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Effect of Satellite Imagery Resolution on Wetlands Area Estimation: Sudd Wetlands

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ملخص عربي
الأراضي الرطبة هي أنظمة بيئية متميزة تغطي مساحات واسعة وتحتاج إلى مراقبة مستمرة لتغيرات الغمر الموسمية. تعد صور الأقمار الصناعية متعددة الأطياف (MSI) أداة جذابة توفر قياسات واسعة النطاق وقريبة من الوقت الفعلي. يجب اختيار منصة MSI بعناية وفقًا لطبيعة المنطقة قيد الدراسة. اثنين من الأكثر استخداما من منصات Landsat 8 و MODIS. تقدم هذه الدراسة تقديرًا للانحرافات في تقدير مساحة الأراضي الرطبة في Sudd كنتيجة لاستخدام صور MODIS متوسطة الدقة بالمقارنةً مع صور Landsat 8 الاكثر دقة. تمتد فترة الدراسة من 2013 إلى 2016. وأظهرت النتائج أن مناطق الأراضي الرطبة الرئيسية والتغيرات الموسمية يمكن تقديرها بدقة باستخدام صور MODIS. في حالة الأراضي الرطبة متوسطة الحجم ، MODIS عند مقارنتها مع Landsat ، تعطي تقدير أقل للمساحة الكلية للأراضي الرطبة. ومع ذلك ، فإنه يلتقط الاختلافات الموسمية. في حين أن للمسطحات المائية الصغيرة الدائمة ينصح بصور لاندسات.

ABSTRACT
Wetlands are distinct ecosystems that cover wide areas and need continuous monitoring of their seasonal inundation variations. Multispectral Satellite imagery (MSI) is an appealing tool that provides wide scale, near real time measurements. MSI platform should be carefully selected according to the nature of the area under study. Two of the most commonly used are from Landsat 8 and MODIS platforms. This study provides a quantification of the deviations in the Sudd wetland area estimation as a result of utilizing medium resolution MODIS images as oppose to fine resolution Landsat 8 images. Study period extends from 2013 to 2016. Results showed that the main wetlands areas and their seasonal variations can be accurately estimated using MODIS images. In the case of medium-sized wetlands, MODIS when compared to Landsat, under estimates the total wetland area. Nevertheless, it captures the seasonal variations. While, for small permanent water bodies Landsat images are recommended.

KEYWORDS: MODIS, Landsat, Resolution, Sudd

1. INTRODUCTION
Wetlands are a complex hydrological and ecological system that contains a variety of habitats. They are known to occupy wide areas and have seasonal behavior. The nature of wetlands imposes a scarcity in ground measurements. Satellite imagery is a remote sensing technique that allows land cover differentiation, which makes it suitable for wetlands inundation monitoring. Satellite images were successfully used in water extent mapping. Many studies estimated water surface areas for lakes and reservoirs form fine resolution Landsat imagery data [1, 2]. While others used moderate resolution (Moderate-Resolution Imaging Spectroradiometer MODIS) imagery data to map flood events [3] and estimate wetlands area [4]. Although, Landsat images have high resolution its small swath (185 km) makes it unsuitable for use in large areas, which are

usually covered by more than one along path tile (row) and cross-path tile (path). Along path tiles have the same time signature, while cross path tiles have shifted time signature by 7 days. This leads to temporal inconsistency and loss of significant changes within month, in highly dynamic eco-hydrological system. The exceptionally large swath width (2330 km) of MODIS images can compensate for such Landsat drawbacks, since it can cover vast wetlands area at the same acquisition time assuring temporal consistency. On the other hand, it has moderate resolutions (250 – 1000 m); that causes a difficulty in detecting small water bodies.

The objective of this study is to compare between wetland areas detected by Landsat and its corresponding MODIS images, in order to assess the effect of using lower resolution satellite images on the wetlands' areas estimation.

2. BACKGROUND

Multispectral images are collected by passive sensors that receive sun radiation reflected off the earth's surface. Data is gathered in the visible and near-infrared portions of the electromagnetic spectrum, in addition to reflectance of longer wavelength energy like mid-infrared and thermal wavelengths. Different land covers have unique spectral signature in the electromagnetic spectrum, which allows for the interpretation of these images and the detection of land cover type from space.

Water classification from satellite images can be performed using two main methods: supervised classification and unsupervised classification. Supervised classification is an accurate method, however, its time consuming and tedious process because it requires manual input and interpretation of each image. While the unsupervised classification can be carried out through density slicing of bands (applying threshold to certain band) or calculating indices using a combination of bands (e.g. *NDWI*, *mNDWI*..etc.) and applying a threshold to them. For clear water a threshold of zero separates water/non-water areas, positive values indicating water. In case of wetlands, a significant portion of the wetlands is covered by aquatic weeds and plants; water is mixed with vegetation and soil can be seen through low water depth. This leads to altering the spectral signature of water markedly and makes detecting water pixels not straightforward exercise. The threshold value is different to each wetland area due to variations in water depth and vegetation types [5].

3. METHODOLOGY

3.1. LANDSAT IMAGES

Landsat satellite products are generated at 30-meter spatial resolution with 16 days revisit period; therefore, it is one of the most commonly used fine resolution satellite images. Landsat satellite data have available since 1972. Landsat 8 Operational Land Imager (OLI), and the Thermal Infrared Sensor (TIRS) is in operation since 2013 until the present time. Science Data Sets (SDS) included in the product are listed in Table. 1. [6]. The Landsat 8 Surface Reflectance Code (LaSRC) product data are used (collection1 level2) in this study. The product is an estimate of the surface reflectance for each band, as it would have been measured at ground level assuming no atmospheric scattering or absorption. It is corrected for the effects of atmospheric gases and aerosols.

Thirty-meter spatial resolution Landsat 8 tiles are generated on a Universal Transverse Mercator (UTM) mapping grid. Quality assurance data mask for clouds and cloud shadows for all the downloaded tiles had to be made before using the data in the calculations.

Table. 1. Science data layers for LaSRC products (Collection 1 Level 2)

Science Data sets	Spectral Range (nm)	Band Name	Units
Surface Reflectance Band 1	435-451	Costal Aerosol	Reflectance
Surface Reflectance Band 2	452-512	Blue	Reflectance
Surface Reflectance Band 3*	533-590	Green	Reflectance
Surface Reflectance Band 4*	636-673	Red	Reflectance
Surface Reflectance Band 5*	851-879	NIR	Reflectance
Surface Reflectance Band 6*	1566-1651	SWIR	Reflectance
Surface Reflectance Band 7*	2107-2294	SWIR	Reflectance
Level-2 Pixel Quality Band*	-	-	Bit Index
Aerosol QA	-	-	Bit Index
Radiometric Saturation QA	-	-	Bit Index
Level-1 Metadata file	-	-	-
Level-1 Angle Coefficient file	-	-	-

The Pixel Quality Band SDS included in the product (Table.1) is used to eliminate pixels assigned as cloud, cloud shadow, and cirrus. The spatial model editor available inside ERDAS Imagine image processing software is used to create the data mask. The spatial model gives pixels that are to be excluded due to quality issues a “NO DATA” value in the raster output to separate it from other pixels. It is possible to create and execute a spatial model within a python scripting language (Python Scripting with ERDAS Imagine Spatial Modeler, Intergraph). A python script is developed to calculate and run the spatial model in a batch mode for all scenes. The script uses ERDAS Imagine Spatial Modeler libraries to load the model, prepare its input data, and write its output. No gap filling is applied to Landsat images; therefore, selected images in this study had to contain minimum cloud cover.

Supervised classification method was chosen to generate Landsat wetlands maps; despite the time consumption and manual interpretation; due to its high accuracy. Landsat false color image (excluding coastal aerosol and blue bands…...Table.1.) was used to identify sample areas as wetlands through visual interpretation of the image using an image classification software package ERDAS IMAGINE. The program studies the spectral signature of the predefined area in selected bands and identifies similar areas in the image using strong statistical analysis producing Landsat wetland maps.

3.2. MODIS IMAGES

MODIS images are frequently used in studies that involve vast areas due to its exceptionally large swath width (2330 km). It provides temporal consistency between the acquired images. MODIS collects imagery in spectral range from 0.41 to 14.39 μm with a revisit time of 1–2 days and a variable spatial resolution (250 m, bands 1–2; 500 m, bands 3–7; 1000 m, bands 8–36; http://modis.gsfc.nasa.gov). MODIS surface reflectance data product collection 6 (MOD09) is used in this study. Two acquisitions from the MODIS satellite are available daily for each image, one from Terra platform MOD09GA and the other from Aqua platform MYD09GA. In this manuscript, datasets from both platforms will be referred to as "MOD09GA"; unless otherwise specified.

MOD09GA data are segmented into tiles with an area of 10º X 10º using a sinusoidal projection. Science Data Sets (SCS) included in the product are listed in Table. 2. [7]

MODIS images are needed for the study area at the same day of acquisition of Landsat8 platform to create Landsat/MODIS pairs for the sake of comparison. Due to the MODIS orbit and swath width compared to that of Landsat, MOD09GA images are not found on the same acquisition day of Landsat 8. As a workaround, daily MOD09GA images acquired from the previous and the following days are considered for comparison with Landsat 8 images. Four MOD09GA images are acquired corresponding to each Landsat image, MOD and MYD images from the day before Landsat acquisition date in addition to MOD and MYD images from the day after. MODIS Images are ranked, through visual inspection, according to the cloud cover. Rank 1 is assigned to the clearest image, and rank 4 is assigned to the image with highest cloud cover. This will be used in the gap filling procedure described later on.

Table. 2. Science data layers for MOD09GA products (Collection 6)

Data Group	Science Data Sets	Band Name	Units
1 km	Number of Observations	-	None
	Reflectance Data State*	-	Bit field
	Sensor Zenith	-	Degree
	Sensor Azimuth	-	Degree
	Pixel to Sensor Range*	-	Meter
	Solar Zenith	-	Degree
	Solar Azimuth	-	Degree
	Geolocation Flags	-	Bit field
	Orbit Pointer	-	None
	Granule Pointer	-	None
500 m	Number of Observations	-	None
	Surface Reflectance Band 1 (620-670 nm)*	Red	Reflectance
	Surface Reflectance Band 2 (841-876 nm)*	NIR	Reflectance
	Surface Reflectance Band 3 (459-479 nm)*	Blue	Reflectance
	Surface Reflectance Band 4 (545-565 nm)*	Green	Reflectance
	Surface Reflectance Band 5 (1230-1250 nm)*	$SWIR_1$	Reflectance
	Surface Reflectance Band 6 (1628-1652 nm)*	$SWIR_2$	Reflectance
	Surface Reflectance Band 7 (2105-2155 nm)*	$SWIR_3$	Reflectance
	Reflectance Band Quality*	-	Bit field
	Observation Coverage	-	Percent
	Observation Number	-	None
250 m	scan value information	-	None

* SDS selected for use in this study

Reflectance Data State and Pixel to Sensor Range SDS (Table.2) are resampled from 1 km to 500 m using the free MODIS Re-Projection Tool (MRT). Pixels at the edge of the swath suffer from severe distortion [3], therefore pixels in the Pixel to Sensor Range SDS with value greater than 1000 km were also excluded. Quality assurance data mask for clouds and cloud shadows for all the downloaded tiles is applied. Cloud and cloud shadow information can be extracted from the Reflectance Data State SDS (Table.1).

For the highest quality data possible, pixels marked as clouds, cloud shadows, or marked as adjacent to a cloud from the data. Also, pixels with any cirrus clouds detected and pixels suspect of fire was removed. In order to perform the data mask, PyMasker python data package is used to extract bit data from MODIS quality data layers and create various masks. The output of the program is a thematic map with 1 for all pixels that can be used and 0 for all pixels that should be excluded. A Python script developed by ElKordy [4] is used to apply the PyMasker in batch mode to all downloaded MOD09GA and MYD09GA scenes.

The Modified Normalized Difference Water Index (*mNDWI*) method proposed by Xu [8] has been widely used and proved robust to differentiate water from non-water bodies [5]. The *mNDWI* is calculated as the ratio of the *Green* band subtracted from the Short Wave Infrared (*SWIR*) band to the sum of the *Green* band and the *SWIR* band. The equation is expressed as follows:

$$mNDWI = \frac{Green - SWIR_2}{Green + SWIR_2} = \frac{Band\ (4) - Band\ (6)}{Band\ (4) + Band\ (6)} \qquad \text{Eq.1.}$$

Water features have positive *mNDWI* values because of their higher reflectance in the *Green* band than the *SWIR* band. While non-water features (soil and vegetation) have negative *mNDWI* values due to their lower reflectance in the *Green* band than the *SWIR* band [8]. Hence, *mNDWI* is calculated for all MODIS images.

Individual band reflectance quality data, for bands used in *mNDWI* calculations (bands 4 and 6), can be extracted from the Reflectance Band Quality *SDS* (Table. 2). An additional mask is created for bands 4 and 6 reflectance quality assurance and applied to the MODO9GA *mNDWI* maps before applying the threshold. Gaps created by the two quality masks (reflectance data state and reflectance band quality) are filled in sequence for individual MOD09GA scenes. NO DATA pixels in image of rank 1 are filled by their corresponding pixels in image rank 2 if available. If not, pixels are taken from rank 3 then rank 4.

A threshold value for *mNDWI* (e.g. simply a value of zero) can be set to separate water features from non-water features. Different *mNDWI* threshold values were tested and the resulting wetland feature/non-wetland feature separations were visually checked. The threshold value of -0.36 was found suitable for wetlands separation. MOD09GA 500 m wetland maps are produced and resampled to 30 m (using MRT) to match Landsat 8 resolution.

3.3. Comparing Landsat/MODIS Pairs

Wetland area under study is sampled to sub areas considering their varying nature in space. Based on the sampling the corresponding Landsat and MODIS tiles are determined. Time matching pairs of Landsat 8 and MODIS images are, then, downloaded to capture the seasonal change in wetlands size. For the created Landsat/MODIS pairs, no data pixels, in either Landsat or MODIS wetlands maps, are removed from both maps. Number of wet pixels is counted and percentage of wet area to the total area is computed for both maps for all pairs using ArcMap software. The deviation in wetland area estimation in MODIS maps with respect to that of Landsat maps is calculated according to the following equation:

$$deviation = \frac{\%\,wet\ area_{MODIS} - \%\,wet\ area_{Landsat}}{\%\,wet\ area_{Landsat}} \qquad \text{Eq. 2.}$$

4. STUDY AREA

Sudd wetlands is one of the largest wetlands areas. It lies in Bahr El Jebel sub-basin of the Nile River Basin. Bahr El Jebel Basin covers an area of about 175,000 km^2 and extends between longitudes 29.39°E and 34.14°E and latitudes 2°N and 9.5°N. Wetlands are fed by Bahr El Jebel River which extends from Lake Albert to the confluence with Bahr el Ghazal at Lake No. Bahr el Zeraf River branches out of Bahr el Jebel River and joins the White Nile between Lake No and the Sobat mouth (Fig. 1). The wetlands are known for the inter-seasonal variation, where there are permanent wetlands throughout the year and seasonal wetlands that are inundated only during the wet season.

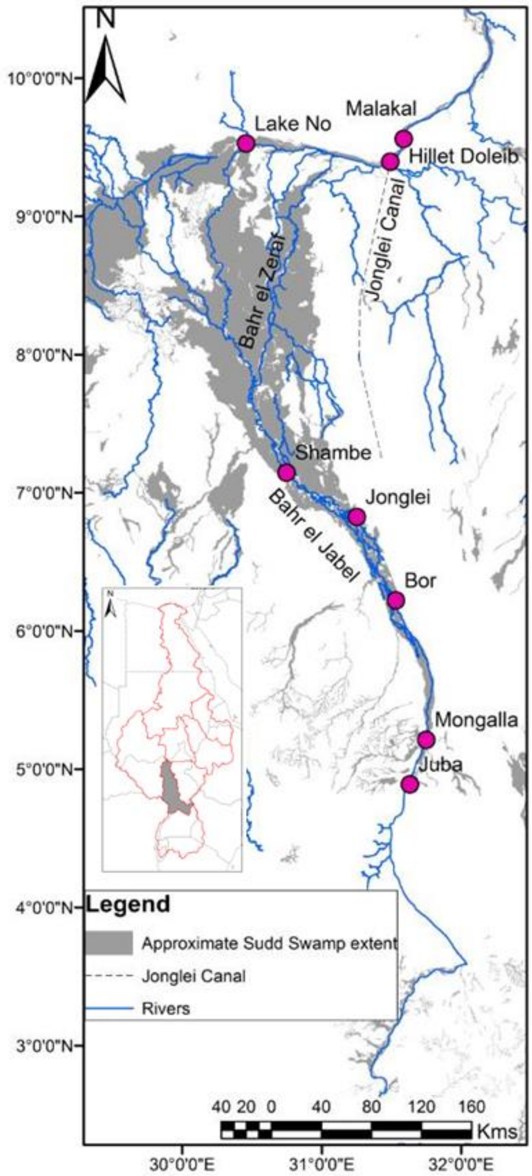

Figure 1. Map of the Sudd Region

5. RESULTS AND DISCUSSION

Sub areas of the Sudd wetlands is selected to cover parts of different natures and the corresponding Landsat and MODIS tiles are determined accordingly (Fig. 2). Time matching pairs of Landsat 8 and MODIS images are, then, downloaded taking into consideration using images in different seasons and with minimum possible cloud cover (Table. 3).

The downloaded MODIS images are re-projected to UTM -WGS84, while the zone varies according to the location of the study area (Table. 3). After that, images are cropped to the study area. Previous steps are executed using MRT.

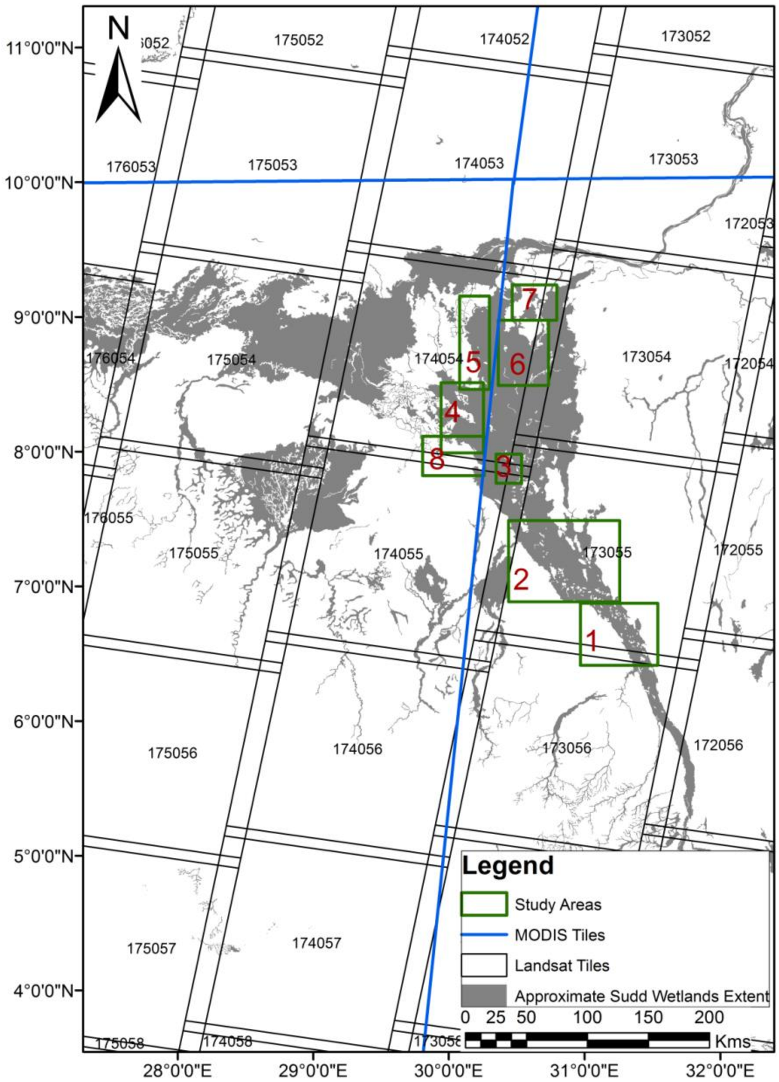

Figure 2. Location of MODIS Tiles, Landsat Tiles, and Sub Areas with respect to the Sudd Wetlands.

Table. 3. Summary of Landsat/MODIS Pairs Results

Pair	Sub Area	UTM Zone	Landsat Tile	MODIS Tile	Acquisition Date	Deviation
1	1	36	173055	h21v08	26-Nov-16	-32.67%
2	2	36	173055	h21v08	26-Nov-16	-38.35%
3	3	35	174054	h21v08	1-Nov-16	-49.62%
4	4	35	174054	h20v08	2-Jan-16	-68.61%
5					28-Sep-15	29.37%
6	5	35	174054	h20v08	2-Jan-16	-34.25%
7					17-May-13	-39.00%
8	6	35	174054	h21v08	1-Nov-16	-61.14%
9	7	35	174054	h21v08	1-Nov-16	-57.05%
10	8	35	174054	h20v08	2-Jan-16	-33.37%
11					28-Sep-15	18.86%

For sub areas 1, 2 and 5 the deviation ranges between 32 to 39 %, as they cover parts where medium-sized disconnected permanent wetlands exist and seasonal wetlands are limited (Fig. 3). While, for sub areas such as 4; containing small permanent wetlands and large continuous seasonal wetlands; deviation in the dry season (Jan), it reaches -68.61% (Fig. 4). On the other hand, in the wet season (Sep); for the same sub area; wetlands detected by MODIS are more than those by Landsat (Fig. 5). Locations where permanent wetlands are medium sized, like sub area 8, the deviation in dry season amounts to -33.37 % and in the wet season MODIS is detecting more wetland areas (deviation = +18.86%).

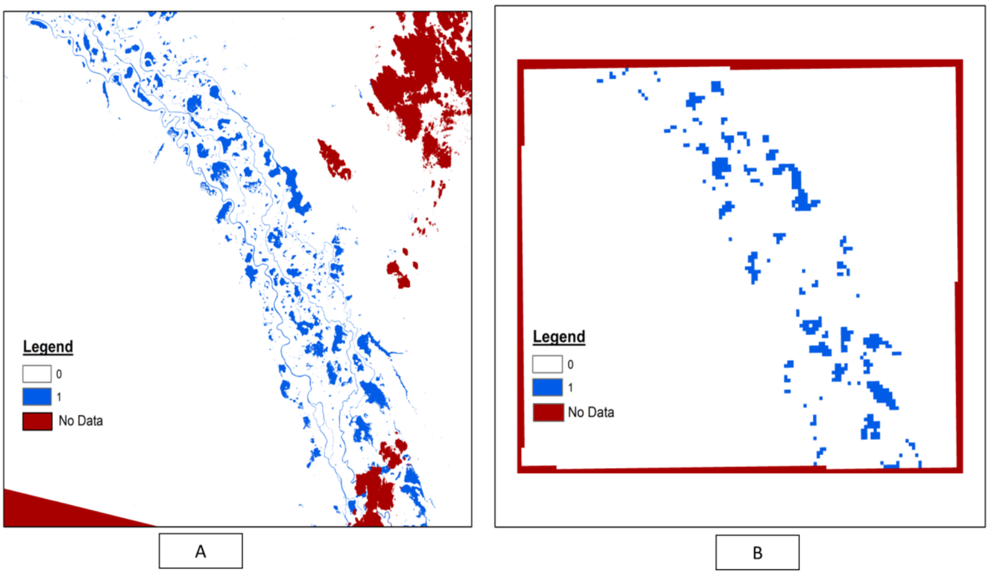

Figure 3. Landsat Wetland Map (A) and MODIS Wetland Map (B) for Pair 1

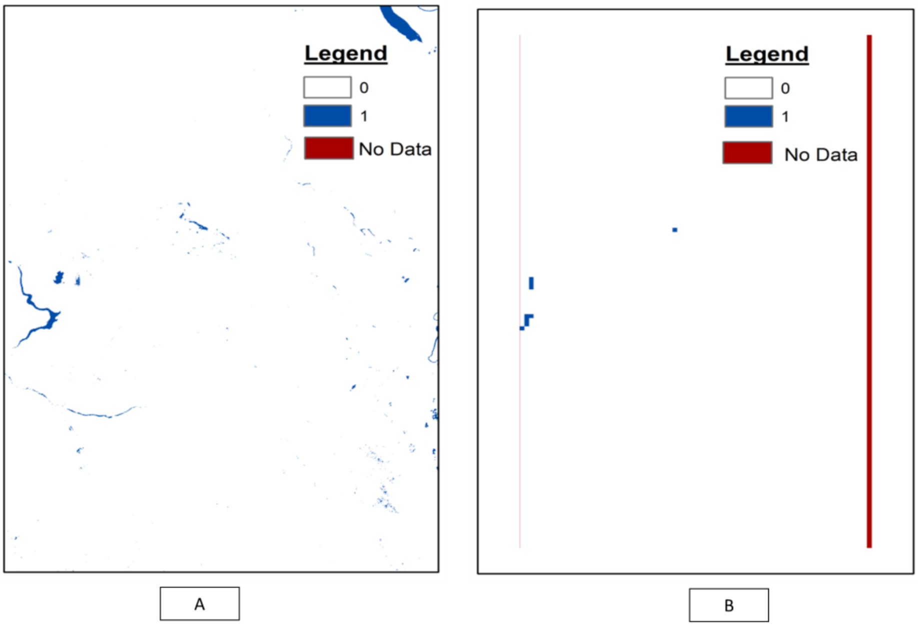

Figure 4. Landsat Wetland Map (A) and MODIS Wetland Map (B) for Pair 4

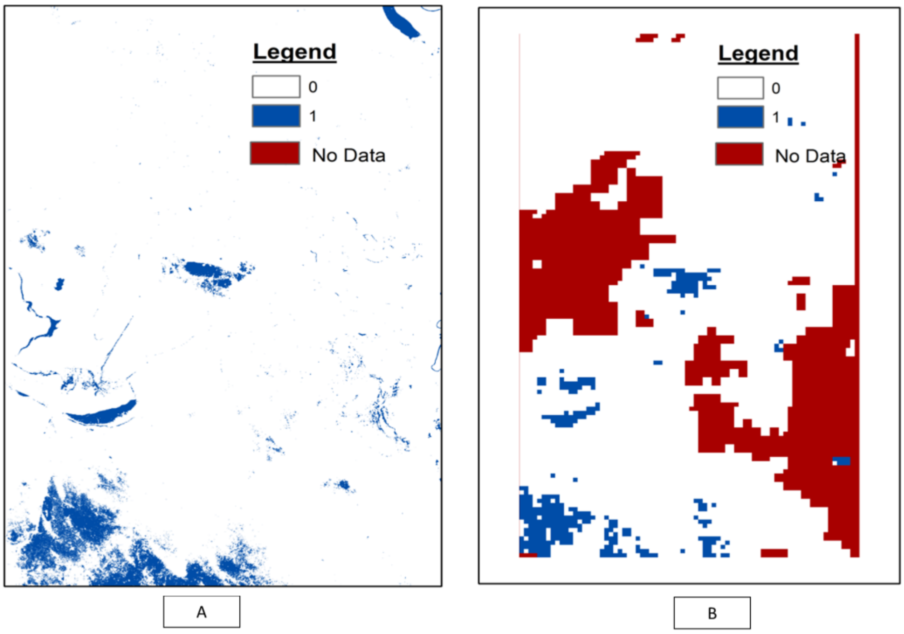

Figure 5. Landsat Wetland Map (A) and MODIS Wetland Map (B) for Pair 5

6. CONCLUSIONS

MODIS satellite images with moderate resolution, is better in detecting of large continuous wetland areas. However, for medium-sized disconnected wetland areas, it under estimates the total area. While for small sized water bodies, MODIS images are unable to distinguish wet areas from dry lands. These undetected wet areas are usually the main rivers feeding the wetlands and small permanent ponds surrounding it. MODIS medium resolution images are more suited for detecting the major wetlands' extent and capturing their seasonal variations. In spite of its medium spatial resolution, MODIS imageries are considered to be very well suited for large scale wetlands mapping. Its temporal resolution compensates for its lower spatial resolution. It is recommended for smaller water bodies (lakes, reservoirs and rivers), with less seasonal variability, to use fine resolution Landsat images.

Different satellites differ in their swath width, spatial resolution, and spectral resolution. Multispectral sensors with coarse resolutions provide better temporal coverage than finer resolution sensors. On the other side, finer-spatial resolution sensors are better adapted to mapping smaller wetlands.

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