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APPLICATION OF REMOTE SENSING, GIS AND DIGITAL SHORELINE ANALYSIS SYSTEM (DSAS) TO ASSESS THE CHANGES OF THE RED RIVER BANK IN THE AREA FROM SON TAY TO GIA LAM (HANOI)

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Abstract. In recent years, some geological hazards relating to the change of channel such as accretion, erosion and landslide of river bank on the Red River bank have occurred more frequently. In this paper, the trend and rate of the change of the Red River bank in the area from Son Tay to Gia Lam (Hanoi) were shown by using remote sensing images of the period 2007–2016, geographic information system (GIS) and Digital shoreline analysis system. The results indicate that bank erosion mainly occurred along the both sides of the Red River bank with the average erosion rate ranging from 1.5 m/yr to 3m/yr. The strongest erosion was along the left river bank in Me Linh commune, Dong Anh district. In Son Tay commune, Phuc Tho district, Vinh Phuc province, some signals of erosion process were also recorded. The accretion process had been occurring in the middle part of the river slowly with the accretion rate of 0.8–1.4 m/yr. In the result, accretion zones were formed and they were aggregated into alluvial flats. In the future, the Red river bank will continue to be changed, erosion and landslide of the channel would be considered as the major hazards in this area.

Keywords: River bank, accretion, erosion, Red river, Digital shoreline analysis system.

INTRODUCTION

Traditionally, the modern scientific tool of remote sensing, GIS is extremely an effective tool in development of databases and to analyze coastal area in the integrated manner and derive management action plans. Remote sensing technology is useful for assessing the coastal environment and monitoring the changes over time in the coastal zone [1]. These remotely sensed data can be used to evaluate the coastal processes like erosion/accretion and shoreline changes. Remote sensing satellites images have been effectively used for monitoring shoreline changes of different locations [2, 3]. GIS is designed to work with data referenced by spatial/geographical coordinates. The major advantage of GIS is that it allows identifying the spatial relationships between features and temporal changes within an area over time. For measuring and monitoring coastal erosion and accretion, satellite imagery is useful in extracting the shorelines, and GIS has been used extensively to overlay multitemporal shoreline maps to detect and visualize changes over time. Recently, the study on shoreline changes has been automated using Digital shoreline analysis system (DSAS) software on different satellite products like IRS-LISS (Linear Imaging Self-Scanning) series and Landsat images [4]. The shorelines extracted from the satellite images are analyzed using DSAS software for measurement of erosion rate and retreating along the coastal area [5]. The DSAS modules such as End Point Rate, Linear Regression, Weighted Linear Regression and Least Median Square are used to estimate the shoreline shift along the coast.

More recently the combination of remote sensing and GIS with spatial models as factual analysis [6] or DSAS [7] was used. Because DSAS is effective for calculating changing rates of shoreline boundary changes incorporating an evidently identified attribute position at separate times [8, 9], it is able to provide a better understanding of the nature, dynamics and trend of shoreline change [6–8].

Vietnamese research using DSAS showed shoreline changes in the Nam Dinh coast [10], Kien Giang coast [6], and in the Ca Mau coast, where long - term changes were documented [11] and assessment of the change of channel in Gianh river from Canh Hoa to the entrance of Gianh river [12]. These results show that the shoreline moved forward 37–39 meters in Xuan Thuy coast during 1905–1992; mangrove extent in Kien Giang coast decreased during period 1989–1992, increased during 1992–2003, and decreased during 2003–2006 [6, 10, 11].

Son Tay - Gia Lam is considered as center area of Hanoi - where there are great potentials about– socio-economic, natural conditions, but also there are many natural hazards which have negative impact on human life. The study area is the Red river bank zone from Son Tay to Gia Lam, limited to $21^{o}00’$ to $21^{o}12’$ North latitude and $105^{o}25’$ to $105^{o}55’$ East longitude. On the right bank of the Red river, it borders Son Tay town and districts: Phuc Tho, Dan Phuong, Hoai Duc, Northern Tu Liem, Tay Ho, Hoan Kiem. On the left bank, it is adjacent to Vinh Phuc province, Me Linh district, Dong Anh district, Long Bien district (fig. 1).

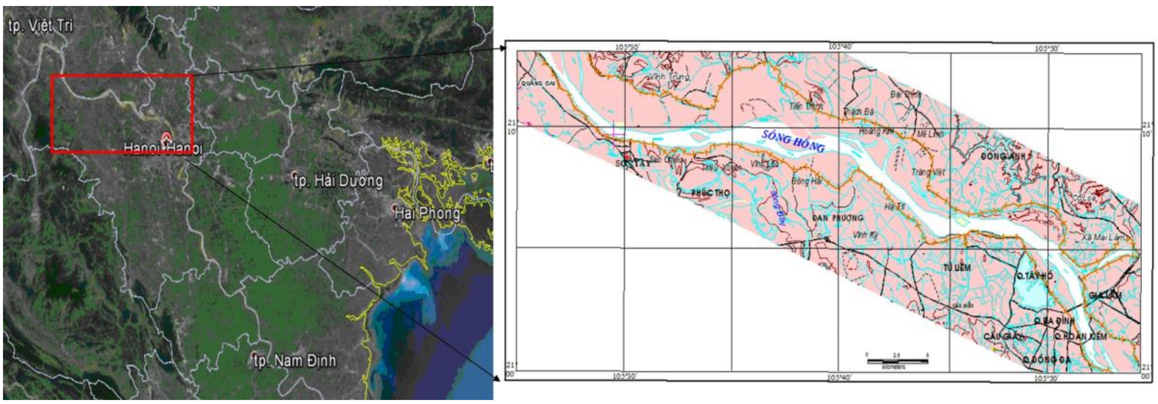

Fig.1. Location map

This article using multi remote sensing images, GIS tools and DSAS for assessing the changes of the Red River bank in the area from Son Tay to Gia Lam. DSAS (version 4.3) is a tool for analyzing shoreline dynamics, which allows for the calculation of shoreline variation rates from one of the historic shoreline locations between multi-temporal remote sensing materials.

BASE DATA AND METHODS

Base data. The objects needed to run this process are a baseline and at least two shoreline vector objects with known date of acquisition. All DSAS input data must be managed within a personal geodatabase, which also serves as the storage location for the program-generated transect feature class and related statistical output tables. For this purpose we have selected the following data resources:

Attribute data: Natural conditions, geomorphology, hydro-geology and engineering geology, current status of the accretion and erosion, landslide river bank, river breathing, flow dynamics.

Spatial data: including maps and remote sensing images. Four Landsat imageries (table 1) were used for analyzing shoreline change. The imageries span a period of 10 years, with time points of 2007, 2010 2013 and 2016.

Table 1. Imagery Characteristics

Scene ID	Acquisition date	Data	Resolution
LE07_L1TP_127045_20071108_01_T1	2007-11-08	Landsat 7	30 m
LE07_L1TP_127045_20101031_01_T1	2010-10-31	Landsat 7	30 m
LC08_L1TP_127045_20131202_01_T1	2013-12-02	Landsat 8	30 m
LC81270452016091LGN00	2016-09-01	Landsat 8	30 m

Methods. Remote sensing processing tool in this paper is ENVI software combine with calculating shoreline variation by ArcGIS tool based on DSAS module application [7, 13–15].

Shoreline Extraction. The dry/wet boundary which approximates the high waterline (HWL) was extracted using semiautomatic and manual methods. Previous studies used the HWL as the shoreline proxy for change analysis in Vietnam [16]. Band ratio between the mid infrared and the green was used to identify the waterland boundary for the Spot images except the 2016 image due to the gaps in the data. This was used so as to reduce the level of subjectivity in delineating the shoreline. For this study band ratio was implemented using the band ratio model in the ENVI software thus the mid infrared/the green.

The resulting image with ratio values between 0 and 3 was sliced and segmented to form a binary image with values less than 1 being classified as water and values greater than 1 being classified as land thereby delineating the boundary between the water and the land as the shoreline. The water class was then converted from raster to vector and exported as shape files for overlay in ArcMap.

In ArcMap, the extracted shorelines were overlaid on the satellite images. The output vector however consisted of other water/land boundaries such as those of creeks and lagoons and could not be directly used for change detection. To extract the target sections, the extracted vector shorelines were overlaid on the colour composites and used as guide to digitize the target shoreline (fig. 2).

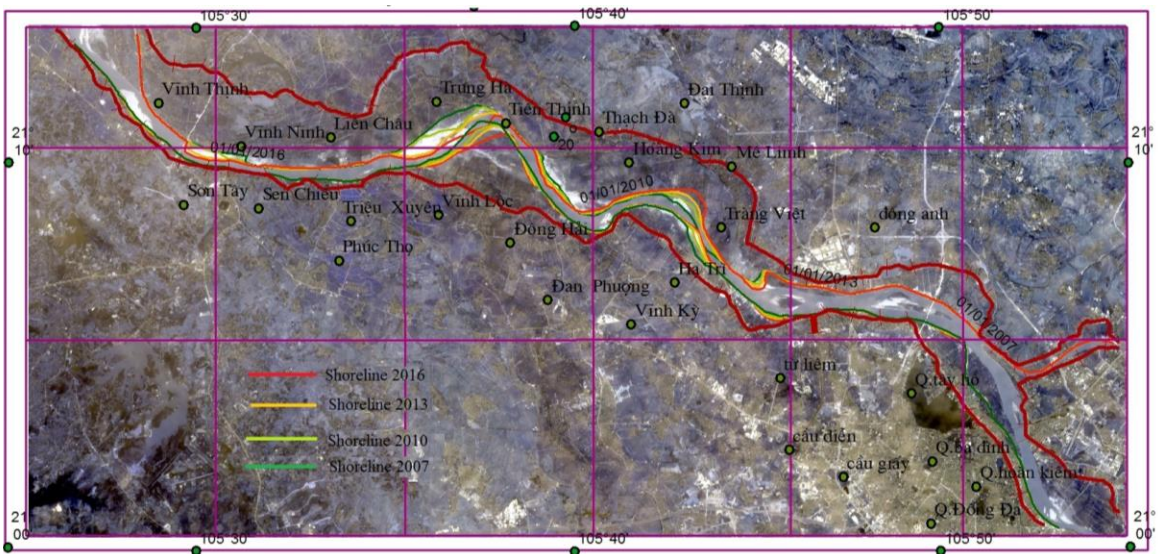

Fig. 2. Extracted shorelines 2007, 2010, 2013 and 2016

Shoreline Analysis. After having shoreline data at each time point (2007, 2010, 2013 and 2016), application of DSAS tool was integrated in ArcGIS to calculate the erosion - accretion rate and assess the trend and rate of change of the Red river bank area from Son Tay to Gia Lam. DSAS supports ESRI ArcGIS software to calculate the rate of change of the shoreline over time by creating orthogonal lines with established distances, thereby calculating the rate of shoreline change. Once all the inputs were ready in the database, transects were constructed. A total of 1120 transects were cast along the entire stretch of river bank (both left river bank and right river bank). The transects were cast at simple right angles from the baseline. Historic rates of shoreline change were then calculated at each transect using end point rate (EPR) and weighted linear regression (WLR).

The historical trend of these shoreline changes is based on indicators of the shoreline geometry. The system controls the following shoreline characteristics: historical shoreline dynamics, shoreline change, development and evolution of gulls, cliff retreat and erosion, shoreline measurement and modeling [17]. In this study, the EPR was employed where only two shoreline positions were available as the case for the period between 2007 and 2016. The distance between the two points where the shoreline intercepts a transect is calculated and this distance is divided by the number of years that have elapsed, in this case 10 years, to give the end point rate [7].

Baseline, historical shorelines, and shoreline uncertainty are input data provided by the shoreline maps of 2007, 2010, 2013 and 2016. The spacing between transects along the baseline and the length of transects was defined based on the shoreline pattern. The distance between two neighboring transects is 100 m. DSAS transects are 56 kilometers long. With a shoreline of 56 kilometers, the maximum number of DSAS transects is 560.

RESULTS AND DISCUSSION

By DSAS, the calculation results for the Red river shoreline in the area from Son Tay to Gia Lam (Hanoi) in the period of 2007–2016 were shown in fig. 3.

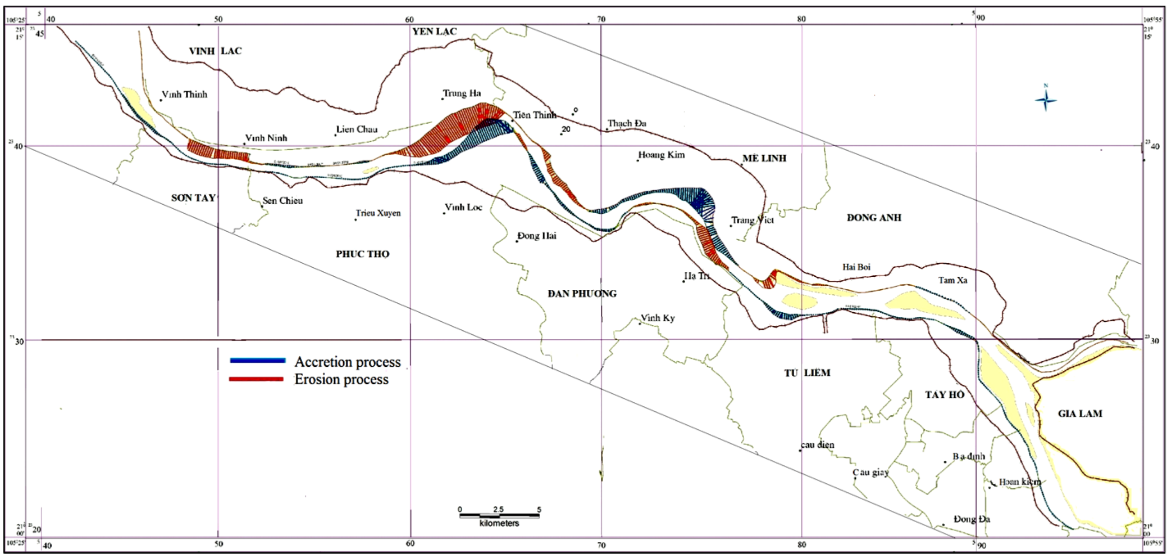

Fig. 3. Map of erosion and accretion trend in Red river's shoreline in Son Tay - Gia Lam (period of 2007–2016)

Based on the analysis of the shoreline's changes using Landsat images of shoreline in this area in the years of 2007, 2010, 2013, and 2016 and comparison of river's shoreline of these years, it can be concluded that landslides in these years are different in this area. Because of the landslide on river bank, the river shoreline was moved toward the south direction with the distance from 5 m to 50 m. In fact, the signal of landslide area on river bank recorded by GIS was larger than the observed area in the field. Based on shoreline data collected in the field, we used a coefficient with the value of 0.4 to calculate the amplitude for the landslide on river bank following GIS data.

The observed research results of deep landslide locations along the river pointed out that the landslide was actually just several meters in length toward the river bank but they were more than 30 m when we analyzed in GIS images. The cause of the difference is actually a wide distribution of the landslide debris.

For the period of 2007–2016, the erosion and landslide activities mainly occurred in river banks and shoreline on the left river bank was almost moved toward the alluvial flat and the levee, these processes occurred most strongly in Me Linh commune, Dong Anh district (Hanoi). In Van Khe - Me Linh, alluvial flat was eroded horizontally to some meters. The right river bank was quite stable, except some areas with shoreline near alluvial flat, especially river banks belonging to Ha Tri and Vinh Loc, Dan Phuong.

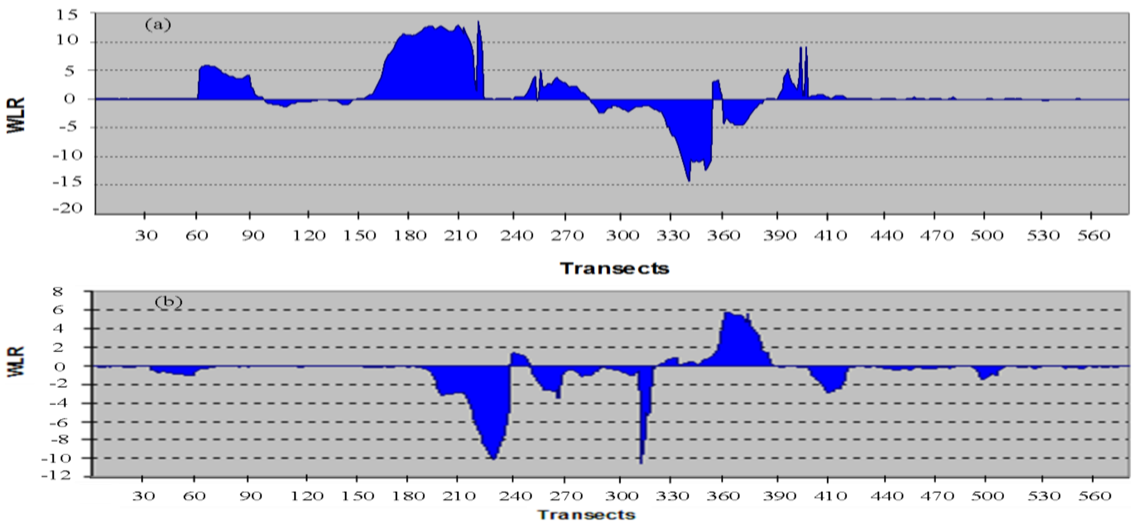

Fig. 4. Graph of erosion and accretion rate: (a) left river bank and (b) right river bank (period of 2007–2016)

Fig. 4 illustrates the fluctuation rate of the Red River shoreline in the area from Son Tay to Gia Lam (Hanoi) as follows:

In the first about 4 km, the right Red river bank was quite stable, then in the following 2 km river bank has signs of light erosion with the rate of 0.5–0.7 m/yr. Far from Son Tay about 7 km to the southeast, river bank was quite stable; in the next 5 km (belonging to Linh Chieu, Sen Chieu), river bank was eroded weakly in horizontal direction, erosion rate was 2.5–6.5 m/yr. In the Vinh Ninh area, the accretion occur mainly on the left river bank with accretion rate of 1.0–1.2 m/yr.

In the area from Phuong Do to Van Phuc (Phuc Tho district), because runoff was in west - east direction, shoreline through these years was changed weakly and runoff started to extend from 50 m to 100 m in the end of Van Phuc commune.

Although the length of shoreline from Van Phuc commune (Phuc Tho district) to Tho An commune (Dan Phuong district) was only 8 km, the shoreline was changed strongly. The direction of runoff was converted from SW - NE to NW - SE. The area of the left river bank was extended by accretion with the rate of 1–1.4 m/yr and the right river bank was quite stable while alluvial flat in river bed was eroded strongly.

In the river bend belonging to Vinh Loc (right river bank), because of the curve flow line around the bend and the different directions between surface and bottom current, the shoreline was replaced and the channel was eroded deeply. On the left bank of Trung Ha area (Yen Lac, Vinh Phuc), the river bank was strongly accreted with accretion rate up to 6–8 m/yr.

On the river bank from Tho An to Ha Tri communes with 11 km in length, the shoreline was unstable, with an alternation of erosion and accretion. Within the first 25 km, the shoreline of the right riverbank was almost unchanged while that of the left riverbank (belonging to Hoang Kim, Me Linh, Trang Viet) was eroded and slumped strongly, the erosion rate was 2–8.5 m/yr. In the section of the levee from Hong Ha to Lien Tri, accretion occurred in the right riverbank with accretion rate of 0.8–1.2 m/yr and erosion was in the left riverbank with the rate of 2–3 m/yr; therefore riverbed was moved toward the left. In Lien Tri, the shoreline was quite stable, but in the next 1 km the right riverbank was accreted slowly, the accretion rate was 0.4–1.0 m/yr.

From Tu Liem to Gia Lam, both sides of the river bank were unchanged. However, alluvial flat in the river bed was eroded strongly. In the period of 2007–2016, the change was mainly in alluvial flats at Phu Gia Levee. The riverbed was opened more widely in Phu Gia and narrowed in Ngoc Thuy levee. At Ngoc Thuy levee in which the Red river intersected with the Duong river, the whole right river bank with a branch flowing into Tu Lien commune was accreted. The river shoreline from Ngoc Thuy to Ngoc Lam was eroded on both sides with small amplitude and in the riverbed had a large alluvial flat.

Comparison of the research results of the change in the Red river's shoreline in 2016 and 2017 in some research areas indicates that calculation results of the trend of erosion and accretion phenomena were similar to the results in actual state. Based on the observation in the field, erosion and accretion occurred alternately in this part of river; however, erosion processes on the both sides were stronger than accretion processes.

The Tam Xa alluvial flat (in Dong Anh, Hanoi) was often slumped, especially at the end of the flat, the erosion rate was 2–3 m/yr in 2010 and increased to 4–5 m/yr in 2014 [18]. The shoreline was slumped in vertical direction with the height of 500 m. This damaged a large area of agricultural land, narrowed the area of alluvial plain and impacted on the stabilization of the levee on the right Red river bank. In the present, this area continues to be eroded strongly (fig. 5).

Fig. 5. Collapse slump at alluvial plain in Tam Xa, Dong Anh in 2014 and 2017

In Me Linh, the shoreline was eroded about 1,000 m in length and created a vertical surface. The erosion is extended more and more widely and causes the loss of agricultural land (fig. 6).

Fig. 6. Slump on the left bank of Red river in Me Linh, Hanoi

The formation of alluvial plain in the middle part of the river in Lien Ha commune, Dan Phuong district, Hanoi made the total runoff flow toward the shoreline on the right Red river bank in Trang Viet commune, Me Linh district. As the result, the shoreline in this area was undercut deeply and eroded strongly (fig. 7).

Fig. 7. Signals of erosion and accretion process in Lien Ha, Dan Phuong, Hanoi (10/2016)

Thus, the erosion - accretion process of the Red River bank in research areas indicates that erosion points were concentrated densely, shoreline's change by landslide on both sides of river was quite complicated. At present, erosion - accretion process develops strongly at the research area and it will continue to change in the future. After 10 years, riverbed has changed locally and the shoreline has been eroded and accreted continuously following the location.

The discussion on the causes of the river bank erosion in Son Tay - Gia Lam area:

The sand exploitation: The sand exploitation activities affect the river water level as it actually lowers the river bed. Particularly, illegal sand mining activities on the river, such as the excavation, sand sucking from the river bed and mudflats which had been accumulating for years, created the frog's jaw along the river banks. The illegal sand mining activities in the Red river in Son Tay - Gia Lam area not only caused landslides in the excavation site, and sand sucking, which could alter the flow causing abnormal landslides; but also in the location where the embankment was built. The studies of Tran Ngoc Huan and other scientists had shown the effect of sand mining on the conductivity changes based on the analysis of some typical river cross sections in the Red river [19]. The results showed that the over-exploitation activities of sand in the river exacerbated the sand and mood balance, causing the lower phenomenon of the river bed as well as severe erosion on the river banks.

The impacts of the hydropower reservoirs: Construction and operation activities of hydropower plants are considered as the main causes of the unbalanced muddy and sand load. The operation of the hydropower plant with the regulation of daily load increased the sudden changes of downstream water level causing both the instability of the structures and collapse phenomenon of the bank in the downstream area. This phenomenon actually occurred in the downstream area of Hoa Binh Hydropower Plant.

The regime of the river flow: The study river section is characterized by a number of curved, bent river sections, unbalance in cross-section on both sides and river width varying along the length of the river flow. The changes in river morphology and currents occur frequently throughout the course development of the nature history. In particular, the more the human interference had, the more changes in river flow occurred.

In addition, due to the geological structure of the Red river which is mostly constituted by the fine sand layers, that's the reason why it is easy to be eroded. Whenever there is a small impact or any change in the river flow, it is possible to create the hydraulic fluctuations then causing the changes to the river bed and river banks.

CONCLUSION

The research result illustrates that the change on the shoreline of the Red river bank from Son Tay to Gia Lam (Hanoi) was quite complicated during the period of 10 years with strong movement processes of erosion and accretion activities. The erosion rate depended on every position of the river, the average rate was 2.5–5 m/yr. The strongest erosion was on the left Red river bank in Me Linh commune, Dong Anh district. The shoreline of the right

Red river bank in Son Tay commune, Vinh Loc district was eroded locally. The accretion process occurred slowly with the rate of 0.8–1.4 m/yr, accretion zones was concentrated to alluvial flats in the middle part of the river.

The paper presented and showed the advanced methods that were applied to study the change of the shoreline. GIS technique is an effective method in the research on the fluctuation activities of the river shoreline. The combination of using GIS data and DSAS helped the authors to record information quickly and assess the actual situation of shoreline's change, landslide in research areas in the Red river.

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