Comparison of Image Resampling Techniques for Satellite Imagery

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ABSTRACT
Image resampling is a process used to interpolate the new cell values of a raster image during a resizing operation. There are many resampling methods available, through a variety of platforms, including GIS and image-editing software. Each resampling method has strengths and weaknesses which should be considered carefully. The purpose of this paper was not to find a "best" method, but rather to explore how different methods implemented by different software vendors (in this case, ArcGIS and Paint Shop Pro) compared. Aggregated Average and Nearest Neighbor are two commonly used resampling methods, but numerous other methods are available (e.g., bicubic, bilinear, cubic convolution, pixel resize, and weighted average). To compare these methods, Landsat imagery was iteratively resampled from 28.5 to 100 meters per pixel (mpp) using each of the available methodologies. Correlation coefficients were determined comparing each resampled image against imagery resampled using 1) aggregated average and 2) nearest neighbor. Resulting correlation coefficients (R^2) ranged from 0.98 to 0.34. Correlation between aggregated average and nearest neighbor was relatively low ($R^2 = 0.41$) as was the correlation between two bilinear interpolation results ($R^2 = 0.393$) as implemented by different software programs. It was concluded that resampling methods should be considered carefully and tested before selecting a software program or technique, as different programs can implement the same method very differently.

KEYWORDS: aggregated average, nearest neighbor, bicubic, bilinear, interpolation, cubic convolution, pixel resize, weighted average

INTRODUCTION

Image resampling is a process by which new pixel values are interpolated from existing pixel values whenever the raster's structure (number of rows and columns) is modified such as during projection, datum transformation, or cell resizing operations (Wade and Sommer, 2006). Various resampling methods can be employed to resize an image (Corel Corp., 2007) and when an image is enlarged or reduced, changes are necessarily made to the value assigned to each pixel. To reduce an image, entire rows and columns are removed, while the enlargement of an image requires the opposite change by adding rows and columns of pixels. In both cases, the spatial extent (minimum and maximum X and Y coordinates) of the imagery is unchanged and only the raster's structure is modified. The effect of image resampling is a concern for image quality in general, and when dealing with remotely sensed data for scientific interpretation, data integrity (i.e., how closely the interpolated value matches the original value of each pixel) becomes a concern as well. This is because raster images store data within the feature (pixel) itself as for example, each pixel from a satellite image represents a measured surface reflectance value derived from a satellite or airborne sensor.

The enlargement of satellite imagery (i.e., increasing the number of rows and columns) is typically not of concern relative to data integrity issues as the rows and columns of pixels added are simply duplicates of existing pixels. This is particularly true when the enlargement factor is a whole number, but not necessarily true when imagery is enlarged fractionally (e.g., spatial resolution of an image is changed from 15 meters per pixel [mpp] to 10 mpp) as this specific procedure does require interpolation. In contrast, the reduction of an image means fewer rows and columns (and hence fewer pixels) will be used to represent the same geographic features across the same spatial extent. A fairly common resampling task involves the conversion of satellite imagery at a relatively fine spatial resolution (e.g., 10 mpp) to a more coarse resolution (e.g., 30 mpp) to readily accommodate comparison with imagery from another satellite sensor. In this scenario, blocks of pixels (kernels) are involved in an iterative resampling process. The value of each pixel within each kernel is evaluated and a new value calculated for the output pixel in the new “resampled” image layer. To effect this change various forms of interpolation have been developed to minimize data integrity losses as a result of resizing. Hence, the study described in this paper was designed to enable a better understanding of the consequences of resampling satellite imagery during a reduction-type resize operation.

Commonly used resampling methods are:

Aggregated Average

The arithmetic mean of all pixels within each kernel is used as the value for the new image pixel. Using aggregated average (AA) all pixels are equally weighted but like all metrics using mean, the output pixel will be strongly influenced by outlier or extreme values that belong to the kernel (Przydatek et al., 2003; Wagner 2004; Li et al., 2005).

Bicubic

Bicubic interpolation is a variation of cubic interpolation (see below) where the process is performed in both X and Y directions (Losinger, 2006). This method is more accurate than nearest neighbor or bilinear interpolation, but slower to run (Goldsmith, 2009). Paint Shop Pro (PSP) graphics software specifically defines its bicubic method as using 16 neighboring pixels in a 4x4 pixel neighborhood (Corel Corp., 2007).

Bilinear Interpolation

Bilinear interpolation uses the arithmetic mean of the four pixels nearest the focal cell to calculate a new pixel value. This resampling method tends to produce a "smoother" image (Goldsmith, 2009), retains better positional accuracy than nearest neighbor resampling (Verbyla, 2002), but may introduce new values never found in the original image with some blurred edges introduced as well (Goldsmith, 2009). As applied within PSP, the new value is based on the average of four neighboring cells in a 2x2 kernel (Corel Corp., 2007) (Figure 1).

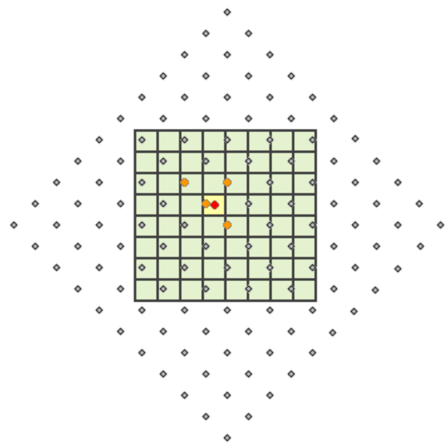


Figure 1. Bilinear Interpolation: The centers of the cells of the input raster are marked with gray dots. The green grid represents the output raster. The red dot marks the center of the target cell (in yellow). The orange dots are the four nearest cells from the input raster that will be used to calculate the value for the desired output cell.
Note: Image courtesy of ESRI.

Cubic Convolution

Cubic convolution (CC) resampling uses a weighted average of the 16 pixels nearest to the focal cell (Figure 2) and produces the smoothest (or most continuous) image compared to bilinear interpolation or nearest neighbor resampling (Verbyla, 2002; Huber, 2009). However, CC resampling takes approximately 10 to 12 times longer to process the computation than nearest neighbor (eXtension, 2008; Huber, 2009).

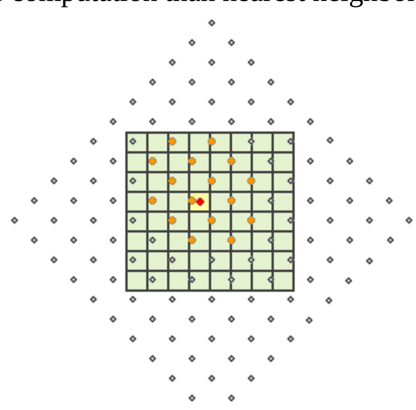


Figure 2. Cubic Convolution: Again, the gray dots represent the centers of the input raster cells and the green grid represents the output raster. The target cell is yellow with the red dot showing the center. For cubic convolution the 16 nearest cells (orange dots) are used for input to calculate the new output value.
Note: Image courtesy of ESRI.

Nearest Neighbor

Nearest Neighbor (NN) resampling is very commonly used and it functions by matching a pixel from the original image to its corresponding position in the resized image. If no corresponding pixel is available, the pixel nearest is used instead (Figure 3). NN works well with horizontal or vertical lines (Goldsmith, 2009) but introduces noticeable error along other linear features where pixel realignment is obvious (eXtension, 2008) and for that reason is generally considered the least accurate method. NN remains widely used because of the speed of implementation and simplicity (Dodgson, 1992). As computers become more and more powerful it is easy to dismiss a less computationally intensive process for one with more accurate results, but with remotely sensed images computation time can still a concern, as imagery can be very large (>1 GB). A notable advantage of NN is that no interpolated values are created; making it ideal for the retention of discrete or categorical data sets (ESRI, 2008; ESRI, 2009; Verbyla, 2002).

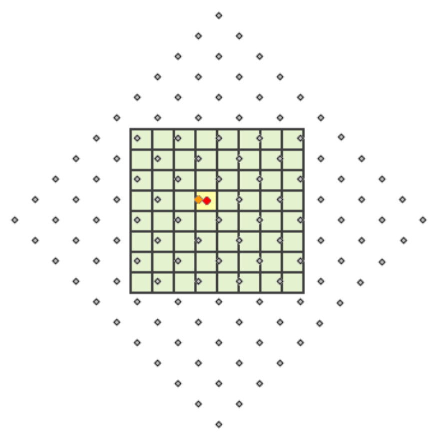


Figure 3. Nearest Neighbor: Using the same setup as in Figures 1 and 2, there is only one value (orange dot) used to create the new output value, which is derived from the cell nearest the target.
Note: Image courtesy of ESRI.

As well as the common methods, many image-editing programs such as PSP have their own, specialized, resampling methods. As well as modified versions of bicubic and bilinear interpolation, PSP also offers the following resampling methods:

Pixel Resize

Pixel Resize duplicates (when increasing the size) or removes (if decreasing the size) the value of the pixel nearest the focal cell to achieve the desired height and width of the new image (Corel Corp., 2007). It is it best for simple images (Shea, n/d) and is the only resample method that can be used on images using 8 bit (or less) color schemes in Paint Shop Pro (Corel Corp., 2009).

Weighted Average

This method uses a weighted-average value of neighboring pixels to determine the value of newly created pixels in the new image (Corel Corp., 2007). It is best for reducing images (Chastain et al., 2005; Shea, 2009).

Affects of resampling

Remotely sensed data, be they from satellite or airborne sensors, are incredibly variable. Spatial resolutions can be very coarse (>100 mpp) to very fine (< 0.1 mpp) and choosing which scale to use for a study can be a difficult process, with limitations including availability of fine resolution imagery, cost constraints, and data processing considerations. With a variety of platforms to choose from, it is fairly common that imagery from one platform may need to be compared to imagery from a different platform (e.g., SPOT 4 [20 mpp] and SPOT 5 [10 mpp]).

In order to compare data from one spatial resolution to another, imagery from the finer resolution are typically resampled to match the spatial resolution of the coarser imagery. This type of resampling can have substantial effects on the integrity of the data being compared (João, 2001). Gotway and Young (2002) provided a brief overview concerning incompatibility of spatial data and looked at some of the methods used to overcome that concern. Bian and Butler (1999) looked at the three most common types of resampling (1-averaging; uses the averaged value of a kernel for the output pixel, 2-central-pixel; uses the most centrally located pixel of a kernel for the output value, and 3- median value; uses the statistical middle value in a kernel dataset as the output) and found that averaging had the most predictable statistical errors. It is noted however, that Goodin and Henebry (2002) found averaging may not accurately preserve the spatial properties desired for research.

Nearest neighbor (NN) and aggregated average (AA) are two commonly used resampling methods applied to remote sensing imagery. NN is useful for its speed and ability to maintain the integrity of categorical data while AA can accurately preserve mean values of images across many levels of aggregation (Bian and Butler, 1999). The purpose of this study was to compare the results of numerous resampling methods to the results of NN and AA resampling, and thereby better understand the affect of resampling and its potential implications on the introduction and propagation of error.

Methods

One Landsat 5 TM scene (path 39 row 30) acquired on June 13, 2006 was used in this study. Prior to applying experimental resampling, the imagery was corrected for atmospheric effects using the Cos(T) method (Chavez, 1996) available in Idrisi Andes. A normalized difference vegetation index (NDVI) was calculated as a simple band ratio of the red and near-infrared bands (bands 3 and 4) following Rouse et al (1974). NDVI was selected for use in this study as it is a very common application for satellite imagery making the reported results more meaningful.

Idrisi Andes, ESRI ArcGIS 9.3, and Corel Paint Shop Pro X2 (PSP) were used to perform resampling (aggregated average, bicubic, bilinear, cubic convolution, nearest neighbor, pixel resize, and weighted average) of the NDVI layer (Table 1). In all cases, Landsat-derived NDVI imagery was resampled from its native 28.5 mpp to 100 mpp. In total, eight resampled layers were produced and using these layers, 100 pixel-values were extracted using the ArcGIS sample tool. The extracted values for bicubic, bilinear interpolation, cubic convolution, pixel resize, and weighted average were then compared to pixel values derived using AA and NN resampling methods. AA and NN values were also compared as were the results of bilinear interpolation using ESRI ArcGIS and PSP. Statistical comparisons were facilitated by calculating a correlation coefficient (R^2) between each pair of image values (n = 12; Table 2).

Table 1. NDVI image layers were systematically resampled using a variety of techniques and software applications.

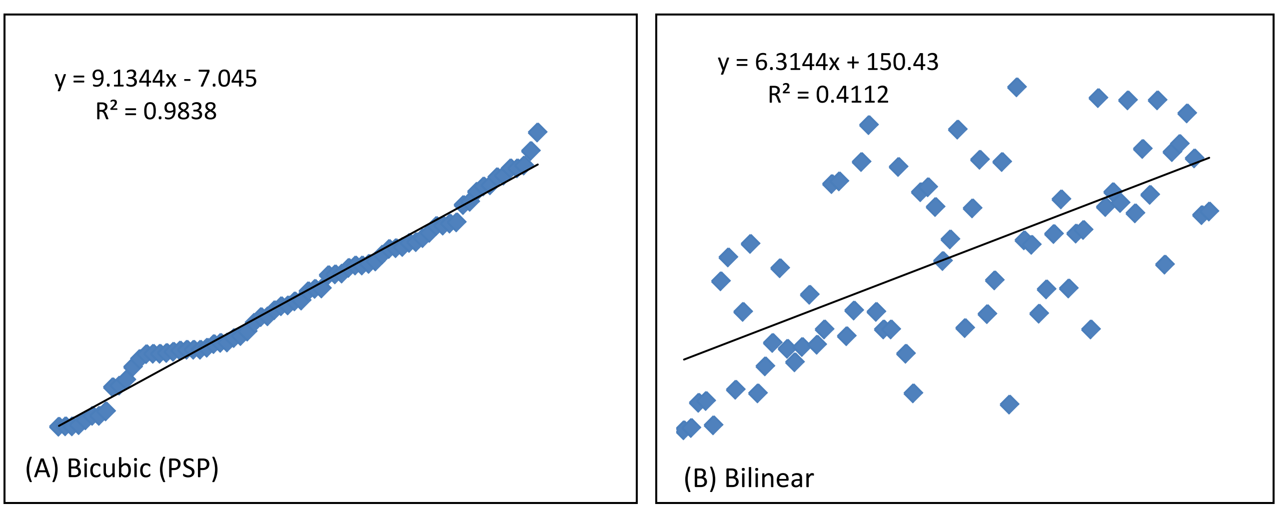
Resampling technique	Idrisi Andes	ESRI ArcGIS	Corel Paint Shop Pro
Aggregated Average (AA)	*		
Bicubic			*
Bilinear interpolation		*	*
Cubic convolution		*	
Nearest Neighbor (NN)		*	
Pixel resize			*
Weighted average			*

Table 2. Pairs of resampled images were statistically compared using linear regression and correlation coefficients (R^2)

Method	AA	BC	BL	CC	NN	PR	WA
AA		*	*	*	*	*	*
BC	*				*		
BL	*		*		*		
CC	*				*		
NN	*	*	*	*		*	*
PR	*				*		
WA	*				*		

RESULTS AND DISCUSSION

The most similar resampling results (R^2 = 0.984) were found between the bicubic and AA methods (Figure 4a). PSP's calculations for Bilinear interpolation resampling were also very similar to AA values (R^2 = 0.964) (Figure 4b). This is not surprising as all three resampling methods calculate output values by averaging values within the input kernel. The only real change from one process to the next is the size of the kernel. The kernel size for AA is unknown, but it is probably close to 16 pixels given how closely it compares to PSP's bicubic results. Some variation can be expected since it is not uncommon for software companies to have specific, patented algorithms that are slightly different from others. This concept is further illustrated in Figure 7 which compares results from ArcGIS's bilinear resampling with PSP's bilinear resampling method. The resulting R^2 value of only 0.393 illustrated that, even though results should be fundamentally identical, each product produced drastically different values.



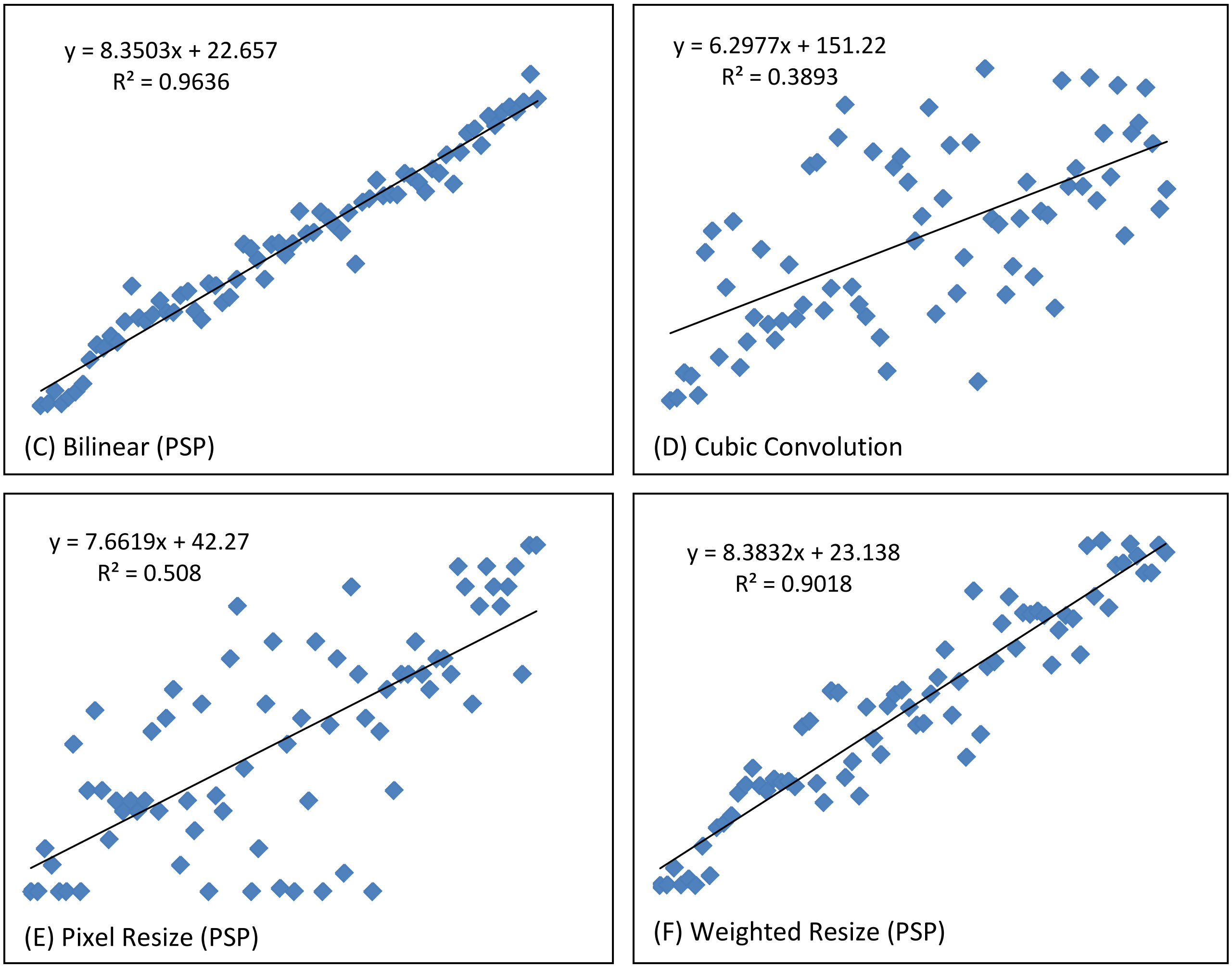
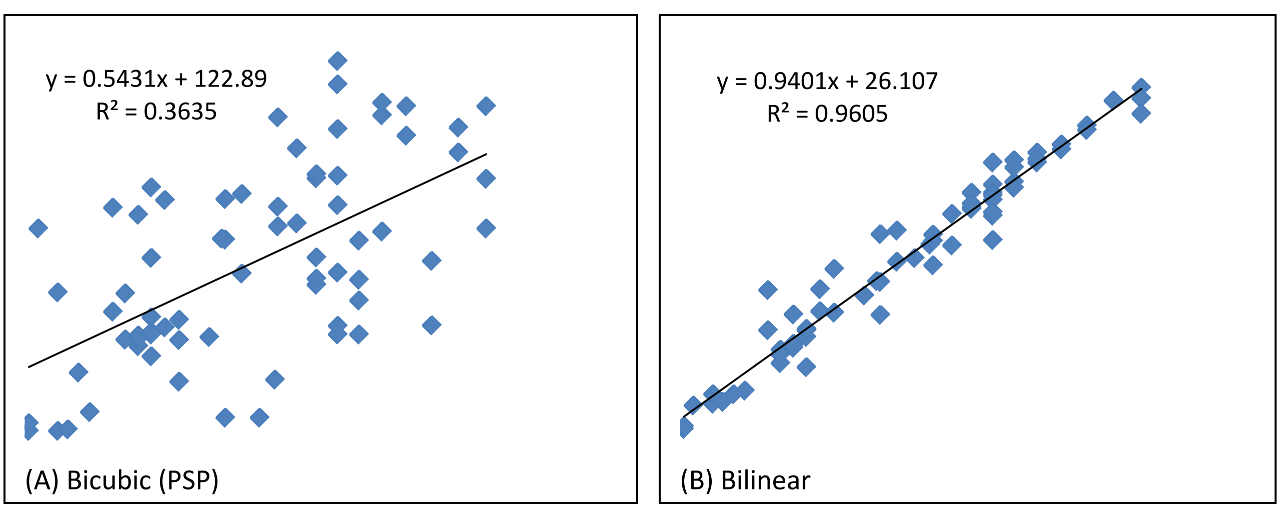


Figure 4. Various resampling method results compared to the results of Aggregated Average resampling. Graphs are shown with linear trendlines, slope and intercept, and correlation coefficient (R^2) values.

The resampling method most similar to NN was CC resampling (R^2 = 0.963) (Figure 5d), and ArcGIS's bilinear resampling (R^2 = 0.960) (Figure 5b). However, it must be remembered that neither of these options would maintain original categorical data values as NN will and both require more computational power relative to NN. Bilinear interpolation does not require as much computational power as CC, so for very large images it may be a suitable substitution to achieve results similar to NN but in less time than CC.



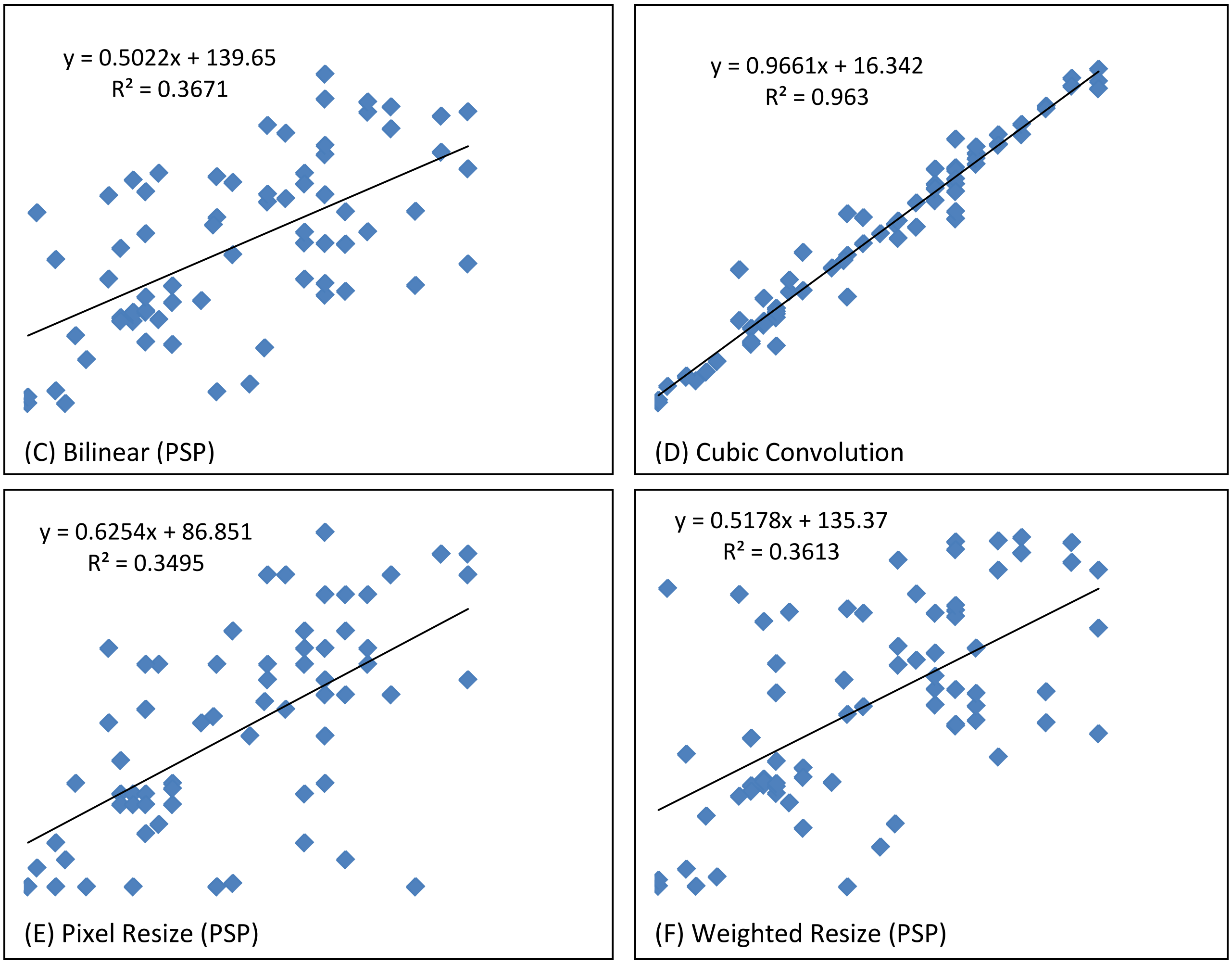


Figure 5. Various resampling method results compared to the results of Nearest Neighbor resampling. Graphs are shown with linear trendlines, slope and intercept, and correlation coefficient (R^2) values.

Figure 6 shows that NN and AA produce very different results ($R^2 = 0.409$) and imagery resampled using these methods are not directly comparable. This is not surprising however, considering how different the resampling methods are. This finding also explains why the other methods tested either compared better with either AA (PSP's bicubic, bilinear, and weighted average) , NN (ArcGIS's bilinear and PSP's CC), or neither (PSP's Pixel Resize).

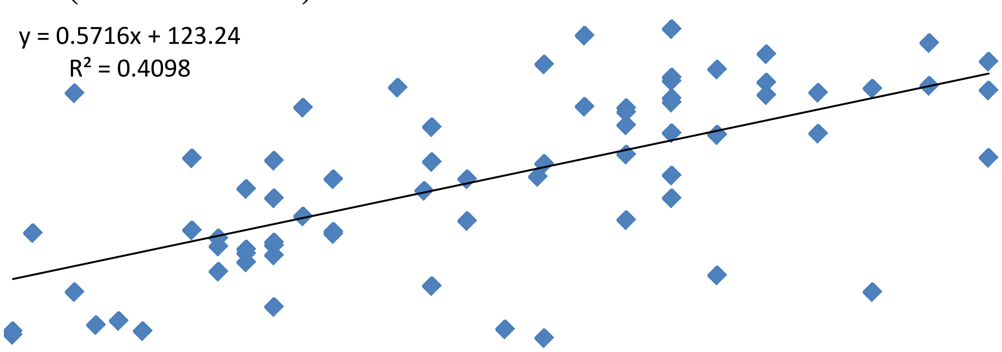


Figure 6. Comparison of values obtained by resampling with the Nearest Neighbor and Aggregated Average methods.

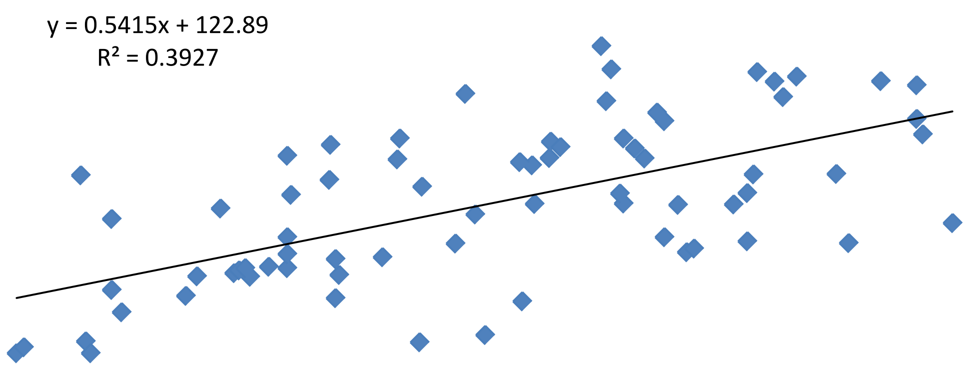


Figure 7. Comparison of values obtained by using an ArcGIS Bilinear resampling and Corel's PSP Bilinear resampling method.

CONCLUSIONS

The purpose of this study was not to determine the best method for image resampling but rather to learn how various methods of image resampling compare to NN and AA as these are most commonly used. Atkinson (2001) raised a concern that those using remotely sensed data tended to choose images without properly considering if the pixel size of that image was appropriate for the study being conducted. The same could be said for resampling methods. There are a many options available for resampling images, and all options should be considered and tested before applying a method.

Additional considerations include the degree to which data values need to be maintained (especially when categorical data is resampled), whether the resulting dataset needs to be statistically or spatially accurate, how much processing power is available to perform the resampling, and what software is available to perform the resampling.

It was determined that image-editing software such as Corel's Paint Shop Pro can be used to perform image resampling, with results comparable to those created from remote sending - or GIS-specific software. However, due to proprietary differences in algorithms, care needs to be taken to make sure the results from one resampling software application can be compared to the results from another. For example, it is not recommended that another image-editing software (e.g., Adobe's Photoshop) be used in lieu of PSP without prior testing.

Based upon results presented in this paper, it is important to carefully select the most appropriate resampling technique for a given set of circumstances and seems most prudent to apply the same resampling technique using the same software to all imagery that is part of a given study. Lastly, it is noted that NN is a unique resampling process in that it is the only method that does not interpolate new values into the dataset, and is therefore the only method that should be used for categorical data.

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