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Mapping mangrove forest cover using Landsat-8 imagery, Sentinel-2, Very High Resolution Images and Google Earth Engine algorithm for entire Cambodia

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Abstract. Currently there is limited information to estimate accurate and reliable mangrove forest area in Cambodia. Previous estimates did not explicitly illustrate the spatial distribution of mangrove for the entire country however, according to Global Forest Resource Assessment 2010, Cambodia's mangrove area cover in 1990 and 2010 was calculated at 79,638 ha and 55,704 ha, respectively using extrapolation of 1992-1996 (original data from Remote Sensing of forest cover 1992/93 and 1996/97) for 1990 and extrapolation of 1996-2002 (original data from Remote Sensing of forest cover 1996/97 and 2002) for 2010. This study mapped the spatial distribution of Cambodia's mangrove forest derived from 30 m x 30 m spatial resolution and polygon spatial extent from Landsat 8 (L8) image. Publicly available Landsat data was acquired from Google Earth Engine (GEE) Explorer including the Landsat Surface Reflectance-Landsat 8 (L8) OLI/TIRS; Top-Of-Atmosphere (TOA) L8 32-Day Reflectance Composite; Landsat Archive Pre-Collection from US Geological Survey (USGS, 2015); VHR Google-derived images (Collin et al. 2014) and field data collection from 63 plots representing the entire Cambodia of Surface Water Ambient Monitoring Program (SWAMP) to create a Google Fusion Table aiming at mapping the spatial resolution and extent. Random Forest (RF) Classifier, a supervised classification technique, was applied to three L8 images Archive Pre-Collection Level-1 (L8 OLI/TIRS) collected in December 2014, February 2015 and April 2015. Statistical analysis indicates the total area of mangrove forest cover reached 73,240ha with overall classification accuracy of 98.2%, 97.9% and 99.5% for three periods and the validation overall accuracy were 91.5%, 89.1% and 97.6%, respectively. Our findings suggest that L8 imagery and Google Earth Engine algorithm can be used to estimate area changes of mangrove forests in Cambodia with higher accuracy. The results of this study may be useful to assist decision making in planning for mangrove ecosystem restoration activities, evaluation of ecological services and in better estimation of carbon stock in mangrove forest. (Tier 1- default emission or Tier 3- plot data are more related to emission factor).

1. Introduction

Given that mangroves have been characterized as having a high C density coupled with a high rate of deforestation, there is an increased interest in including mangroves as part of climate-change mitigation



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strategies that would reduce the anthropogenic emissions of greenhouse gasses (Kauffman et al. 2011). Many studies have reported that below-ground C pools account for 49–98% of the total ecosystem C stock in mangroves (Donato et al. 2011, Adame et al. 2013). A recent study estimated that deforestation of mangroves released 0.07 to 0.42 GtCO₂ / yr (Donato et al., 2011).

Mangrove forests are distributed in the inter-tidal region between the sea and the land in the tropical and subtropical regions of the world between approximately 30°N and 30°S latitude (Giri et al. 2010). Despite their importance and significance, our understanding of the present status and distributions of mangrove forests of the world remain inadequate (Giri et al. 2010). Mangroves form the foundation of a highly productive and biologically rich ecosystem which provides a home and feeding ground for a wide range of species, many of which are endangered (UNEP, 2014). According to trend analyses of the available data, some 15.2 million hectares of mangroves are estimated to exist worldwide as of 2005, down from 18.8 million hectares in 1980 and the most extensive mangrove area is found in Asia, followed by Africa and North and Central America (FAO, 2007). About 35% of mangroves were lost from 1980 to 2000 (MA, 2005), and the forests have been declining at a faster rate than inland tropical forests and coral reefs (Duke et al. 2007). Classification and distribution of mangrove vegetation are vital information for the proper development of a mangrove management plan (Sulong et al. 2002).

In Cambodia greenhouse gas inventory report, the highest contributor of national emission was Land Use Change and Forestry (LUCF) which accounted for about 49% of total emissions and 100% of total removal. Although estimating carbon emissions and removals from LUCF is complicated due to (1) the complexity of biological factors, and (2) a lack of reliable data, as well as (3) activity data that are generally spatially coarse and need to be completed by global estimates or secondary statistics (GSSD, 2015). In case of mangroves, the assessment is conducted by Global Forest Resource Assessment and the result indicated that the area has decreased from 1990 to 2010. While the values and ecosystem services of mangroves are well known, few data exist for mangrove area extent in the country. Statistical data from Ministry of Environment also show the decrease of mangrove area from 1997 to 2005 from 63,039 ha to 55,419 ha (MoE, 2007). However, the recent assessment on this forest type has not been made publicly available. From its first and second national communication, Cambodia did not explicitly report mangroves in different section either for national greenhouse gas inventory or national forest inventory though the mangroves still exist in the country. The mangrove data is only the result of Global Forest Resource Assessment. Therefore, if the country has the intention to move from Tier 1 to Tier 2 or Tier 3 for its inventory, this kind of study is vital not only for the mangrove extent estimation but also for the improvement of uncertainty assessment. The result of this study can be served as country specific activities data and if the estimation is improved, this forest category can play important role in national removal. Moreover, a better estimation of mangrove area will also assist in the national forest management planning and conservation strategies so as REDD+.

This study aims to better achieve estimation of the mangrove areal extent and map the spatial distribution of mangrove using newly available platform (GEE) and publicly available Landsat data from Global Land Survey with higher accuracy assessment. To achieve the map result, 63 permanent sample plots from mangroves, salt pans and aquaculture ponds representing the entire Cambodia sample plots will be used as ground trusting data in combination with the plots collected from Google Earth Engine using remote sensing technique. The ground trusting plots are from a previous study conducted by joint program of USAID Low Emission for Asia Development Program, US Forest Service and the government of Cambodia for C stock assessment using Surface Water Ambient Monitoring Program (SWAMP).

2. Materials and Methods

Cambodia is a low-lying plat land country located in southeastern part of Asia between 10°21'–14°38' N and 102°18'–107°37' E (Figure 1). The climate is characterized by monsoon which starts from May until November. In Cambodia, mangroves can only be found in Southwestern part of the country (FAO, 2010) between 10°43'–11°85' N and 102°88'–104°44' E covering four provinces: Koh Kong, Preah Sihanouk, Kompot and Kep. Mangroves are found along almost all the coasts of Cambodia; they occur

around Veal Renh and Kompong Som Bays and north of Kas Kong up to the border with Thailand, and only in a residual form as narrow, broken strips that eventually may continue fairly far up the water courses, while the larger areas are found at the main estuaries (e.g. Peam Krasop, Andong Tuk, Sre Ambel, Chak Sre Cham, and Prek Kampot) (FAO, 2005). According to this same source, the main species are *Rhizophora apiculata* (syn *R. conjugata*), *R. mucronata*, *Bruguiera gymnorhiza*, *B. sexangula*, *Ceriops tagal*, *C. decandra*, *Sonneratia alba*, *Lumnitzera littorea*, *L. racemosa* and *Xylocarpus granatum* (syn. *Carapa obovata*).

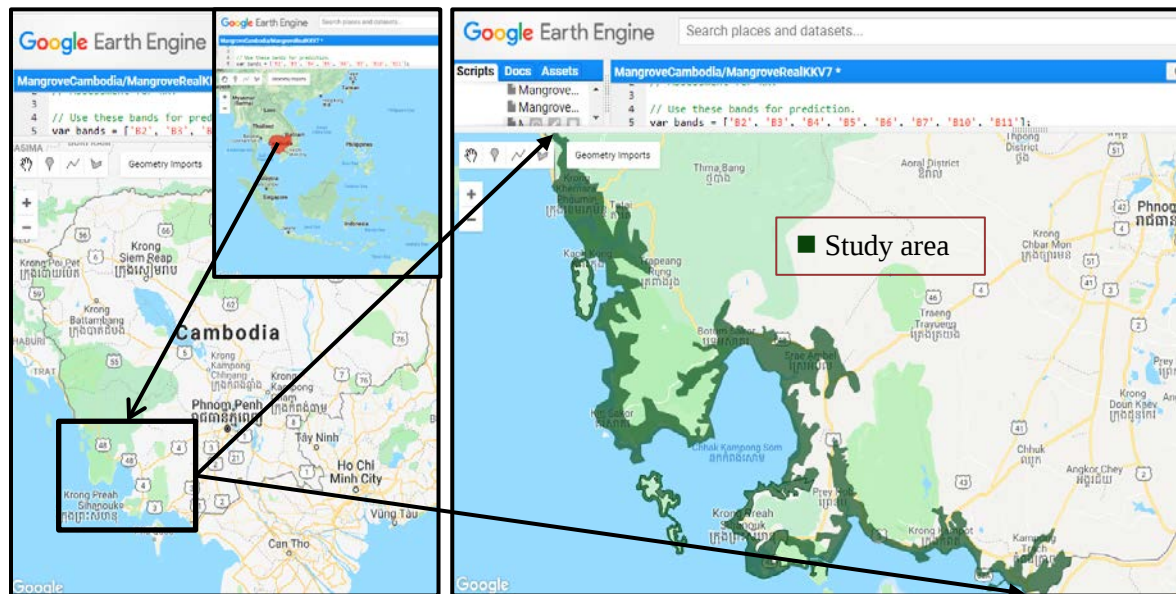


Figure 1. Preliminary determination of study area using Google Earth Engine

This study employs the GEE to classify and estimate the area of mangrove, aquaculture pond, urban/settlement, agriculture, mudflat, ocean, terrestrial forest, salt pan in coastal areas of Cambodia. The methodology of the study is prescribed in (Figure 2).

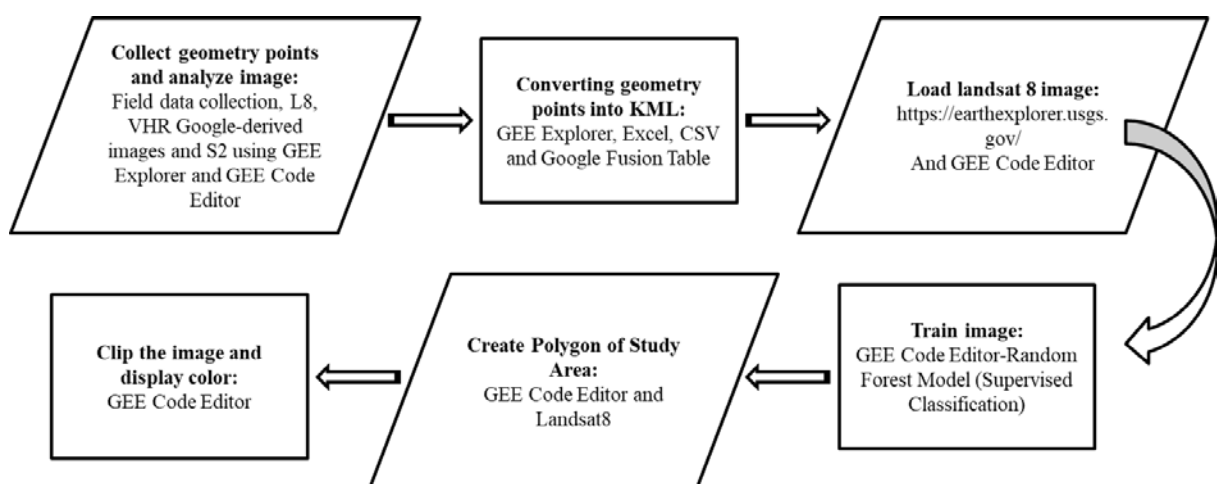


Figure 2. Brief description of methodology of the entire mapping process

2.1. Data and plot information

To cover all mangrove areas in Cambodia, three Landsat-8 (L8) images of year 2014 and 2015 were downloaded from <https://earthexplorer.usgs.gov/> (Figure 3). The acquisition date of the imageries is selected to be consistent with the date of mangroves field data collection for carbon stock assessment training which were conducted at the end of 2014 and beginning of 2015. Image 1 was the image of Landsat Archive Pre-Collection Level-1 (L8 OLI/TIRS) with Landsat Scene Identifier: 'LC81270522015038LGN00' and Acquisition Date: 07 February 2015 (Fig. 3. a). Image 2 was the image of Landsat Archive Pre-Collection Level-1 (L8 OLI/TIRS) with Landsat Scene Identifier: 'LC81260532015015LGN00' and Acquisition Date: 15 January 2015 (Fig. 3 b). Image 2 was the image of Landsat Archive Pre-Collection Level-1 (L8 OLI/TIRS) with Landsat Scene Identifier: 'LC81270532014355LGN00' and Acquisition Date: 21 December 2014 (Fig. 3 c):

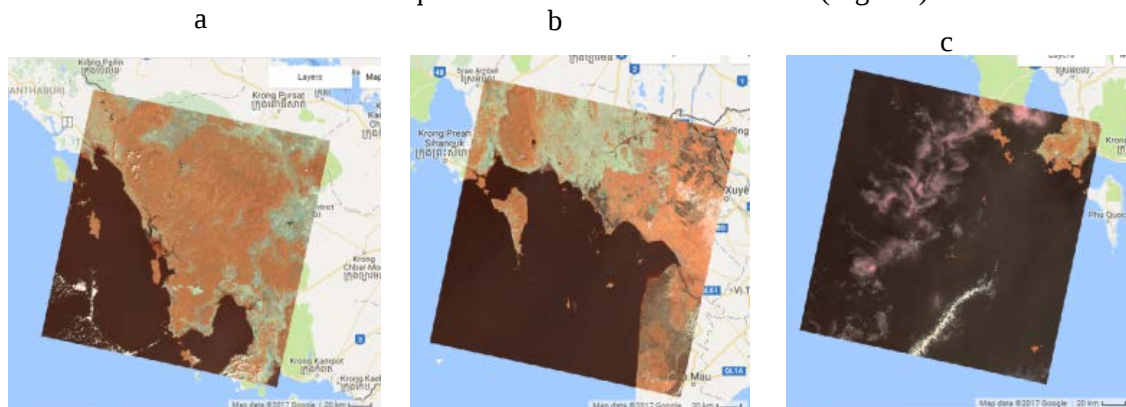


Figure 3. Image of 3 L8 covering the entire Cambodia. a) L8 covered Koh Kong and Srae Ambil area. b) L8 covered Prey Nop and Kampot area. c) L8 covered Krong Kampong Som

2.2. Image interpretation

The vegetation slopes could be discriminated at Band 4-red in L8 whilst B5- Near Infrared (NIR) emphasizes biomass content and shorelines and B6- Short-wave Infrared (SWIR) discriminates moisture content of soil and vegetation, penetrates thin clouds (USGS, 2016).

2.3. Classification method

Each plot was assigned according the land-use class that was previously identified using L8 32-Day Top Of Atmospheres (TOA) Reflectance Composite images. VHR images represent mangrove in darker green area comparing to other vegetation; Sentinel-2 (S2) images and ground truth data from the field. For S2 images, mangroves can also be differentiated from other vegetation using images of color combination of band 8, 4 and 3 (Near Infra-Red Green Blue) reflecting mangroves in striking red hue. Using L8 imageries, mangroves can be characterized visually through combinations of bands because false color combination of bands 5-6-7 (infraredmidinfrared1- midinfrared2) represents mangroves in a striking orange hue compared to other vegetation in (Homer, 2015).

2.3.1. Mangrove detection. Determination of mangrove conducted with visual interpretation and delineation object showing existence mangrove (Umroh et al., 2016). We consider mangrove as evergreen forest and this green property exists for the whole year. We separated mangrove area from non-mangroves by using L8 32-Day Top of Atmospheres (TOA) Reflectance Composite images at bands 5-6-4, VHR images, S2 of color combination of band 8, 4 and 3 (Near Infra-Red Green Blue) and our ground trusting data from field as indicated in (Figure 4). Mangroves just like other objects, have their own spectral signature which can be used for their classification. Spectral signature refers to the unique response of object when subjected to varying wavelengths of the electromagnetic spectrum (Homer, 2015).

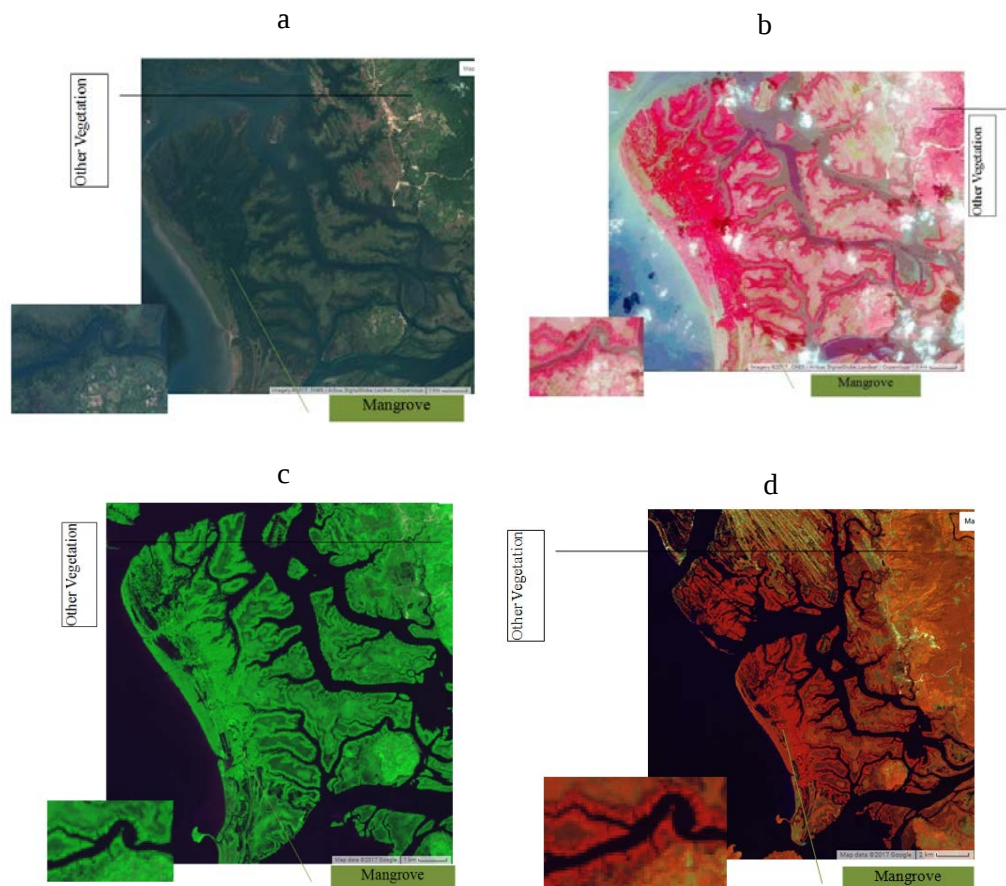


Figure 4. Discrimination of mangrove from other vegetation. a) using high resolution image b) using s2 image c) using L8 image at Band 3,4,5 and d) using L8 image at band 5,6 and 4

2.3.2. Salt pan detection. Visual interpretation and delineation objet were also applied to determine the salt pan area in Cambodia. Preliminary field interview was also conducted to characterize the existence of the salt pan and determine the hyperspectral discrimination. The ideal time to collect exploit the saltpan spectral characteristics in hyperspectral imagery was late in the dry season in southern Australia (Anna et al., 2009) which is more likely true for the salt pan practice in Cambodia. The lack of surface water meant that spectral features pertaining to soil properties could be maximized (Lobell and Asner, 2002).

2.3.3. Aquaculture pond detection. Through the various image processing technique, field survey and (Geographic Information System) GIS analysis, the mapping of the suitable area for aquaculture and marine fish resource could be delineated (Rajchandar and Karuppasamy, 2012). Bridger et al. (2003) recognize four classes of marine aquaculture sites according to degree of exposure: (1) land-based facility, (2) coastal environments (protected bays and fjords), (3) exposed sites and (4) offshore sites. The status of shrimp/fish farming was recently evaluated as being composed of mostly semi-intensive culture systems and they are usually reared in cages, ponds and pens (FAO, 2011).

3. Results and discussion

From field data, we noticed that at value of band of the three land use types is significantly different at L8 32-Day Top Of Atmospheres (TOA) Reflectance Composite images at bands 5-6-4. We found that all coordinates from field are located inside the area of interest that was previously defined. The red color of the point representing mangrove, the purple color representing aquaculture pond and the blue color representing salt pan location as indicated in (Figure 5). The reference spectra were also collected

to differentiate between tropical inland forest, salt pan and aquaculture pond comparing to the spectra from field data as shown in (Figure 6). The result of the reference spectra analysis of forty geometry points of the mangrove indicated different behavior of mangroves comparing to other three land use type (tropical inland forest, salt pan and aquaculture pond). Field investigation using preliminary interview with local interviewee was also consistent with the visual interpretation to confirm the existence of the mangrove in the study area. The extent of the mangrove is determined using L8 32-Day Top of Atmospheres (TOA) Reflectance Composite images at bands 5-6-4 along the coast line where the image pixel is striking orange-hue color. The Shuttle Radar Topography Mission (SRTM) by Farr et al. 2007 digital elevation data was also used to clip the mangrove extent. The mangrove exists in the area of elevation less than 100 m. Using Landsat allows us to map mangrove land cover area at 30 m x 30 m spatial resolution. A similar study was also conducted to map mangrove forest using L8 OLI in the West and Central Africa and in the Sundarbans delta and the overall accuracy check was generated an overall accuracy of 84.1% with kappa coefficient 0.74 (Dan et al., 2016). Another finding for mapping the spatial distribution and areal extent of the Philippines' mangroves circa 2000 was also based on Landsat imagery (Jordan and Giri, 2011). The later study also used publicly available Landsat data acquired primarily from the Global Land Survey to map the total extent and spatial distribution by applying ISODATA clustering, an unsupervised classification technique, to sixty-one Landsat images. By using Random Forest model, we could achieve higher accuracy assessment (above 90% for three images) which is also consistent with results found by Remie et al. (2015) for mangrove land cover mapping using Landsat 5 TM and ALOS PALSAR imageries

GEE allows us to employ algorithm to map the land use type by applying different model classification for better accuracy. A study to detect industrial oil palm plantations on Landsat images also used GEE platform to map the area of oil palm in Tripa, Aceh, Indonesia. The study also found Classification and Regression Tree and Random Forest algorithms produced classified land cover maps provided with higher overall accuracies and Kappa coefficients than the Minimum Distance (MD) algorithm. Based on the overall accuracy scores, CART classification using ALL bands came in first (93.6% with a Kappa coefficient of 0.92), followed by Random Forest (RFT) classification using ALL bands (91.2% with a Kappa coefficient of 0.89), and CART classification using RGB bands (84.9% with a Kappa coefficient of 0.82).

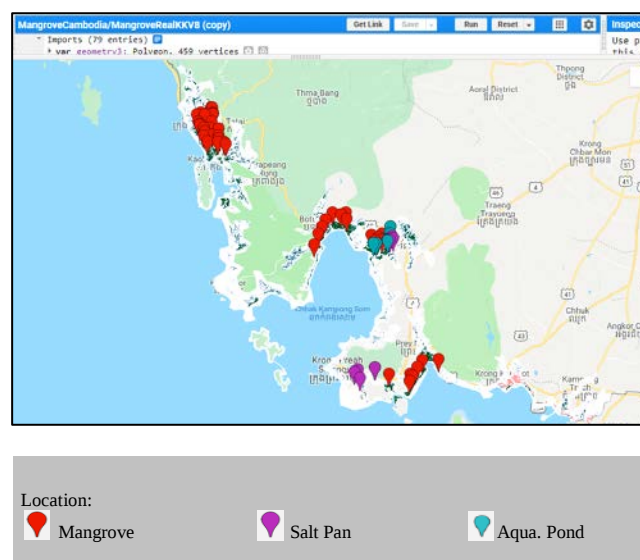


Figure 5. GPS location of the data collected from the field training in 2014 and 2015. All GPS points are located in the boundary of our polygon collection that was pre-defined for mangrove, salt pan and aquaculture pond

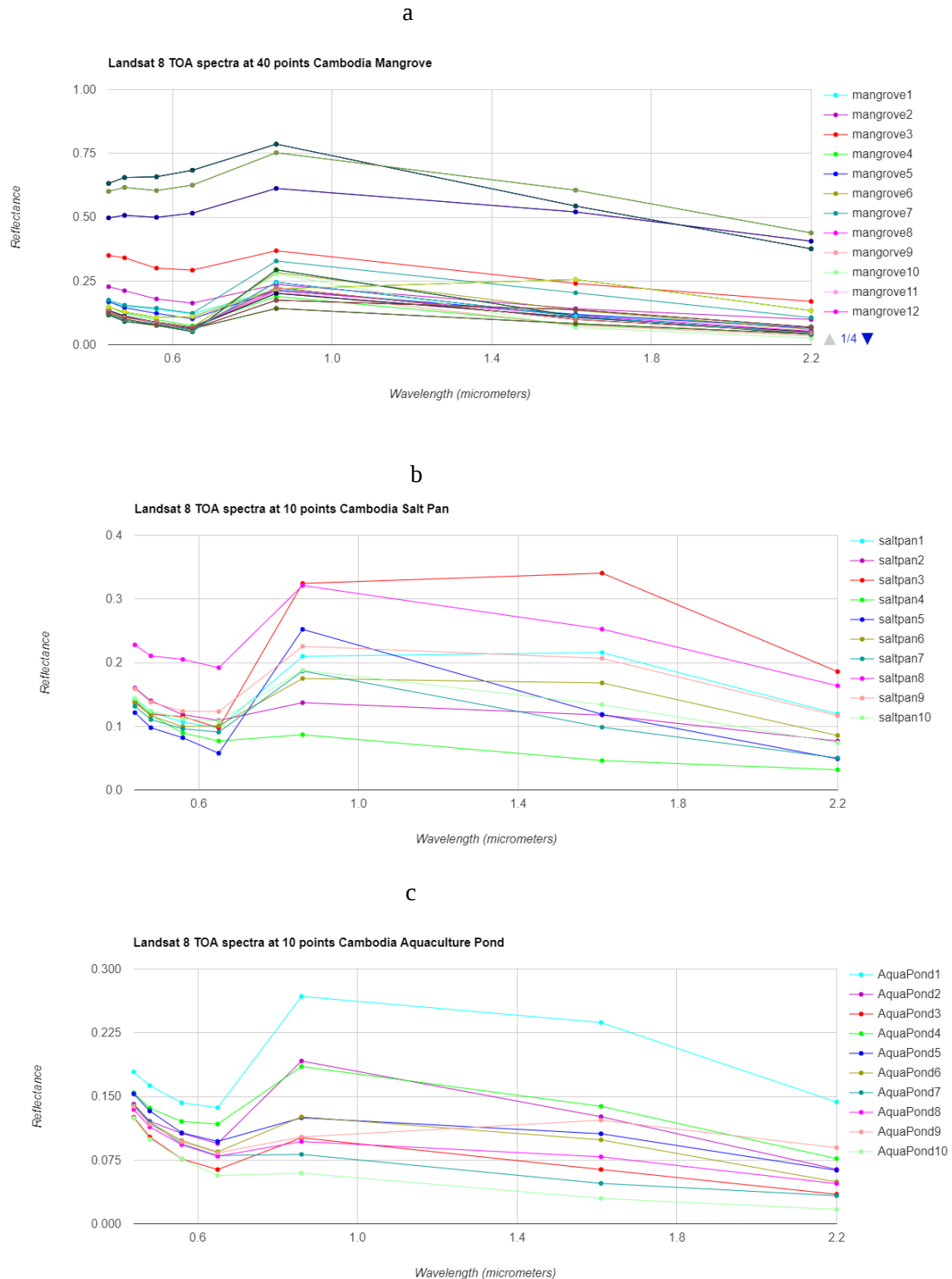


Figure 6. Spectra analysis of three land use categories at wavelength 0.44, 0.48, 0.56, 0.65, 0.86, 1.61, 2.2 a) represent the behavior of each geometry point of mangrove b) represent the behavior of each geometry point of salt pan c) represented the behavior of each geometry point of aquaculture pond

Our main focus was on three land use types (mangroves, salt pans and aquaculture ponds) though in this methodology we classified eight land use types. Therefore, in our map results, we only displayed the color and area estimation of the three main land use types following our priority.

The mapping result and the distribution of mangrove for the entire Cambodia and per province is shown in (Figure 7). The most-dense mangrove was located in Koh Kong Province following by Preah Sihanouk, Kompot and Kep. The Global Forest Assessment also concluded that mangroves are mostly found in protected area such as: Ream National Park, Batum Sakor National Park and Peam Krasoap Wildlife Sanctuary (FAO, 2005). Salt pan activities mostly happened in Kompot and Kep. This result is consistent with previous findings which stated that some mangroves in Kampot Province and Kep Municipality have been cleared for salt production (FAO, 2005). Koh Kong also has more aquaculture pond areas comparing to other provinces. The result of training model was more consistent and accurate comparing with L8 images. The breakdown of marine aquaculture is 218 ha of earthen ponds (10 232 ponds), 1 571 ha of pens (292 pens) and 14 ha of floating net-cages (1 898 cages) (FiA, 2014). However, the distribution and extent of mangrove has not been studied explicitly.

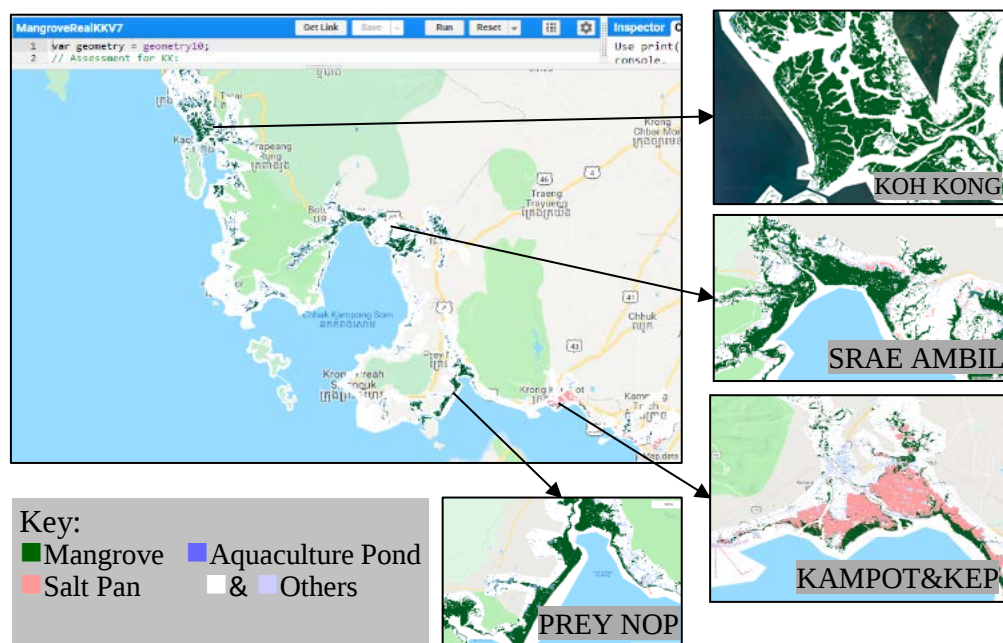


Figure 7. Image of result of classification for entire Cambodia and by area of interest

From the model trained, we estimated the area of mangroves, salt pans and aquaculture ponds for each distribution. The result of estimation is shown in Table 1. Among our three areas of interest, we found the largest mangrove area in Koh Kong Province and the largest salt pan area in Kom Pot. These findings are different from the result of desk review of Reference of Global Forest Resource Assessment of FAO which estimates the mangroves area of the entire Cambodia at 50,000 ha in 2015 (FAO, 2015).

Table 1. Estimation of area by ROI (in hectare)

ROI	Mangrove	Aqu. Pond	Salt pan
Koh Kong	30,143.86	2,011.82	162.95
Srae Ambil	29,204.18	3,047.74	1,803.20
Prey Nop*	13,891.32	1,151.29	6,052.37
Total	73,239.36	6,210.85	8,018.52

4. Conclusion

This study presents the possibility of using freely available data combining with remote sensing technique and Artificial Intelligence (GEE) to assess and validate the maps as well as valuate the recent condition of mangrove forest based on free data at large scale such as country assessment. The result of accuracy assessment indicated good performance on overall training for training accuracy. The validation of error could be improved if more sample are collected as reference data in google fusion table or additional detail information such as images or ground thrust data of ROI are collected. Our study found the area of mangrove forest decreased comparing to the estimation between 1990 to 1995 and this number remain almost stable since 2000 when the Participatory Management of Mangrove Resources project was implemented in Peam Krasoap Wildlife Sanctuary (PKWS) in Koh Kong province in 1997 (Lisa, 2011) despite the factor that mangrove forest is under the protection of the decree "Creation and Designation of Protected Areas", signed by the King in 1993 (Nirmal, 2000). Though this study found the mangrove area less significant than the finding from desk review of global assessment of 23,240 ha (FAO,2015).

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References

- [1] Adame M F, Kauffman J B, Medina I, Gamboa J N, Torres O, Caamal J, Reza M, and Herrera-Silveira J A, 2013 Carbon stocks of tropical coastal wetlands within the karstic oligotrophic landscape of the Mexican Caribbean. *PLoS ONE* 8(2):e56569.
- [2] Anna D, Lewis M, and Ostendorf B 2009 The Suitability of Airborne Hyperspectral Imagery for Mapping Surface Indicators of Salinity in Dryland Forming Areas. *International Starndard Book Number-13: 978-1-4200-6502-2 (Hardcover)*.
- [3] Bridger C J & Costa-Pierce B A 2003 Open Ocean Aquaculture: From Research to Commercial Reality. The World Aquaculture Society, Baton Rouge, Louisiana, USA.
- [4] Collin A, Nadaoka K and Nakamura T 2014 Mapping VHR Water Depth, Seabed and Land Cover Using Google Earth Data. *Journal ISPRS Int. Geo-Inf.*, Vol 3, pp 1157-1179.
- [5] Dan T T, Chen C F, Chiang S H, Ogawa S 2016 Mapping And Change Analysis In Mangrove Forest By Using Landsat Imagery. *Congress of XXIII ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol 3 (Czech Republic: Prague)
- [6] Lobell D B and Asner G P 2002 Moisture Effects on Soil Reflectance. *Journal Soil Science Society of America Journal* Vol 66 ed Davi M *et al* pp 722-727.
- [7] Donato D C, Kauffman J B, Murdiyarso D, Kurnianto S, Stidham M, and Kanninen M 2011

- Mangroves among the most carbon-rich forests in the tropics. *Nature GeoScience* Vol **4** pp 293–297.
- [8] Duke N C *et al* 2007. A world without mangroves? *Science Magazine* Vol **317** ed Kavanagh E pp 41–42.
- [9] Fishery Administration (FiA) 2014 the Department of Fisheries. *Annual reports of the Fisheries sector in Cambodia*.
- [10] Food and Agriculture Organization of the United Nations (FAO) 2005. *Global Forest Resources Assessment 2005 Thematic Study On Mangroves, Cambodia*.
- [11] Food and Agriculture Organization of the United Nations (FAO) 2011 Fishery and Aquaculture Country Profiles. *Cambodia Country Profile Fact Sheets* (Rome: FAO Fisheries and Aquaculture Department)
- [12] Food and Agriculture Organization of the United Nations (FAO) 2015. *Global Forest Resources Assessment 2015 Desk Reference*.
- [13] Food and Agriculture Organization of the United Nations (FAO) 2007 The world's mangroves 1980-2005. *A thematic study prepared in the framework of the Global Forest Resources Assessment 2005*. (Rome: Viale Delle Terme di Caracalla).
- [14] General Secretariat, National Council for Sustainable Development (GSSD) 2015. *Cambodia's Second National Communication under the United Nations Framework Convention on Climate Change*. (Phnom Penh: Ministry of Environment, Kingdom of Cambodia).
- [15] Giri C, Ochieng E, Tieszen L L, Zhu Z, Singh A, Loveland T, Masek J and Duke N 2010. Status and distribution of mangrove forests of the world using earth observation satellite data. *Journal of Macroecology: Global Ecology and Biogeography* Vol. 20 ed McGill B pp 154-159
- [16] Google Earth Engine (GEE). <https://code.earthengine.google.com> and <https://explorer.earthengine.google.com>.
- [17] Pagkalinawan H 2015. Mangrove Forest Mapping Using Landsat 8 Images. (State of the Mangrove Summit: Northwestern Luzon Proceedings) Indd: 60-64.
- [18] Long J B and Giri C 2011. Mapping the Philippines' Mangrove Forests Using Landsat Imagery. *Journal Sensors (Basel:)* Vol **11** pp 2972–2981.
- [19] Boone K J, Heider C, Norfolk J, and Frederick P 2014. Carbon stocks of intact mangroves and carbon emissions arising from their conversion in the Dominican Republic. *Journal Ecological Applications* Vol **24** ed Craft C pp 518–527
- [20] Waldick L 2011. Protecting mangrove forests in Cambodia. International Development Research Centre (IDRC).
- [21] Long J B, Napton D, Giri C and Graesser J 2014. A Mapping and Monitoring Assessment of the Philippines' Mangrove Forests from 1990 to 2010. *Journal of Coastal Research* Vol **30** pp 260–271.
- [22] Millennium Ecosystem Assessment (MA) 2005 Mille ecosystems and human well-being: synthesis. *Island Press* (Washington DC).
- [23] Ministry of Environment (MoE) 2007. Sustainable Use and Management of Coastal Wetland Department of Nature Conservation and Protection.
- [24] Paul N C 2000 Mangrove Area Encroachment in Cambodia: Problems and Findings. Forests/Multiple Commons, Environmental Science Digital Library Of The Commons Repository INDIANA UNIVERSITY.
- [25] Padmanaban R and Karuppasamy S 2012. Marine Fishery Information System and Aquaculture Site Selection Using Remote Sensing and GIS. *Journal Advanced Remote Sensing and GIS* Vol **1** pp 20-33.
- [26] Jhonnerie R, Siregar V P, Nababan B, Prasetyo L B and Wouthuyzen S 2015 Random forest classification for mangrove land cover mapping using Landsat 5 TM and ALOS PALSAR imageries. *Journal Procedia Environmental Sciences* Vol **24** ed Setiawan Y *et al* pp 215 – 221.

- [27] Sulong I, Mohd-Lokman H, Mohd-Tarmizi K And Ismail A 2002 Mangrove Mapping Using Landsat Imagery And Aerial Photographs: Kemaman District, Terengganu, Malaysia. *Journal Environment, Development and Sustainability* Vol **4** ed Hens L pp 135–152.
- [28] U.S Geological Survey (USGS) Earth Explorer. <https://earthexplorer.usgs.gov/>.
- [29] Umroh, Adi W, Saric S P 2016 Detection of mangrove distribution in Pongok Island. *Journal Procedia Environmental Sciences* Vol **33** ed Setiawan Y *et al* pp 253 – 257.
- [30] UNEP 2014 The Importance of Mangroves to People: A Call to Action. United Nations Environment Programme World Conservation Monitoring Centre, Cambridge pp 128.