FLOOD INUNDATION MAP OF BANGLADESH USING MODIS SURFACE REFLECTANCE DATA

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ABSTRACT

Remote sensing images can be effective and efficient tools to determine flood inundation areas. In the past, many studies have been conducted using remote sensing data to detect spatial and temporal changes of flood inundation areas, delineate wetlands and study its changes, flood damage assessments in urban areas, dynamics and behaviors of floods.In this context, detecting spatio-temporal extents inundation of floods in 2007 and 2004 were studied using time-series MODIS surface reflectance data. Flood inundation maps were developed from vegetation and land water surface indices derived from surface reflectance. The inundation map developed from MODIS data has been compared with a consequent RADARSAT image. The estimates show a strong correlation with the inundated area derived from RADARSAT products (R^2: 0.96). The products derived from MODIS 500m imagery shows the ability to study flood dynamics and performs similar to RADARSAT based flood assessments. Considering that MODIS products have a great advantage in the high-frequent observation, we conclude that this is a useful method to clarify the entire extent of the temporal floods in Bangladesh.

Keywords: *EVI, LSWI, MODIS, NDVI, RADARSA*T

1. INTRODUCTION

Flood is very common phenomenon in Bangladesh due to its geographic location. Natural river floods occurred almost every year during monsoon season between June to September. Every year one fourth to one third of the country is inundated during monsoon season by overflowing rivers. Flood disrupts people's live, damage infrastructures and road networks in urban areas. In rural areas it damages crops, causes death to livestock and people become isolated due to the unavailability of communication mode. On the other hand flood has many positive impacts to the environment. Flood supplies nutrients to the soil, recharges ground water, enhances diversity of aquatic species, and naturally washes out solid wastes. It is very common that crop production in the country gets almost doubled right after any major flood. In the past many studies were carried out to investigate the hydrologic behavior of the floods in Bangladesh (Chowdhury et al., 1998; A. S. Islam and Chowdhury, 2002; K. M. N. Islam, 2006; Rahman et al., 2005). However, compared to the wide range of research conducted in other countries, research works carried out in Bangladesh on determination of current status of flood inundation map have been very few. Status of flood inundation in time and space is important in evaluating the relationships between variations in the water regime, local agricultural activity, and ecosystem behavior from a global viewpoint.

Remote sensing images can be effective and efficient tools to determine flood inundation areas. In the past, many studies have been conducted using remote sensing data to detect spatial and temporal changes of flood inundation areas, delineate wetlands and study its changes, flood damage assessments in urban areas, dynamics and behaviors of floods. Those studies mainly detect surface water resources using a range of sensors and satellites. To select suitable sensor which is both cost effective and efficient to develop flood inundation is a major challenge. One of the major problems of optical sensors is its inability to penetrate clouds. On the other hands, in the monsoon period when flooding occurs, the sky is covered most of the days by cloud. In this context, Synthetic Aperture Radar (SAR) has been considered as the most effective sensor in detecting flood inundated area. Although RADARSAT and other synthetic aperture radars are a capable of monitoring land surface, it is not feasible to use them for monitoring a huge areas for a long time due to its high data acquisition cost. Keeping in mind the cost of production, inundation maps were developed using data from various low resolutions optical sensors. Data from NOAA/AVHRR of 1.1km, SPOT of 1km (Harris and Mason, 1989; Liu et al., 2002; Xiao et al., 2002a), SSM/I of 13km, and MOS/SMR of 23km spatial resolution (Jin, 1999; Tanaka *et al.*, 2000; Tanaka *et al.*, 2003) has been considered as alternative means of mapping water surface. Most of these data are freely available from internet for daily basis which makes it possible to detect changes of inundation areas for a large area.

Right after its launching in December 1999, MODIS satellite with its moderate-resolution optical sensor of 250–500 m becomes useful tools for scientific studies and research. Many studies were conducted to determine surface water content such as estimating the extent of paddy fields by Xiao et al. (2006; 2005), detecting inundation areas through vegetation cover conversion by Zhan et al. (2002) etc. The Dartmouth Flood Observatory (2006) monitors flood disasters all over the world using MODIS data. Up to 2007, the observatory published an annual inundation map of Bangladesh via the Internet (Anderson *et al.*, 2005). Sakamoto et al. (2007) was developed a methodology to detect the spatio-temporal flood distribution in the Cambodia and Vietnam using MODIS data. The main advantages of this methodology are: (1) time series data is available during flood period, (2) data is available for the globe, (3) data can be downloaded free of cost through internet and (4) the accuracy of flood inundation map lies within the acceptable range [R^2 lies between 0.77 and 0.97]. Application of their methodology for flood inundation mapping of Bangladesh is also a difficult task due to dissimilarity of the hydro-geological conditions among Cambodia, Vietnam and Bangladesh. Some modifications are essential to adopt their methodology that is proposed in this study. Using this modified methodology, spatio-temporal changes in the extent of flood inundation of Bangladesh are studied.

2. STUDY AREA

Bangladesh is taken as study area which is located between Latitude 20–27 °N and Longitude 88–93 °E (Figure 4.1). The country is located a floodplain delta of three major river basins: the Ganges, the Brahmaputra and the Meghna (GBM). About 80% of the annual rainfall of Bangladesh occurred during monsoon season between June to September. The major cause of the monsoon flood relies of the intensity, duration and magnitude of the rainfall in the GBM basin. Every year one fourth to one third of the country is inundated during monsoon season by overflowing rivers. However, the degree of this inundation sometimes become severe and cause damage to infrastructures, crops, communication system, and human being. Floods in 2007 and 20004 were one such sever floods in recent years in terms of magnitude and duration.

The spectral signature has been changed for different land use types and therefore, study of those signatures is very important to classify the inundated areas from satellite image. A total of nine categories of land use /land type have been selected to analyze inundation areas (Figure 1). These are 1) single-crop rainfed rice in the Haor area of north-eastern region , 2) single-crop irrigate rice in the south-west region, 3) double-cropped irrigated rice in north region, 4) triple-cropped irrigated rice in the Brand area of north-west region, 5) forest area in the Sundarbans, 6) settlement area of Dhaka city , 7) Kaptai lake, 8) Bay of Bengal ocean, and 9) the Padma river.

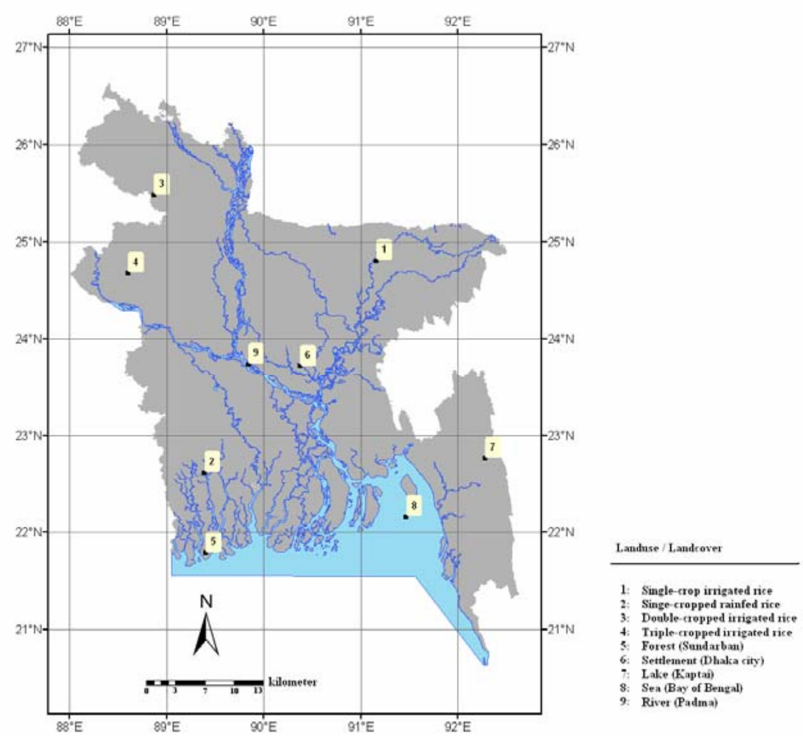

Figure 1: Location map of the study area.

3. DATA

3.1 MODIS/Terra time-series data

This study uses MODIS satellite images acquired by TERRA instrument which can be freely downloaded through the Earth Observing System Data Gateway (EOS, 2006). The present study involves an analysis of 8-day composite data of MODIS during 2007 and 2004. The label of this product is “MODIS/TERRA SURFACE REFLECTANCE 8-DAY L3 GLOBAL 500 M SIN GRID V005”. The spatial resolution of this product is approximately 500 m, and atmospheric correction has already been carried out (Vermote and Vermeulen, 1999). This 8-days average data is delivered as a composite product called MOD09 which took the best surface spectral-reflectance within this period with the least effect of aerosols and other atmospheric ingredients.

3.2 Flood inundation map based on RADARSAT images

Inundation map produced by Center for Environmental Geographic Information Services (CEGIS) are used as a reference to evaluate the estimates derived from MODIS data. This map area produced based on Digital Elevation Model (DEM) data, hydrological data, and RADARSAT images acquired on 3rd August (DOY 215) using the ScanSAR Narrow B Mode . Bearing in mind that C-band microwaves can penetrate cloud cover and easily discriminate open water on the basis of backscatter coefficient data at a high resolution (50 m), it is assumed that inundation map based on the RADARSAT images reveal the details of the flood distribution at a satisfactory spatial resolution, even under cloud coverage. The inundated areas in this map were aggregated within each grid at 500 m resolution to enable comparisons with results derived from the MODIS data.

4. METHODS

4.1 Detecting water related surface using MODIS data

In the past, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) were used to identify water related surface (Rogers and Kearney, 2004). The main reason of using NDWI is that short-wave infrared (SWIR) is highly sensitive to moisture content in the soil and the vegetation canopy. A number of studies have been conducted in use of the spectroscopic characterization of SWIR to detect water content (Gao, 1996; Jackson et al., 2004; McFeeters, 1996; Rogers and Kearney, 2004; Tong et al., 2004). Xiao et al. (2002b) showed that NDWI in paddy fields exceeds NDVI derived from SPOT data for the same period of flooding and rice-planting in eastern Jiangsu Province, China. In recent years, Xiao et al. (2006; 2005) used anomalies between the Land Surface Water Index (LSWI) and Vegetation Indexes (NDVI or EVI) in an algorithm to estimate the distribution of paddy fields in South China and South and Southeast Asia. In Table 1, detail description of the indices derived from MODI S data along with the band number and solar spectrum has been presented. Methodology used in the present study is originally developed by Sakamoto et al. (2007). The algorithm used by the Sakamoto et al. (2007) was modified in this study. A flow-chart of the method used in this study has been shown in Figure 2. The previous algorithms are examined and some components are excluded from it. In previous algorithm, wavelet based filter is used to smooth data by removing noise component and interpolate of missing information. This algorithm creates artificial data and therefore, that algorithm of filtering was not used in this study. The first step is to detect cloud cover pixel from the image. If blue reflectance (Band 3 of MODIS) is equal to or greater than 0.2 (Thenkabail *et al.*, 2005; Xiao *et al.*, 2006), it is considered as cloudy pixel. Using this formula data over cloudy pixel was removed from the image. Next step is to estimate EVI, LSWI and their difference DVEL for each of the land class cover types. In this study, discrimination of Water-related pixel and Non-Flood pixel was conducted in accordance with the pioneering method developed by Xiao et al. (2006; 2005). EVI, LSWI and DVEL are exclusively used to discriminate Flood, Mixed, Non-Flood and Water-related pixels. Changes of EVI, LSI and DVEL for different land use types during 2007 are shown in Figure 4. If EVI is greater than 0.3, it can be classified as Non-Flood related pixel. The EVI curve of “Forest (the Sundarbans)” land use type exhibits a value more than 0.3 during the year except flood season. EVI of permanent water bodies such as “River” and “Sea” land use type are less than 0.05 or even negative value throughout the year. DVEL of “River” and “Sea” land use type have a DVEL value less than 0.05. It can be infrared that water related pixel should have DVEL less than 0.05. But for “Lake” land use type, DVEL value is not always less than 0.05. To overcome this problem, another criterion is set to identify water related pixel. In such cases, if EVI is less than or equal to 0.05 and LSWI is less than or equal to 0, the pixel will be identified as Water-related pixel.

Table 1: MODIS derived indices used to detect spatial and temporal distribution of flood.

Indices	Equation
Normalized Difference Vegetation Index (NDVI)	$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$
Normalized Difference Water Index (NDWI)	$NDWI = \frac{\rho_{RED} - \rho_{SWIR}}{\rho_{RED} + \rho_{SWIR}}$
Enhanced Vegetation Index (EVI)	$EVI = 2.5 \times \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + 6 \times \rho_{RED} - 7.5 \times \rho_{BLUE} + 1}$
Land Surface Water Index (LSWI)	$LSWI = \frac{\rho_{NIR} - \rho_{SWIR}}{\rho_{NIR} + \rho_{SWIR}}$

Where, ρ_{NIR} is the reflectance of near infrared (841–875 nm, MODIS Band 2), ρ_{RED} is the reflectance of red (621–670 nm, MODIS Band 1), ρ_{BLUE} is the reflectance of blue (459–479 nm, MODIS Band 3) and ρ_{NIR} is reflectance of short-wave infrared (1628–1652 nm, MODIS Band 6) of the solar spectrum.

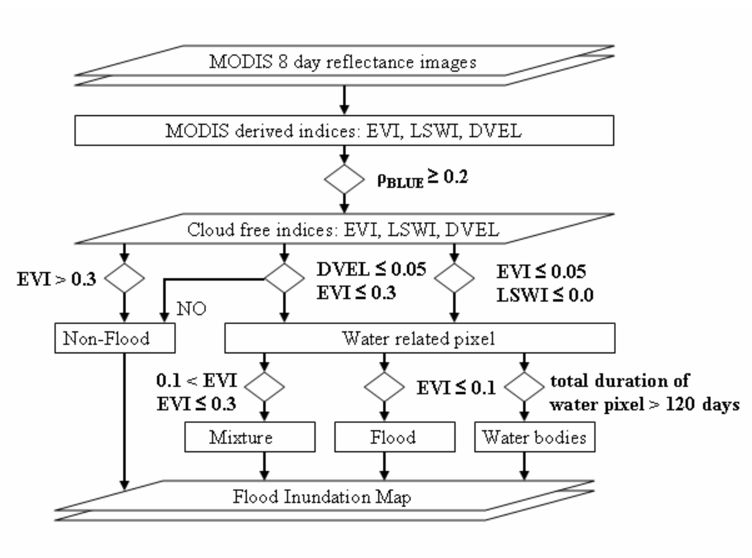

Figure 2: Flood chart for developing Flood inundation map using MODIS data.

After identifying Water-related pixel it is essential to classify whether it is Flood pixel or Long term water bodies or a Mixed type pixel. Due to moderate resolution (500m) sensor of

MODIS/TERRA, a pixel can be composed of various mixture types of land surfaces. It is difficult to identify vegetation mixed with water and vegetation completely flooded by water. It is found from Figure 3 that EVI of "Sea", "Lake" or "River" is below 0.1 and this criterion can be used for further classification of Water-related pixel. If Water-related pixel has EVI less than 0.1, it will be considered as Flood pixel. If EVI is greater than 0.1 but less than 0.3, Water-related pixel will be identified as Mixed pixel. Finally, the areas which are inundated through out the year should be separated from Flood and Mixed pixels. There have been many water bodies in Bangladesh such as Beels and Haors where water can be found more than 6 months. Therefore, Water-related pixel which has inundation period more than 120 days will be classified as Long term water bodies. Using this proposed methodology, changes of spatial extent with time are analyzed and flood inundation maps are developed for 2004 and 2007.

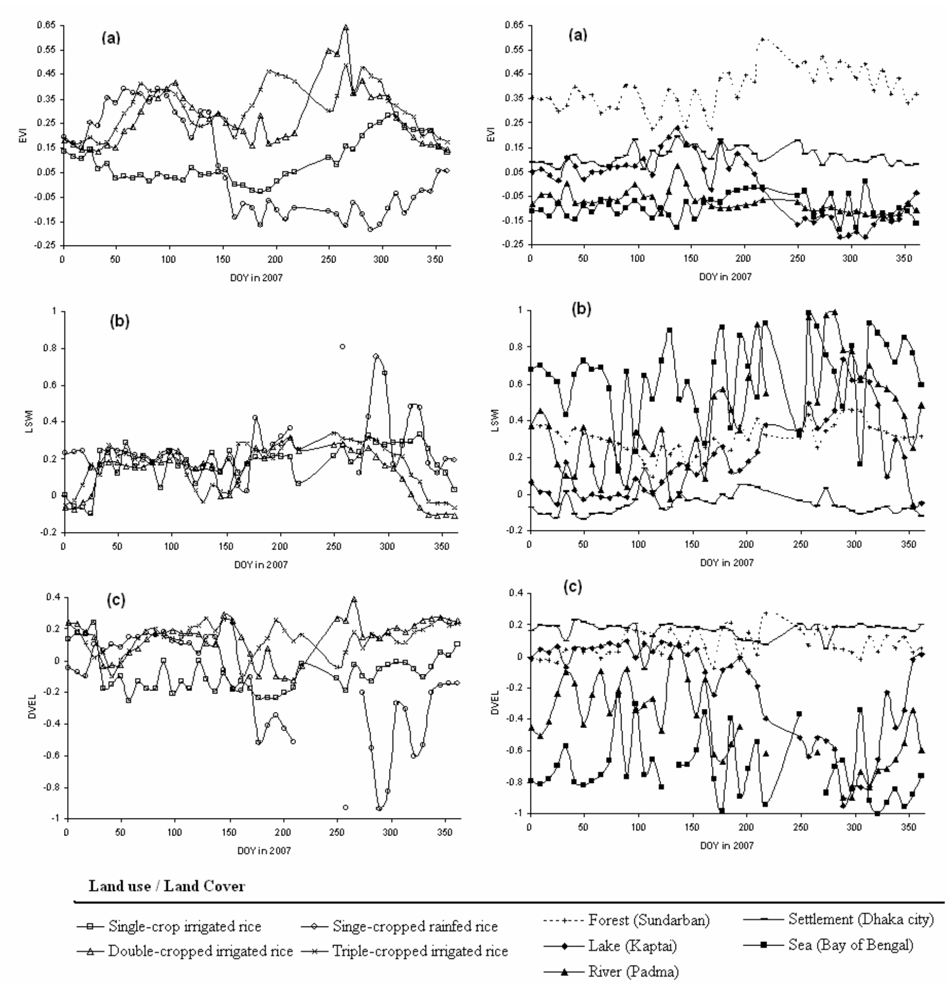

Figure 3: MODIS derived indices: (a) EVI, (b) LSWI and (c) DVEL for the Seven Land use/Land cover areas shown in Figure 1.

4.2 Validation of proposed techniques

The proposed technique used to identify the water surface from MODIS time series data and validated it with standard product. A comparison of MODIS derived inundation map on 28th July (DOY 209) with the subsequent available RADARSAT derived inundation map on 3rd August (DOY 215) is shown in Figure 4 using image crossing. Most of the area in both images shows quite a good match between images from these two types of satellite and sensors. In south west part, MODIS shows more inundation areas than RADARSAT. On the other hand, in the north-east region RADARSAT presents more area as inundated than MODIS image. Figure 5 shows scattered plot of the crossing of both the inundation maps.Value of R^2 was found 0.96 between the inundation map derived from MODIS and RADARSAT. A very good agreement between these two products shows the high capabilities of estimating inundating area using MODIS with this algorithm.

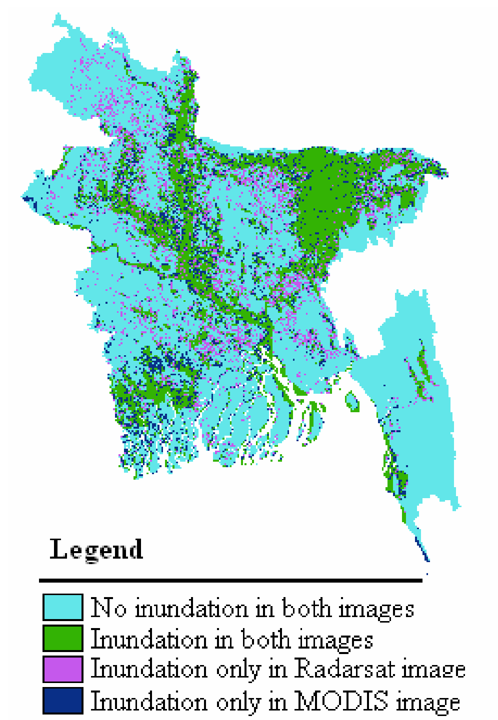

Figure 4: Overlay of MODIS derived inundation map on DOY 209 with the nearest available RADARSAT derived inundation map on DOY 215. Inundation area derived from MODIS includes Flood pixels and pixels of Long term water bodies.

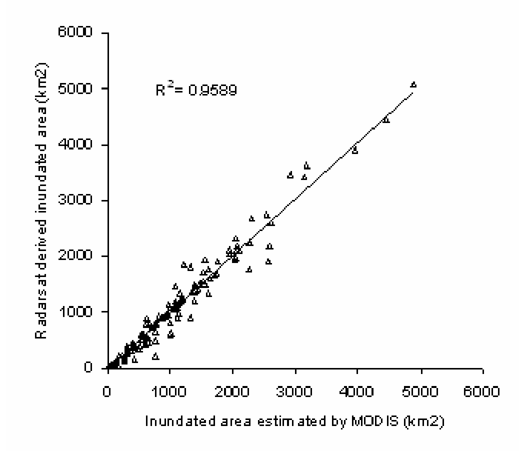

Figure 5: Correlation of inundation area determining from MODIS with that of RADARSAT. Correlation coefficient R^2 is found very high of about 0.96.

4.3 Spatial extents of floods in Bangladesh

Maximum extent of the flooded area can be detected by overlaying a series of images during the flood (Sheng and Gong, 2001). This inundation map can be useful to create flood vulnerability maps and flood risk zones. Figure 6 shows maximum area of food inundation during floods in 2004 and 2007 respectively. Blue, green, and white colours represent areas of Flood, Mixture, and Long-term water bodies, respectively. It is also evident from this map that the extent of flooding varies from year to year. The areas which are common for both major floods should be classified as the most vulnerable areas.

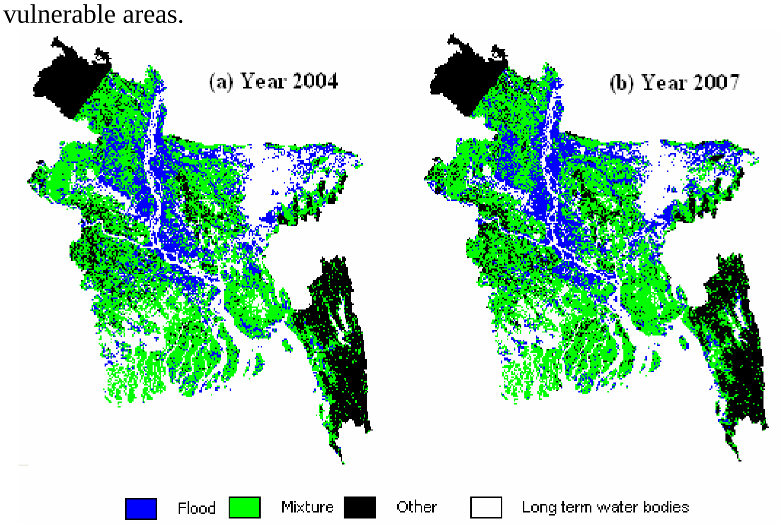

Figure 6: Flood inundation map of Bangladesh using MODIS images for (a) Year 2004 and (b) Year 2007.

5. CONCLUSIONS

This study modifies a methodology which was developed by Sakamoto et al. in order to detect spatial extents and temporal changes of flood inundation of Bangladesh during monsoon season. Using this modified methodology, MODIS satellite images were used develop flood inundation maps for floods in 2007 and 2004. This low resolution (500m) MODIS based maps area compared with subsequent flood inundation maps based on high resolution (50m) RADARSAT satellite images. MODIS estimates show strong correlation with the inundation areas derived from RADARSAT with R^2 values of 0.96. Considering this fact, the flood maps derived from MODIS images shows ability to flood characteristics and behavior. Such inundation maps will be useful for integrating water resources management and the maintenance of ecosystems of wetlands of Bangladesh.

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