces such as Koh Kong province, Sihanoukville, Kampot, and Kep province (FAO, 2010). In recent years, mangrove forests were declined by anthropogenic activities, and threatened to future Sea level rise (SLR) caused by climate change (Ward et al., 2016). SLR in Cambodia, a 10 cm rise already observed in the last 40 years, and estimated to rise by 40 to 60 cm in Koh Kong by the end of the 21st century. Previous studies have indicated that SLR 1 m would lead to loss of 44 km^2 of coastline in Koh Kong and significantly raise the risk of severe flooding.

Remote Sensing (RS) has assisted as a supportable tool in mangrove forests studies can be found since 1956 (Kumar et al., 2013; Vaiphasa, 2006; Blasco et al., 2001). RS has evolved with the mangrove distribution mapping and monitors the extent of change in mangroves (Jia M, Tian J, Wang L, Yin D, et al. 2019). Until now, it provided the precise discussion of climate change factor impact on mangrove forests. Recently, research by Srivastava et al. (2015) showed that SLR was significantly affected to mangrove extent and mangrove species density by integrating remote sensing with meteorological data.

Thus, mapping the mangrove extent and analyzing the relationship between SLR and mangrove forests are essential for mangroves and as an indicator system for vulnerability assessment and conservation on coastal mangroves in Cambodia.

Due to these problems, the main purpose of this study is to apply the advanced technology of RS and GIS with proposed three objectives, 1) to extract mangrove forests in PKWS, Cambodia, from 2015 to 2020 derived from Sentinel-2 images with Random Forest Classification, 2) to analyze mangrove forests changes from 2015 to 2020 using MOLUSCE, and 3) to assess the vulnerable area of mangrove forests under different SLR scenarios using a Geospatial model based on IPCC's SLR projection.

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2. METHOD

2.1. Study Area

Peam Krasop Wildlife Sanctuary (PKWS) is a coastal wildlife sanctuary covering 25,897 ha and a unique supporting significant mangroves ecosystem located in Koh Kong Province in the Southwestern of Cambodia. PKWS is an area that concerns about the decline of mangrove forests and vulnerable to rising sea levels caused by climate change (Dara et al. 2009).

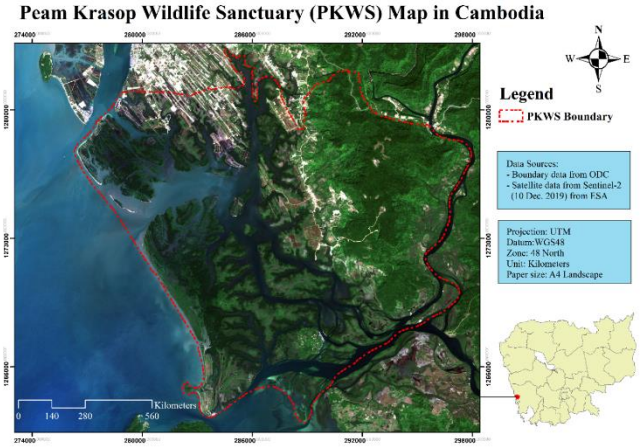

Figure 1. Map of study area

2.2. Data Acquisition

There are significant data include Sentinel-2A multi-temporal data from 2015 to 2020 derived from USGS and ESA. SRTM DEM was collected from USGS in 2014 with spatial resolution 1 Arc-Second Global covering with absolute vertical accuracy of less than 16m (RMSE of 9.73m). Sea level rise (SLR) under IPCC RCP 8.5 emission scenario based on AOGCMs model from CMIP5 are essential as the raster cells data for processing with SRTM DEM data to create a geospatial model of inundation level of SLR impact on mangrove forests areas.

Table 1. Summarized data acquisition

Data	Spatial resolution	Temporal coverage	References
Sentinel-2 L1C	10m	2015-2020	USGS & ESA
SRTM DEM	30 m	2014	USGS
SLR Rates	40cm, 60cm, 1m	The end of 21st century	IPCC's SLR scenarios

2.3. Data Processing

Mangrove forests extraction has been classified using Sentinel-2 images multi-temporal data with Random Forest by dzetsaka Plugin in QGIS. There are two steps for work procedures are training data and perform the type of classification. For training RF algorithm per every satellite image were 240 training data according to create a total of six classes.

There are three levels of land cover classification, land cover in level I, analysis of 6 classes include water body, mangrove forests, saltmarsh, forest lands, settlements, and other lands, and three land cover classes in level II, and one class in level III. The land cover classes level II are merge from land cover classes in level I which there are only three classes include water body, mangrove forests, and non-mangrove forests (merge of saltmarsh, forest lands, settlements, and other lands). For the land cover class in level III, there is only one class of mangrove forests class which other classes have been divided as the NoData.

After land cover classification has been completed, mangrove forests result in 2015 to 2020 were analyzed changed from mangrove forests class to other land cover classes every year between these time period (2015, 2016, 2017, 2018, 2019, 2020) using MOLUSCE in QGIS.

In the last part, mangrove forests extraction in 2020 was used to overlay with a geospatial model from SRTM DEM and SLR scenarios to determine the vulnerable area of mangrove forests in PKWS due to future SLR based on three different SLR scenarios were adopted such as SLR 40 cm, SLR 60 cm, and SLR 1 m.

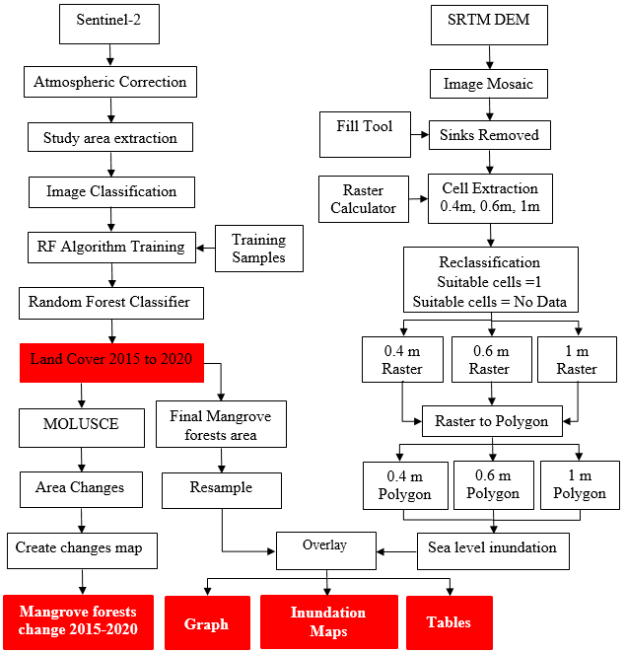

Figure 2. Methodology workflow.

2.4. Accuracy Assessments

For accuracy assessment of land cover classification was assessed using a confusion matrix from Random Forest algorithm training. Accuracy assessments calculated included overall accuracy (OA), kappa statistic, producer accuracy (PA), and user accuracy (UA) calculated using Confusion matrix online calculator based on Marco Vanetti (2007).

3. RESULTS

3.1. Mangrove Extraction

The result of mangrove forests maps in PKWS shown in green polygon (Tab.2, Fig.3). Mangrove forests area in PKWS were 7157.90, 7495.21, 7337.47, 6436.26, 6761.66 and 7045.64 ha in, 2015, 2016, 2017, 2018, 2019, and 2020.

The confusion matrix of the Random Forest algorithm indicated the mangrove forests class with Producer Accuracy around 99.962% and 99.996 in 2015 and 2016, and 100% from 2017 to 2020. The User Accuracy,

mangrove forests were estimated accuracy of 100% every year.

Table 2. Mangrove forests area (Hectare) from 2015 to 2020

Land cover	Area (Hectare)					
Year	2015	2016	2017	2018	2019	2020
Mangrove forests	7157.90	7495.21	7337.47	6436.26	6761.66	7045.64
PA (%)	99.96	99.96	100	100	100	100
UC (%)	100	100	100	100	100	100

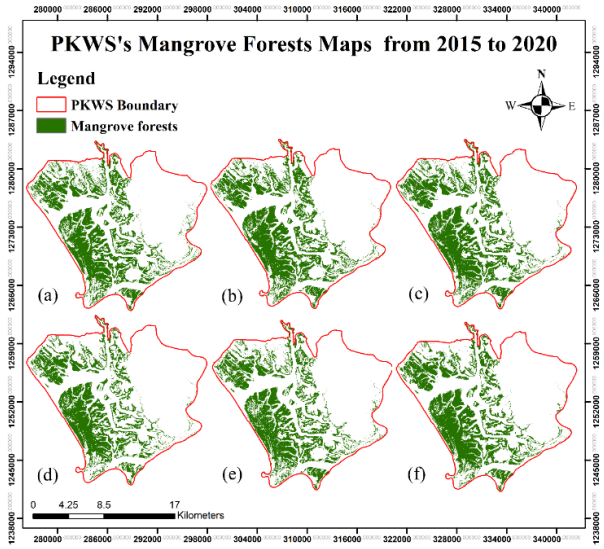

Figure 3. Land Cover Map of PWKS's mangrove forests from 2015 to 2020. (a) Classify 2015, (b) Classify 2016, (c) Classify 2017, (d) Classify 2018, (e) Classify 2019, (f) Classify 2020.

3.2. Mangrove Forests Change from 2015-2020

Mangrove forests estimated to decrease 112.26 ha occurred in PKWS from 2015 to 2020 due to mangrove forests converted to other land cover classes. Additionally, Mangrove forest areas converted to forest lands, other lands, settlements, and water, which were about -387.53, 115.78, 59.57, and -1.29 ha (Fig. 4, Tab. 3).

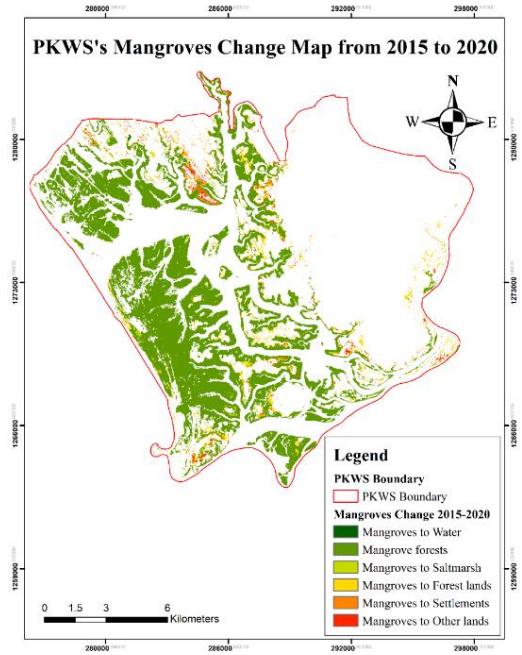

Figure 4. PKWS's Mangrove forests change 2015-2020

Table 3. Mangrove forests change (ha) from 2015 to 2020

Classes	2015	2020	Total
Mangrove to Water	15.62	14.33	-1.29
Mangrove forests	6281.89	6281.89	6281.89
Mangrove to Saltmarsh	167.05	618.96	451.91
Mangrove to Forest lands	505.22	117.69	-387.53
Mangrove to Settlements	60.27	0.7	-59.57
Mangrove to Other Lands	127.85	12.07	-115.78
Total (Hectare)	7157.9	7045.64	**-112.26**

3.3. Potential Inundation of SLR on Mangrove Forests Area

The results specify that potentially inundated mangrove areas will submerge by Sea level rise at the end of the twenty-first century for these different Sea level rise scenarios. Mangrove forests are projected to be inundated 40.44 ha by increasing SLR 40 cm and 60 cm by the end of the year 2100 and reached 53.14 ha by SLR 1 m, respectively.

Table 4. The potential inundation of different SLR scenarios vulnerable to mangrove forests areas in Peam Krasop Wildlife Sanctuary.

Mangrove forests areas	Sea Level Rise Scenarios		
	40 cm	60 cm	1m
Vulnerable area (hectare)	40.44	40.44	53.14

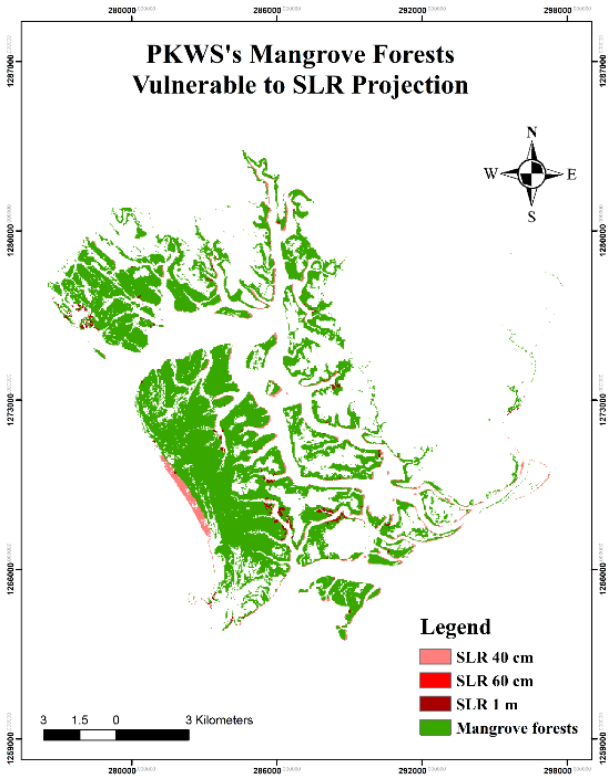

Figure 5. Analysis the inundation of mangrove areas in Peam Krasop Wildlife Sanctuary due three different SLR scenarios

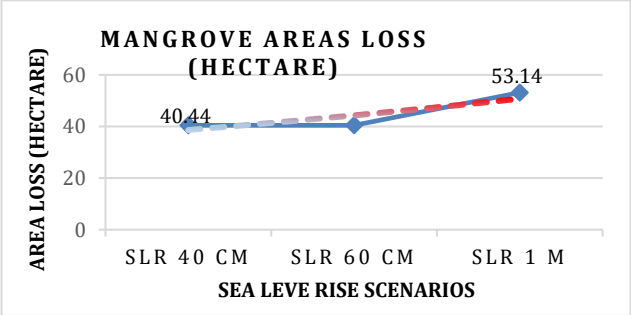

Figure 6. Total mangrove forests area loss under three different SLR scenarios in Peam Krasop Wildlife Sanctuary by the end of twenty-first century

4. DISCUSSION

In this study, mangrove forests maps of Peam Krasop Wildlife Sanctuary in Cambodia from 2015 to 2020 were produced. To the best of my knowledge, this is the first interesting topic conducted in Cambodia about the potential impact of Sea level rise to the mangrove forest areas in Cambodia based on Remote Sensing and GIS techniques. For conducted these mangroves maps from 2015 to 2020 defined from classification employed time-series data of multi-temporal Sentinel-2 L1C optical imageries with Random Forest classification in dzetsaka plugin that can be achieved an overall accuracy reach to 99%. This accuracy is based on the Random Forest algorithm training with 240 samples per satellite imageries.

For future work will focus on developing a geospatial model of combination DEM with high spatial resolution and Sea level rise data observing by tide gauge or altimeter satellite. This could be assessing the accuracy of this model in the future. This future work should be considering and research in more detail in Cambodia, while our research was the first knowledge about the vulnerable area of mangrove forests that will be affected by future Sea level rise using advanced technology of Remote Sensing (RS) and GIS model. Our research result might be accurate or not accurate depended on developing a geospatial model using the medium spatial resolution of DEM overlap with land cover's mangrove forests. The main reason to research as s study about the potential impacts of Sea level rise to mangrove forests, in the previous research studies, mostly used the lower accuracy DEM to create the GIS model to assess the impact of Sea level rise on land cover. Although this study is really important to enhance the mangrove forests changes and show resilience to future Sea level rise.

5. CONCLUSION

A quantitative of mangrove forests maps in Peam Krasop Wildlife Sanctuary between 2015 and 2020, result has shown mangrove forest areas estimated 7157.90, 7495.21, 7337.47, 6436.26, 6761.66, and 7045.64 ha in 2015, 2016, 2017, 2018, 2019, and 2020.

Either, mangrove forest areas in PKWS in this study were analyzed changed from 2015 until 2020 based on MOLUSCE. We contribute to mangrove forest area changes in this period. Mangrove forests increased by 337.31 ha between 2015 and 2016. In contrast, mangrove forests in PKWS were decreased 157.74 ha in 2017. Similarly, mangrove forests have continued to lose 901.21 ha from 7337.47 ha to 6436.26 ha in 2018. However, mangrove forests started increasing 325.40 ha in PKWS in 2019 increased from 6436.26 ha to 6761.66 ha. Mangrove forests continued to increase by approximately 283.98 ha in 2020 as well. The total long-term changes of mangrove forests in Peam Krasop Wildlife Sanctuary from 2015 to 2020, mangrove forests were lost about 112.26 ha from 7157.90 to 7045.64 ha.

Therefore, this study provides new knowledge about the vulnerable area of mangrove forests that will influence by future Sea level rise in Cambodia. Especially, lowly area of mangrove forests projected to inundate or impact areas about 4.44 ha by SLR 40 to 60 cm at the end of the twenty-first century and predicted to be inundated 53.14 ha by SLR 1 m.

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