Automated quantification of river morphodynamics from satellite imagery for large multithreaded rivers

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ABSTRACT:

In recent years, various studies have appeared on (automated) processing of river morphodynamics from satellite images. A key challenge in such approaches is to use appropriate and consistent methods to quantify eroded and deposited areas and channel migration rates. This is particularly important in highly dynamic multi-threaded rivers, where apparent bank lines can move significantly with changing water levels. To assure a consistent treatment of bank lines we use a methodology where channels are identified by detecting the vegetation boundary. We apply this methodology to a 250 km reach of the Ayeyarwady river (Myanmar) and extract metrics for eroded and deposited areas and channel migration. These morphological metrics are compared to hydrologic conditions, and significant correlations were found. It shows that the proposed method may help to classify and better understand river dynamics rivers of large multithreaded rivers.

1 INTRODUCTION

River morphodynamics are driven and influenced by a wide variety of processes and conditions, such as flow variability, climate, human interference, vegetation development, sediment characteristics and valley geometry. Anticipating the long term and large-scale dynamics of river planforms is therefore difficult, and requires insights into dominating processes and their impacts. There have been many attempts to characterize and classify river planforms, such as definitions of planforms of straight, meandering and braided. Empirical observations are the basis of achieving such understanding, and this can supported by modeling studies or theoretical considerations. Large dynamic rivers are often characterized by anabranching channel patterns, with relatively stable vegetated islands (Latrubesse, 2008). The understanding of physical processes and drivers that lead to the formation of anabranching river planforms is still limited (Carling et al, 2013). Remote sensing, specifically satellite imagery, might be a key instrument to study planforms dynamics of such large multithreaded rivers. By measuring actual morphodynamic observations on large scales, the key drivers of planform dynamics can be quantitively investigated.

Nowadays, remote sensing data offers new opportunities to investigate surface water changes from observations, which resulted in a rapid growth of such studies in the last decade (Huang et al., 2018). These methods can be computationally demanding, but with the availability of free cloud computing services such as offered by Google Earth Engine (GEE) this type of research has become much more accessible. Using GEE, Donchyts (2018) already delineated surface water on a global scale. Also, there have been various studies specifically focusing of river morphodynamics, such as Hossain et al. (2013) and Baki & Gan (2012) that studied reach scale bank erosion. Besides, more and more generalized and automated tools are now available that derive river morphology metrics from satellite imagery, for example ChanGeom (Fisher et al., 2013), Rivmap (Schwenk et al., 2016), SCREAM (Rowland, et al., 2016), and PyRis (Monegaglia et al., 2018). Many of these tools are mostly designed for analysing single thread meandering rivers, such as Pyris, Rivmap and ChanGeom. Furthermore, in many studies remote sensing studies of river morphodynamics the focus is on multi-year time intervals, which can obscure important temporal details of key drivers in planforms dynamics, such as yearly variability in flood discharge. In this paper we therefore investigate the possibilities of satellite imagery to study reach scale morphodynamics and their drivers on yearly time scales for large multithreaded rivers.

2 AUTOMATED DETECTION OF RIVER MORPHODYNAMICS

The analysis of river morphodynamics with satellite imagery is performed using automated classification in Google Earth Engine. For the detection of river changes Landsat imagery is used, which provides images over the last 30 years with a horizontal resolution of 30 meters. Change is studied on a yearly time scale, where images are selected from each dry season due to the low cloud cover.

A factor that complicates river change analysis with automated classification is the change in water surface area with varying water levels in the river, which is especially important for natural (multi-channel) rivers with gently sloped banks. Even though water level fluctuations may be relatively small during the dry season, we circumvent the effect of water level variability by detecting the vegetation boundary to mask the active channel. For this approach, a combination of a water index (Normalised Difference Water Index or NDWI) to detect the water surface and the Short Wave Infrared (SWIR) band to detect sediment bars is used. A similar approach was used by Monegaglia et al. (2018), who focussed on migration of meandering rivers. Further river studies that use remote detection of the vegetation boundary can be found in Rowland et al. (2016) and Schwenk et al. (2016).

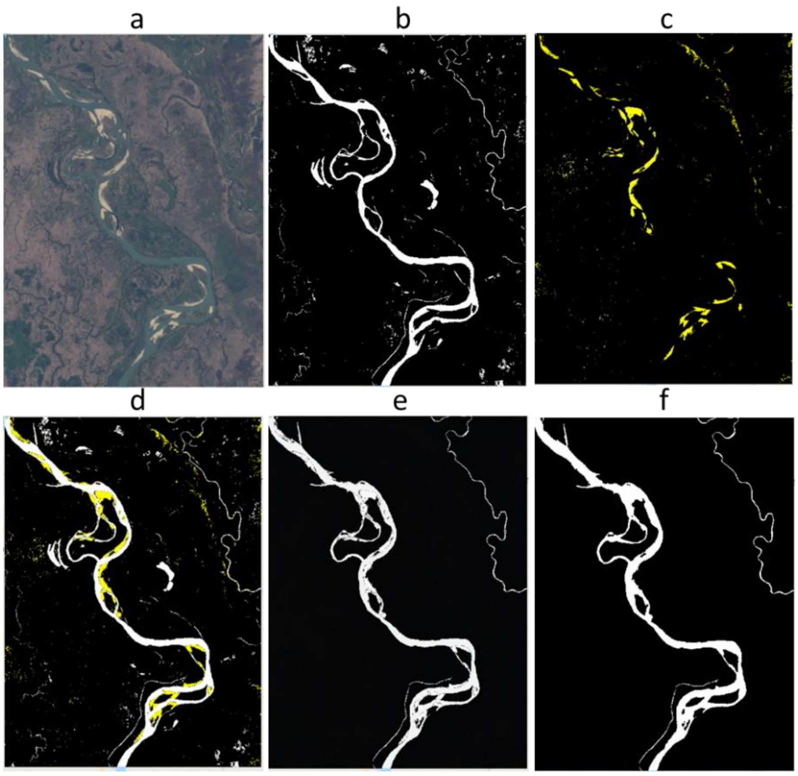

Figure 1: Visualization of channel detection method: a) Landsat image. b) Water surface (NDWI). c) Sediment bars. (SWIR) d) Merging sediment bars mask and water mask. e) Removing noise based on connectivity with the centerline. f) Remove unwanted gaps with binary closing.

The masking process for channel detection is composed of several steps (see Fig. 1). Thresholding for the water index was performed with Otsu thresholding (Otsu, 1975), which takes into account changing conditions of the atmosphere and the changing river conditions (e.g. sediment concentration). For the detection of sediment bars with the SWIR band, a constant threshold was used, which was found to provide sufficiently accurate results due to low interference of the atmosphere and stable reflective properties of sediment bars over time. Following the approach from Yang et al. (2019), misdetections of surface water due to for example shadows, and disconnected lakes were removed based on connectivity with a centreline from a global centreline database. Also, small gaps in the river mask were removed.

To quantify morphological changes between consecutive years we calculate the eroded surface area, the deposited surface area and the total active river surface (total area between river bank lines). Also, we defined a relative migration rate which represents the amount of migration (erosion + deposition) compared to the total river surface. A local migration rate of 1 means that the river has migrated an entire river-width.

3 SELECTED CASE: LOWER AYEYARWADY RIVER, MYANMAR

We chose a ~250km long section of the Ayeyarwady river in Myanmar as case-study (see Fig. 2). With a mean annual discharge of approximately 13.000 m^3/s (Jansen et al., 1994), it is one of the larger rivers of Asia. Furthermore, it is one of the last long free flowing rivers in Asia (WWF, 2019), which means the natural variation in discharge and sediment transport dynamics is still present. The Ayeyarwady river is characterised by intense morphological changes, including significant channel shifts, bar movements and avulsions on a year-to year basis. The hydrology in the Ayeyarwady basin shows distinct dry and wet seasons, with relatively steady low water levels during the months December–April (dry season) and 5 to 8 m higher water levels in the months June-October (wet season), see Figure 3 for some typical years. Figure 3 also shows the variability in average flood stage during the wet season, which at the considered river station ranges from 6 to 8 m in the period of 2014-2018.

The studied river section can be considered as the start of the delta and is characterised by wide floodplains. Just like many of the other large rivers of the world, the Ayeyarwady river can be characterised by an anabranching river planform, recognised by the large vegetated islands in the planform (see Figure 2). Nevertheless, in the river reach considered here the planform displays a variety of characteristics, with some sections having multiple channels, whilst others are more single threaded with some islands.

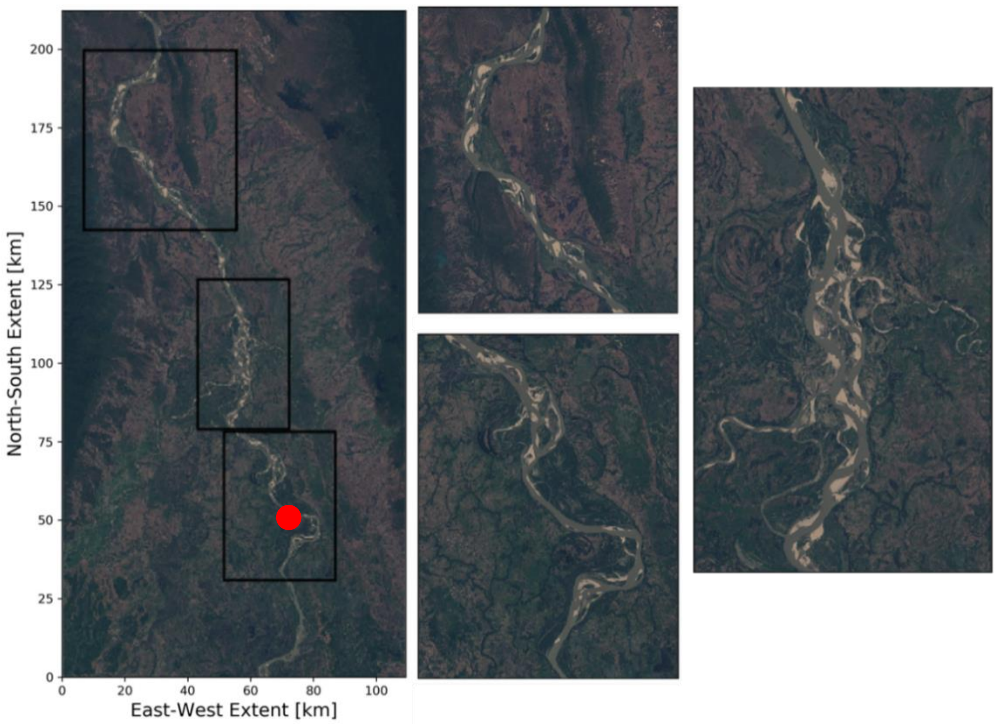

Figure 2. Division of the study area in three different regions, with different morphological characteristics. The red dot indicates the water level measurement station of Danubyu.

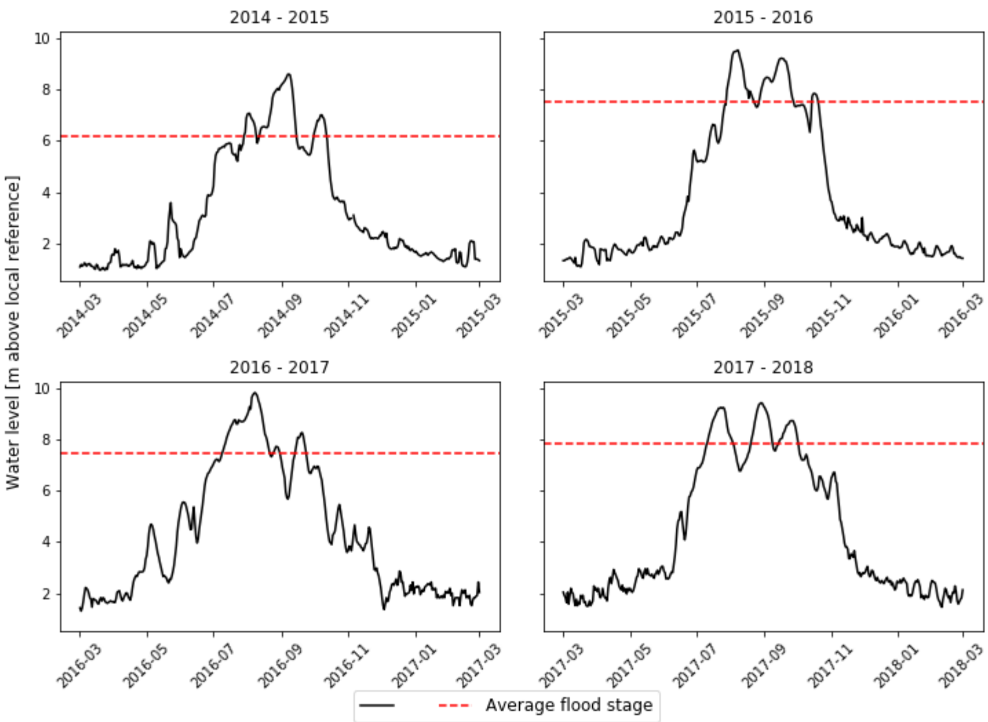

Figure 3. Recorded water levels for station Danubyu (see Figure 2) for the period 2014-2018, which is a small part of the time series that is investigated in this paper.

4 QUANTIFYING RIVER MORPHODYNAMICS

Change in river lay-out is studied on a year-to-year basis. Per year, images are selected from the dry season because the cloud cover is lowest during this period and channel structure is best visible due to low water levels. We select and combine multiple images per dry season to achieve an as-good-as-possible detection of the yearly channel lay-out. Differences between detections give an indication of the uncertainty in the channel detection. From changes in detections between years we quantified eroded and deposited areas.

Figures 4-6 show some results for three distinct subsections in the river reach. Figure 4 shows the northern section, which is characterised by relatively intense formation and migration of braid bars and islands but low lateral migration. The middle region in Figure 5 is the most intensely braided part, with highly unstable channels and large lateral migration rates. The dynamic behaviour is likely sparked by the presence of two bifurcations, that split off from the Ayeyarwady river in this region. The southern section in Figure 6 is slightly meandering and largely single-threaded. It shows high lateral migration rates and the presence of large islands.

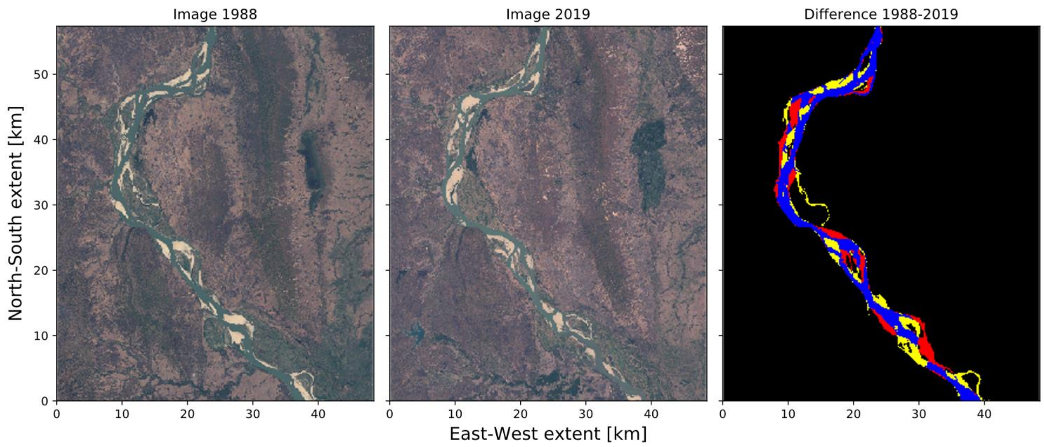

Figure 4. Changes in the river lay-out in the northern river section between 1988 and 2019. The difference tile on the right shows the eroded areas (red), the deposited areas (yellow) and the area with no change (blue).

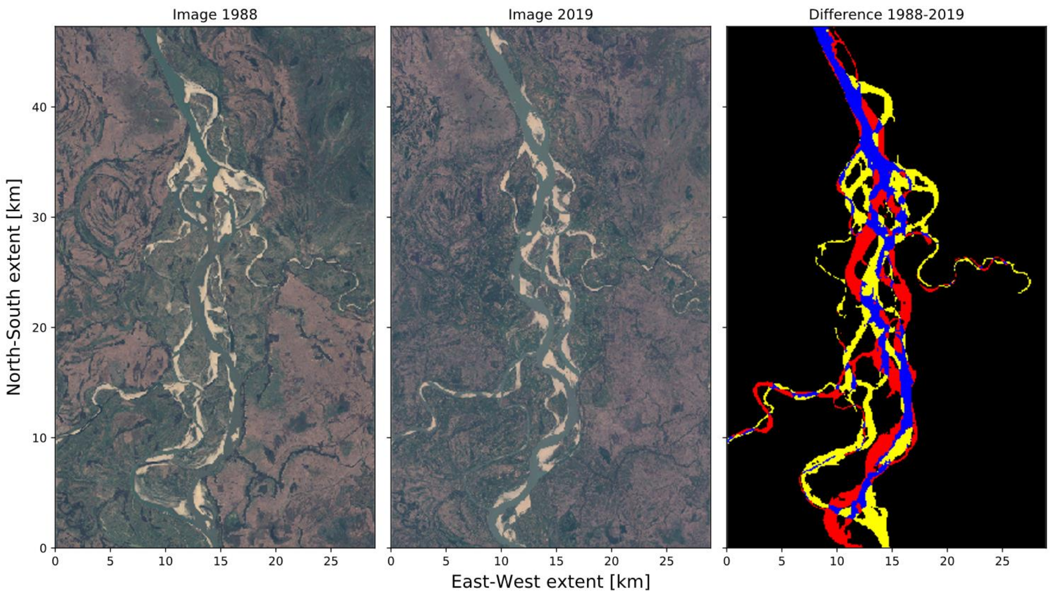

Figure 5. Changes in river lay-out for the middle river section. The difference tile on the right shows the eroded areas (red), the deposited areas (yellow) and the area with no change (blue).

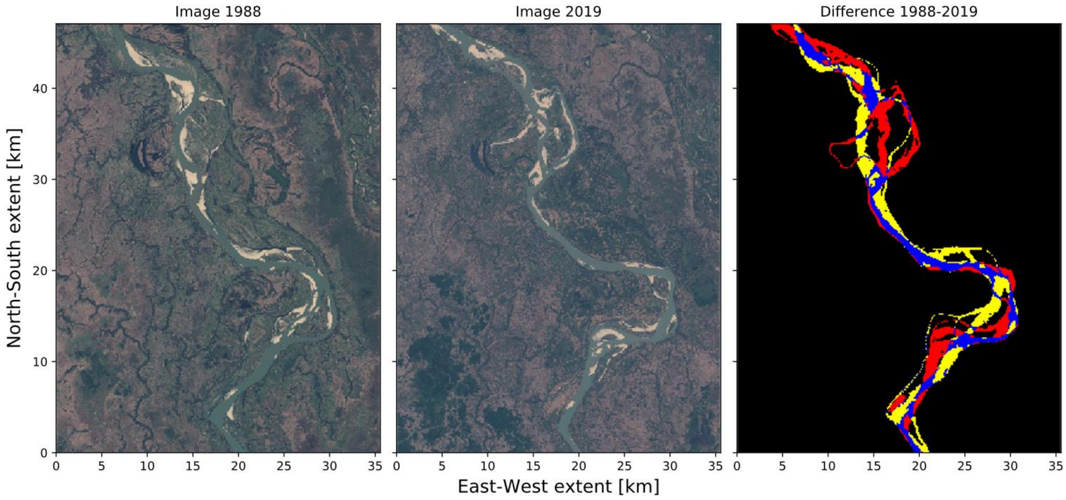

Figure 6. Changes in the river lay-out in the southern river section. The difference tile on the right shows the eroded areas (red), the deposited areas (yellow) and the area with no change (blue).

To quantify channel migration rates separately for different river sections, we split up the entire river reach in 15 parts of about 15 km each, as shown in Figure 7 (see section 2 for the definition of the calculated migration rate). This method allows us to distinguish highly dynamic from less dynamic sections in the river, as was also visually observed in Figures 4-6. The graph in Figure 7 shows that area number 7 is the most dynamic, which falls in the reach where two distributaries are located (see also Figure 5).

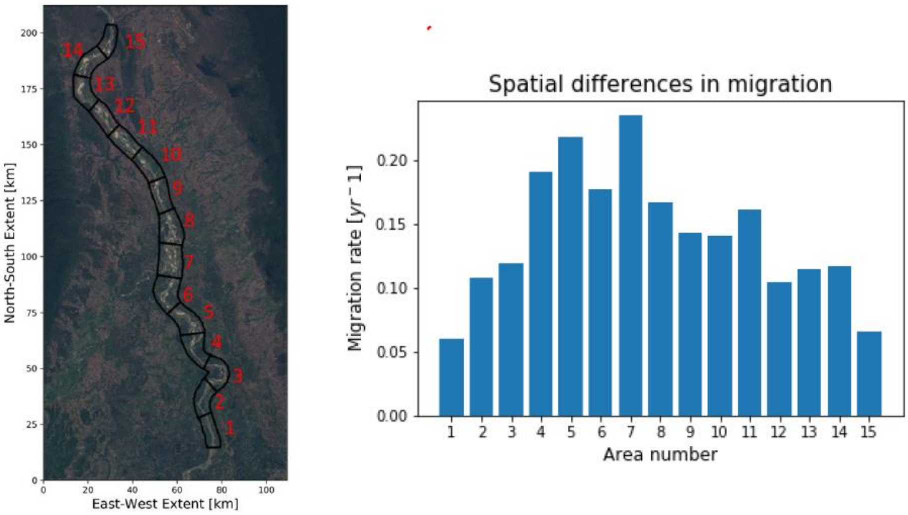

Figure 7. Average relative migration rates per year within 15 separate river sections. This number is the average of the migration of 19 different wet seasons that were in the samples

Next, Figure 8 shows the total amount of erosion between consecutive years as detected for the entire river reach of 250 km. It shows that there is a large variation in erosion between the years. In some years, erosion is a factor 3 larger than in other years. We did a similar analysis to quantify yearly depositions, migration rates and change in active channel area (not shown here) which show similar variations. Next, we compared the metrics to the magnitudes and duration of the high water levels during the preceding wet season. We defined the average yearly flood stage (averaged water level during the 4-month wet season, see red dashed line in Figure 3) and found strong correlations to the various defined morphodynamic metrics (Figure 9). This result clearly indicates the importance of the overall intensity of the flood season. The positive relation between the morphodynamic metrics, erosion, migration and change in active channel area, and the average flood stage, can be easily understood: higher and longer flood periods bring high flow velocities and thus lead to more erosion. The negative relation with deposition values seems counter intuitive as higher and longer floods deliver more sediment. However, as the deposition is detected by measuring the advance of the vegetation boundary a different dynamic is responsible. Not only sufficient sediment supply is needed, but vegetation needs time and space to develop. For vegetation-covered areas to expand the average flood season intensity needs to be low (see also Figure 9, relation between change in active channel area and stage). This explains the negative relation between metric of deposition and the stage.

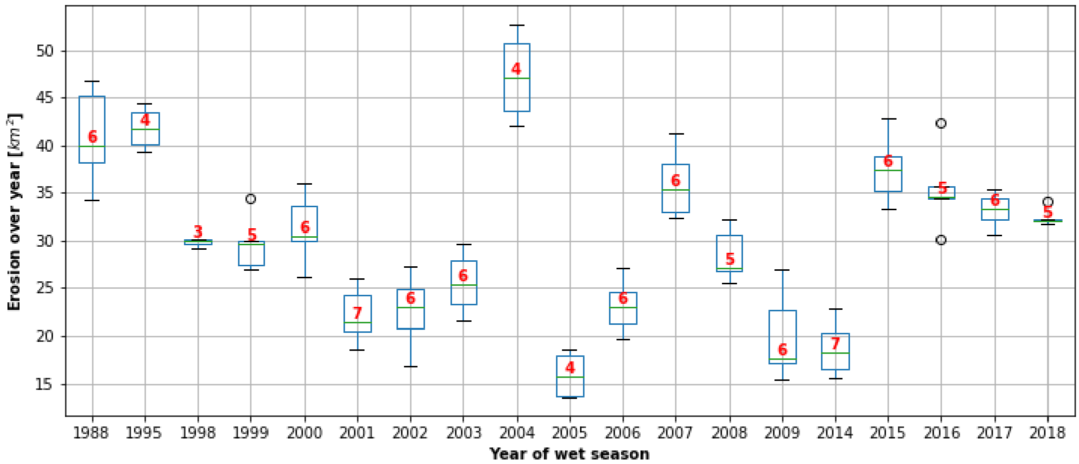

Figure 8. Box plot of measured eroded areas over the entire 250 km reach. In red the total number of samples per year. Skipped years are those where not enough imagery was available (1989-1994, 1996-1997, 2010-2013).

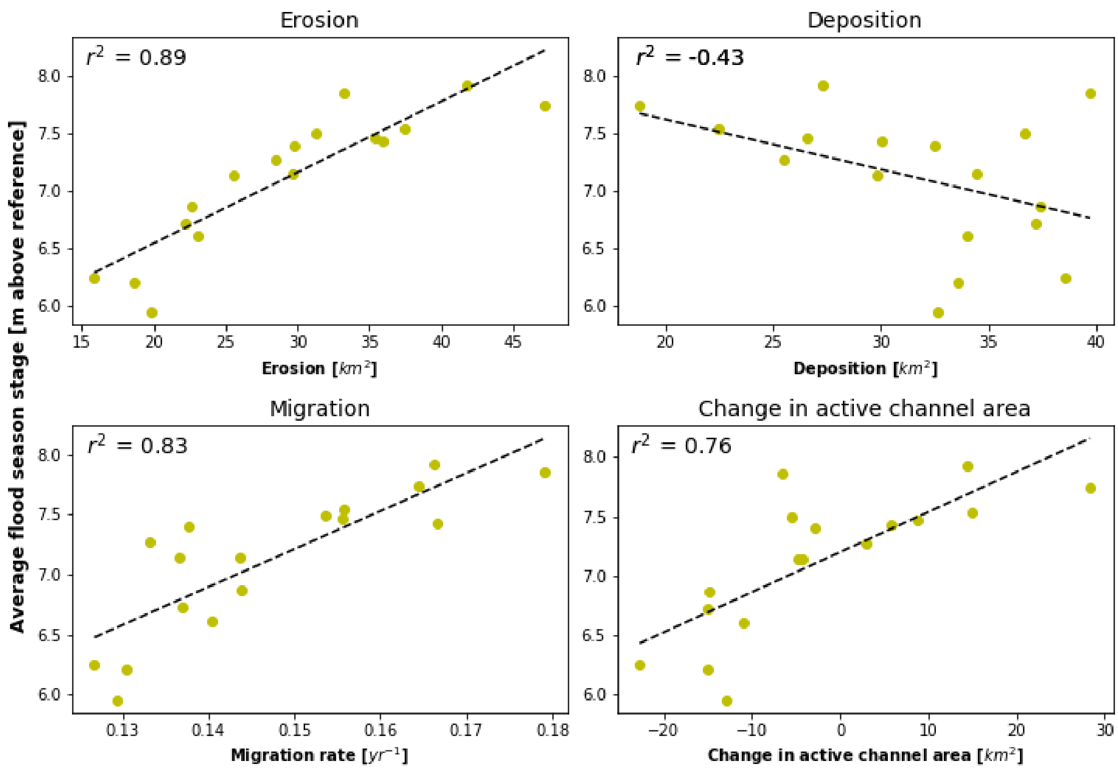

Figure 9. Correlation between the average flood season stage and morphodynamic metrics.

5 CONCLUSION AND DISCUSSION

We proposed morphodynamic metrics derived from satellite imagery that can help detecting differences in time and space. Next, we compared the morphodynamic metrics to hydrological data (water levels) and found meaningful correlations. We found that there are significant differences in intensity of morphological change over the studied 30-year period. A main driver of these differences is hydrological intensity, where especially the average water level during the flood season appears suitable to explain the morphological variations between years.

With the availability of the Google Earth Engine platform, in which every step of the method (both classification and change analysis) can be performed, our proposed method can be easily transferred to other applications. Based on the current resolution of Landsat imagery (30 m), change analysis on a yearly scale is limited to highly dynamic rivers with a relatively large river width. Furthermore, a key condition for good performance of the algorithm is a clear distinction of a vegetation boundary. Nevertheless, this study shows that a yearly time scale allows to study the relation between flow characteristics and morphodynamics. Furthermore, the metrics can be used to further explore of key drivers of planform dynamics. With satellite imagery becoming more widely available and of higher resolutions, combined with improved automated processing techniques, and identification of useful metrics as proposed here, the prospects are promising to achieve better understanding of river morphodynamics through global-scale investigations.

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