Journal of the Korean Society of Surveying, Geodesy, Photogrammetry and Cartography
Vol. 34, No. 2, 153-159, 2016
http://dx.doi.org/10.7848/ksgpc.2016.34.2.153
ISSN 1598-4850(Print)
ISSN 2288-260X(Online)
Original article

Thematic Map Construction of Erosion and Deposition in Rivers Using GIS-based DEM Comparison Technique

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Abstract

Rivers refer to either natural or artificial structures whose primary functions are flood control and water conservation. Due to recent localized torrential downpours led by climate change, large amounts of eroded soil have been carried away, forming deposits downstream, which in turn degrades the capacity to fulfill these functions. To manage rivers more effectively, we need data on riverbed erosion and deposition. However, environmental factors make it challenging to take measurements in rivers, and data errors tend to prevent researchers from grasping the current state of erosions and deposits. In this context, the aim of the present study is to provide basic data required for river management. To this end, the author made annual measurements with a Real-time Kinematic-Global Positioning System (RTK-GPS) and a total station in Pats Cabin Canyon, Oregon, United States, and also prepared thematic maps of erosion and deposition thickness as well as water depth profiles based on a GIS spatial analysis. Furthermore, the author statistically analyzed the accuracy of three dimensional (3D) measurement points and only used the data that falls within two standard deviations (i.e. $\pm 2\sigma$). In addition, the author determined a threshold for a DEM of Difference (DoD) by installing measurement points in the rivers and taking measurements, and then estimated erosion and deposition thickness within a confidence interval of ±0.1m. Based on the results, the author established reliable data on river depth profiles and thematic maps of erosion and deposition thickness using pre-determined work flows. It is anticipated that the riverbed data can be utilized for effective river management.

Keywords : RTK GPS, Totalstation, River Erosion, Deposition, DEM Construction, GIS-based

1. Introduction

One of the factors to consider in river maintenance and management is erosion and deposition thickness, as it reflects changes in river basins. By referring to measurements made by a RTK-GPS and a total station concurrently, in accordance with the conditions of river basins, it is possible to establish digital evaluation models (DEM) for watersides and riverbeds (Wheaton, 2008; Kasprak *et al*.,2011).

Moreover, by comparing DEMs at different time points erosion and/or deposition, we can determine the presence or absence of erosion and/or deposition. Regular measurements of erosion and deposition thickness are crucial in maintaining and managing rivers. For this reason, Yellowstone River Conservation District Council mapped changes in rivers during the period between 1950 and 2001, and created river management data (Tony *et al*., 2009). For instance, between 1948 and 2001, they found an eroded area that is 633 feet deep.

Furthermore, they prepared land use plans around rivers by utilizing data obtained by setting buffer zones and overlaying them on satellite images. In India, researchers have utilized existing topographic maps as well as STR-C and SAR data (X-SAR) in applying analogue and digital methods for an erosion analysis of the Pravara River, and then determined DEMs and performed analyses using GIS

Received 2016. 03. 30, Revised 2016. 04. 07, Accepted 2016. 04. 27
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techniques (Antonello *et al*.,2015; George *et al*.,2013; Ishtiyaq *et al*.,2013; Lim *et al*.,2005; Sainath *et al*., 2014). In general, researchers prefer the conventional method of obtaining data, where water depth information, a total station, and a GPS are utilized to make regular measurements in river at intervals (Czarnomski *et al*., 2011; Susannah, 2013). It is commonly argued that remote sensing or photogrammetry only allow brief, large-scale surveys, and these approaches cannot provide detailed data that can be obtained by field surveys. Meanwhile, a group of researchers have invented a simple deposition measurement device (Gerardo *et al*., 2003), but it is less effective in measuring large areas.

GPS is generally used to make measurements for exposed grounds around rivers whereas a total station is used more frequently in areas with trees and/or obstacles. It is believed that shallow rivers can be more effectively measured by obtaining coordinates of riverbeds via a RTK-GPS. There is currently a need for a new method for acquiring reliable DEMs and DoD using 3D coordinates.

River areas in Pats Cabin Canyon were chosen as a survey area, and obtained DEMs by making 3D measurements around watersides, riverbeds and water surfaces twice during the period between 2009 and 2011 and by applying a statistical tolerance interval to the data. We also determined a threshold for estimating highly reliable data for erosion and deposition thickness by comparing DoD and actual measurements. Moreover, the study estimated water depths using the DEMs for both river basins and water surface, and produced their profiles starting from upstream to downstream. The objective of this study is to create a thematic map of erosion and deposition thickness which is essential in maintaining and managing rivers, by comparing and analyzing the DEMs in 2009 and 2011.

2. Study

2.1 Three dimensional measurements of river basins

The author selected a section (650m*350m) from the branches of the John Day River in Pats Cabin Canyon, Oregon, United States, and determined the waterside area based on the mainstream (Fig. 1). The soil in the river basins consists of sedentary deposits, containing a mixture of clay and sandy soil, and thus the area is subject to vigorous erosion and deposition activities after localized heavy rains every year. By using a RTK-GPS and a total station for measurements in 2009 and 2011, the researcher was able to gather approximately 5,600 points, respectively.

In making RTK-GPS measurements, the team installed reference stations on the existing points, received corrected values from the stations, and determined the locations of unknown points with centimeter level accuracy in real time.

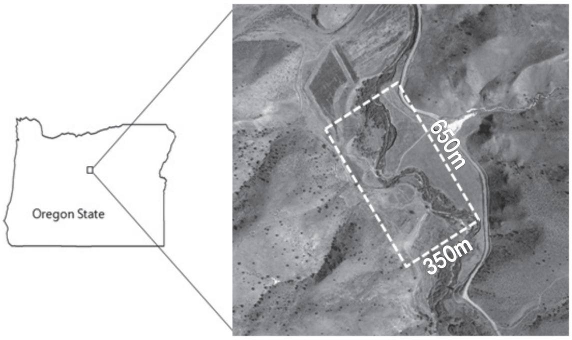


Fig. 1. Study area (Pats Cabin Canyon)

Since GPS measurements are made in the field, there is a risk of some data being left out. To avoid this issue, we surveyed the adjoining areas surrounding the selected survey area. The standard deviation of the coordinates is shown in (Table 1).

Table 1. Root mean square error (RMSE) of GPS measurement points

Year	RMSE (m)		
	Sx	*Sy*	*Sz*
2009	±0.0236	±0.03012	±0.0856
2011	±0.0198	±0.02986	±0.0945

As presented in Table 1, the RMSEs are similar between 2009 and 2011, as identical reference points and measurement techniques were used. The average 3D standard deviation of the measurement values was ±0.017m. The distribution of absolute values is illustrated in (Fig. 2).

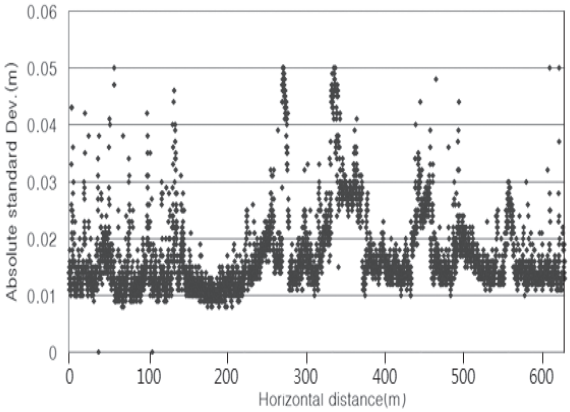


Fig. 2. Absolute value distribution of standard deviation of measurement points

96.6% of data were within two standard deviation (2σ) of ±0.034m, and any coordinates that deviated from the error range were excluded. Since the total station values use a conventional geodetic coordinate reference system (NAD1983 UTMZone12N), they had to be transformed into GPS coordinates (WGS1984). To do this, we obtained coordinates of six reference points by using GPS and total stations respectively, as presented in (Fig. 3). The reference points of both coordinate data were transformed by an affine transformation, and then matched against GPS coordinates. The transformed measurement points are illustrated in (Fig. 3).

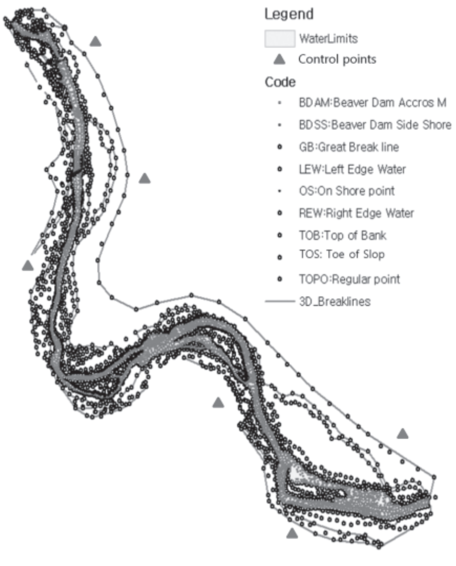


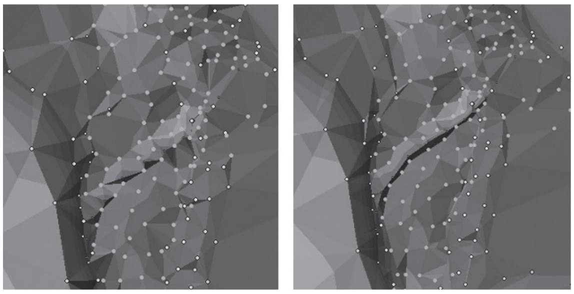
Fig. 3. 3D Surveying data points

Fig. 4. Wide pole brackets

Ground underneath watersides and riversides tends to be unstable and thus can sink if measurement poles are used. Therefore, wide brackets, as illustrated in (Fig. 4), were used for the measurements instead. The measurement points were breaks of slope, while the break lines were flatland, sharp cliffs and roads.

2.2 Generation of precise DEM

DEMs that only include 3D data tend to be less topographically accurate due to interpolation. In particular, when water surfaces are involved, they become even more inaccurate, making it difficult to estimate erosion and deposition thickness. Therefore, the flatland and breaks of slope require 3D break lines. Furthermore, we made additional measurements for TOB (top of bank), TOS (toe of slop), and GB (great break line) to create break lines, and also separately calculated shoreline polygons (Water_limits.shp), in order to establish boundaries for water depth. Fig. 5 below compares a TIN that considers 3D break lines with the TIN that does not have 3D break lines. When applied with 3D break lines (b), we can clearly see that the topography contains more details, even beaver dams.



(a) (b)

Fig. 5. Effect of 3D break lines on TIN generation: (a) unapplied case, and (b) applied case

Since erosion and deposition occur in watersides, separate GPS measurements had to be made for watersides and water depths. Later, we combined the two sets of data to create DEMs. Since GPS measurement points have deviated from the selected survey areas in the past, we limited the survey area using polygons (Survey_ Extents.shp) this time and utilized them in generating TINs as a reference for clippings. Furthermore, spots that have any vegetation within the survey area were deleted from the data, as they are not relevant to the erosion and deposition analysis. After correcting the generated TIN, we produced the final version of TIN and DEM (Fig. 6). The DEM was generated by the NATURAL_NEIGHBORS algorithm (Watson, 1992) because the study area has complicated topography. Natural neighbor interpolation produces smoother results than linear interpolation.

(a) (b)

Fig. 6. TIN and DEM for surface of riverside including water area (2009) : (a) Generated TIN, and (b) DEM construction

2.3 Establishment of Water_Depth DEM

The methods specified in (Fig. 7) have been used to obtain data on water depths. We extracted data on the left edge of water (LEW) and the right edge of water (REW) from the measurements, and established a DEM for water surfaces, limited by water_limits polygons (Fig. 8).

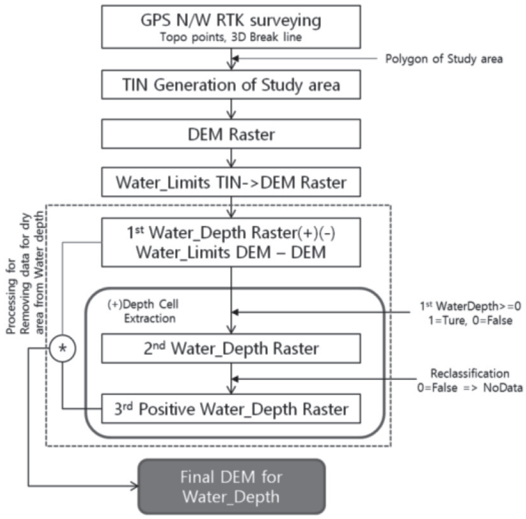


Fig. 7. Work flow of DEM generation

Fig. 8. DEM of water surface

$$Water\_Depth = DEM_{Water\_Surface} - DEM \quad (1)$$

Among the data, + values represent water depth, whilst – values such as –1.23 and -1.10 represent deposits placed higher than the water surface (i.e. dry stream), as demonstrated in

Fig. 8. Therefore, any cells containing – values were deleted by using the following method: + cells were logically sorted as 1 and – cells as 0; all zeros were classified again as NoData (=null); and the obtained DEM (3rd) was multiplied by the Depth DEM (1st generation) to calculate a DEM for water depth (Fig. 9). The dashed line box in the work flow presented in Fig. 7 shows the process of eliminating the data on the dry stream deposits from the data on the water depth. Meanwhile, Fig. 10 demonstrates the depth from upstream to downstream obtained by using the DEM for water depth. The maximum water depth was approximately 1.1m, and the upstream areas were deeper compared to the downstream areas. Water depths close to 0m indicate beaver dams.

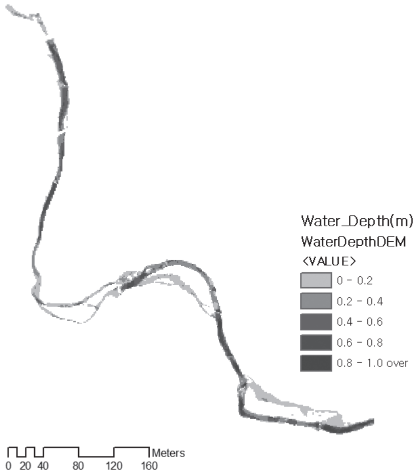


Fig. 9. Water depth

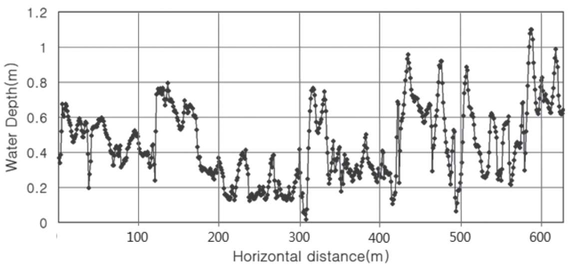


Fig. 10. Water depths from upstream to downstream

2.4 Estimation of erosion and deposition thickness

The erosion and deposition thickness was first estimated in accordance with the work flow shown in (Fig. 11). As already described in 2.2, we created a DEM for the same watersides in 2009 and 2011, and calculated the DoD (Difference of DEM) shown in (Fig. 12).

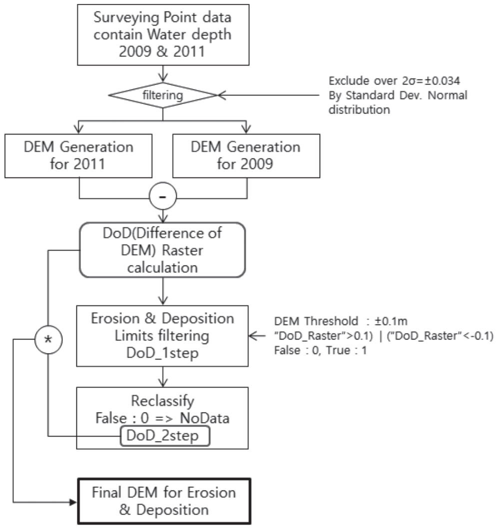


Fig. 11. Work flow of DEM for erosion and deposition

However, since the measurement points in 2009 could not generate exactly the same values in 2011, this difference cannot be interpreted as erosion and deposition thickness. Moreover, as it is impossible to find the previously used 5,600 points and measure them, the actually measured coordinates and DEM obtained by interpolation are bound to produce a difference, where all values fall within a certain range.

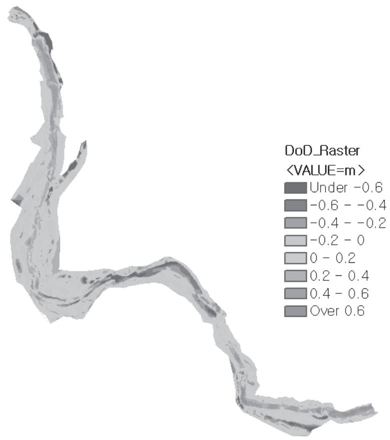


Fig. 12. 1st Generation of DoD (2009-2011)

Therefore, it was first necessary to set a threshold for the DoD, by determining the difference between the actually measured coordinates and DEM obtained by interpolation. To obtain coordinates, ten check points were installed in the survey area for GPS measurements as shown in (Fig. 13). We confirmed that the check points were located in the same spots in 2009 and 2011, and then calculated and compared the erosion and deposition thickness (ΔH).

$$\Delta H = (H_{2011} - H_{2009}) - DoD \quad (2)$$

H_{2011}, H_{2009} : *height of check points*

DoD : difference of DEM

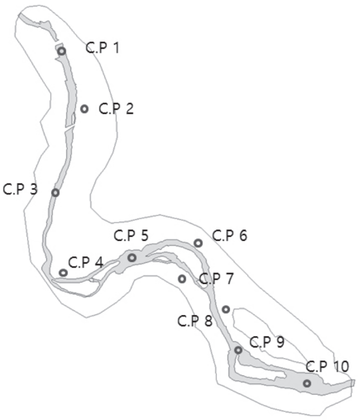


Fig. 13. Check points (C. P) for erosion and deposit comparison

Table 2. Difference between actual measurements and DoD for check points

No.	East	North	ΔH
1	715227.74	4952275.08	0.091
2	715255.23	4952209.98	-0.075
3	715224.79	4952120.35	-0.050
4	715252.43	4952065.67	0.045
5	715297.62	4952070.57	-0.012
6	715344.06	4952088.64	0.007
7	715345.30	4952062.01	0.097
8	715393.73	4952019.40	-0.038
9	715397.76	4951986.10	0.024
10	715479.49	4951957.68	0.067

The threshold for DoD was set to ±0.1m, as the maximum value of was 0.097m (Table 2).

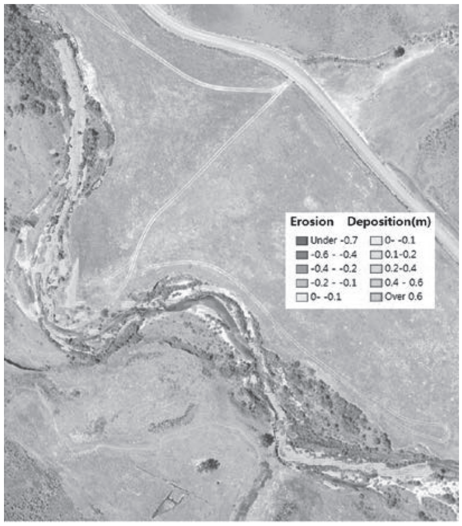


Fig. 14. Thematic map of erosion and deposition

We calculated a new DoD to exclude the values within ±0.1m (Fig. 14) by multiplying the DoD, which was obtained by using the method proposed in Fig. 11, by the reclassified DoD. The + values represent the deposition thickness while – values represent the erosion thickness.

Fig. 14 demonstrates that the maximum deposition thickness is around 0.6m, and the maximum erosion thickness is –0.7m. Thick deposits were found in the downstream areas with gradual slopes as well as at the starting points at the upstream areas. On the other hand, deep erosions were found more in a few sections of the upstream areas and on the outer side of the bend in the midstream areas. In addition, since the rivers had several dry streams during the dry seasons, few of the deposits were isolated from the mainstream.

3. Conclusion

To establish a precise DEM, this study obtained 3D data points where 96% were within two standard deviations (±2σ) of ±0.034m, by applying the RTK-GPS technique to the areas that provides mask angle and using total stations to the areas that have obstacles.

A new DEM was created by eliminating errors exceeding ±2σ from the data. We also excluded the DEM for water depth made previously based on the water_limit data, and in doing so we were able to create a new DEM for water depth as well as water depth profiles.

By applying the GIS-based change detection technique, we calculated the 1st erosion and deposition thickness based on the difference between the DEMs of 2009 and 2011. To improve the reliability of the data, the threshold was set to ±0.1m by comparing difference against the actual measurements and by calculating the final value of erosion and deposition thickness after filtering the DoD values.

If DEMs for the same points can be obtained after time elapses, objective results can be expected. Moreover, if the difference between the thresholds for the DoD can be reduced by increasing the number of check points, highly reliable data on erosion and deposition thickness will be obtained. We believe that the results of this study can be utilized as basic data for maintaining and managing rivers.

Acknowledgment

This research was supported by the Research Foundation System (2015) of Kongju National University. The author would like to thank Dr. Joe Weaton at Utah State University for his support.

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