

# An Empirical Study on the Influence of Image Filters in Effective Closed Contour Extraction of Lakes in Satellite Images

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## Abstract

**Objectives:** The water contour extraction models using satellite images could be highly useful in monitoring the long term changes in river tributaries, lakes and other coastal areas. The lakes are termed for a localized basin of varied size where the water from river tributaries got reserved. These lakes are one among the prime source of water consumption for human needs. Hence, change monitoring in water levels of lakes is a highly needed measure for sustainability. **Methods/Statistical Analysis:** Though use of bathymetry and elevation data can aid the coastal monitoring models, a simple automated closed contour extraction model can support shape based change monitoring or satellite image based water volume assessment models. In general, the contour extraction of lakes or any water bodies is relatively difficult when compared with urban structures from spatial data. It is due to the indefinite shape of water bodies on varying levels of water. The use of image filters to improve the power of boundary discrimination is inevitable. However, it may also deteriorate the image quality leading to loss of information. Hence, the proposed model has examined the influence of widely used image filters both for smoothening and sharpening with respect to satellite image on applying suitable image quality assessment metrics. **Findings:** On the empirical analysis of the chosen image filters, the Adaptive wiener and Gaussian filters are found to be the more effective sharpening and smoothening filters respectively for satellite images. Further, the outstanding image filters found on evaluation is combined with local thresholding; shape based filtering and morphological operations in a sequence to extract an effective closed contour of water bodies. **Applications:** The proposed model can be applied for satellite image preprocessing for effective noise suppression and edge preservation. The closed contour extraction can be applied with change detection based applications for satellite images.

**Keywords:** Contour Extraction, Image Filter, Lake, Preprocessing, Satellite Image

## 1. Introduction

The environmental monitoring applications using satellite images require more accuracy and speed in object detection for better forecast<sup>1,2</sup>. Though the datasets available from authorized data centers are initially preprocessed and orthorectified, in order to reduce the effects on illumination and other noise artifacts for effective object discrimination, more effective preprocessing steps are in need to be performed. Suitable geometric corrections must also be performed to conduct long period change analysis using multi-temporal spatial data<sup>3</sup>.

The coastal or wetlands monitoring models need efficient water extraction methods for tracing the changes in any course of time. The major issue in satellite image based water extraction models is the adverse weather conditions and heavy cloud coverage since the clouds may deter or override the bound limits of a water region. But efficient cloud removal algorithms are still not available<sup>4</sup>. The threshold selection approach for removing cloud region is also not much successful. Hence, cloud screening can be done to choose cloud free images for examining through analyzing data from suitable seasons<sup>5</sup>.

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The selected cloud free region may also include certain level of noise due to different illumination conditions and mixed pixel issues in moderate resolution images. Hence suitable image filters are need to be applied for noise removal and sharpening of image details<sup>6</sup>. The image filters can be applied for noise reduction through averaging or Blurring<sup>7</sup> where the median filter has been widely applied for both noise removal and sharpening in satellite images<sup>8</sup>. Gamma correction alters the contrast of an image based on the power law transformation to offer better visualization in the enhanced image<sup>9</sup> such as, if gamma value is lesser than 1, the image looks dark and otherwise, brightness gets improved<sup>10</sup>. The adaptive histogram equalization method overcomes the issues of traditional histogram equalization method through sub-region analysis and use of bilinear interpolation for combination of neighboring sub-regions<sup>11</sup>. Radiometric corrections may also be done for overcoming the issues on missed pixels due to detector imbalance. Suitable Atmospheric correction methods are applied for Surface Reflectance (SR) product conversion in satellite images<sup>12</sup>.

The influence of SR values lead to the rise of numerous spectral index based change monitoring applications<sup>13</sup>. The clustering and thresholding methods can be applied for water bodies segmentation from satellite images. However the spectral based water extraction using spectral indices would be more prominent<sup>14</sup>.

In contour extraction models the Binarization of objects improves object discrimination. This Binarization has been carried out using thresholding where setting up an appropriate threshold is still not efficient<sup>15</sup>. Generally, it has been done using either global or local thresholding. If the image is susceptible to more changes and illumination disturbances, local thresholding which is performed locally in every pixels covering the regions of entire image can be used. However, if the image is not subjected to any noisy disturbances, global thresholding using a single threshold value can be used. The otsus' threshold has been widely used for Binarization object segmentation in images<sup>16</sup>. However, the use of Bernsen threshold achieved better segmentation with respect to the local contrast value based Binarization<sup>17</sup>. Also has examined the performance of threshold functions on degraded images and found local thresholding based on local contrast and mean values are good<sup>17</sup>.

In case of moderate resolution satellite images, the active contour mapping of water bodies using level set methods, polygonal and piecewise linear approximation

models are widely been used<sup>18,19</sup>. Nowadays, the launch of numerous satellites and advanced technological sensors lead to more improved exploitation of spatial data for environmental monitoring. The availability of elevation data favoured analyzing heights of the urban buildings, mountaineous regions and water depths etc.<sup>20-22</sup> has analyzed the scarcity of water in water bodies using the 90m resolution SRTM Digital Elevation Model (DEM) data, topographic maps and contour lines with the use of GIS tools. Similarly, many data that could achieve an elevation model such as Synthetic Aperture Radar (SAR) and LIDAR etc. are used for tracing the water depths in coastal areas<sup>22</sup>. However, these data are not available for past many years. Hence, the long period change analyses using satellite an image depends on the coarse resolution data for evaluating the changes in water body.

This paper focuses on bringing a simple contour mapping of water bodies through examining the influence of image filters in satellite images which can be applied for shape based change monitoring or surface area assessment in lakes. The following section details the overall architecture of the proposed model and the satellite image datasets chosen for evaluation. Further, the remaining sections are organized for detailing the empirical evaluation of image filters and the workflow of the contour extraction model with the results and discussion.

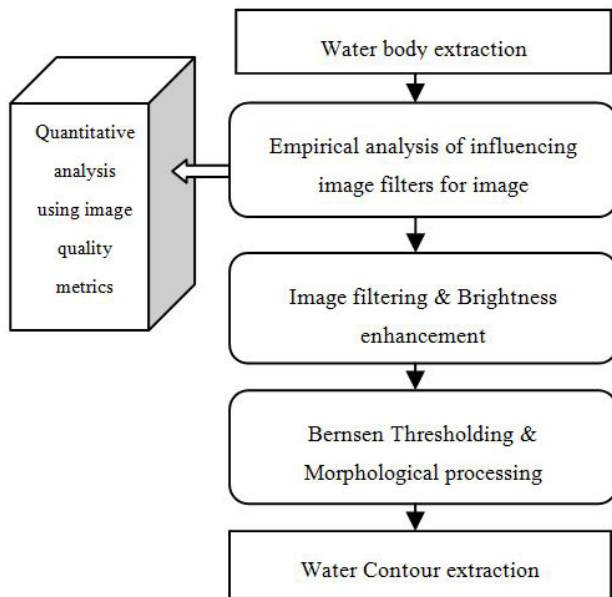
## 2. Materials and Methods

### 2.1 Water Contour Extraction Model

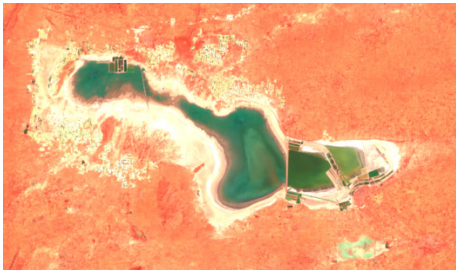
In this work, a filter based water contour extraction model is proposed which is shown in Figure 1. This proposed model for water contour extraction combines image filtering, brightness enhancement methods, Bernsen Thresholding, morphological operations and range filter for effective contour extraction. The eminent filters found on an empirical analysis of the influence of filters with respect to satellite images have been chosen for improved contour extraction.

The multitemporal Landsat 8 data from different seasons from USGS portal of Sambhar Lake at Rajasthan in India has been chosen for analyzing the proposed model<sup>23</sup>. The False Color Composite of the study region is shown in Figure2. The raw satellite images are very less in contrast and not have better visualization. Hence a combination of near infrared (NIR), green and blue bands

replacing the Red band in true color composite has been derived and is termed as False Color Composite (FCC).



**Figure 1.** Filters Based Water Contour Extraction Model.



**Figure 2.** FCC of Sambhar Lake (2015).

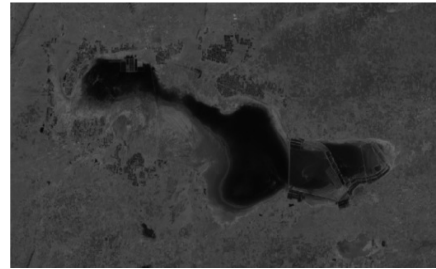
Numerous water indices are available to extract the water body from the satellite images where the Normalized Difference Moisture Index (NDMI) is the most notable spectral index<sup>24</sup>. The raw satellite images are needed to be atmospherically corrected for applying these image rationing methods. Here, the chosen dataset gets atmospherically corrected using Dark Object Subtraction (DOS) method using QGIS for being converted into SR Product<sup>25</sup>.

Every satellite image has different bands of observed reflectance of the earth. The Landsat 8 image has eleven reflectance bands where each band comprises different wavelengths of the observed electro-magnetic spectrum. In these image rationing methods for Spectral indices, the appropriate region of interest has been extracted through their relative influence in spectral wavelengths<sup>26</sup>. The

widely used NDMI based water extraction method given in Equation 1 has been chosen for water body extraction in this model.

$$NDMI = \frac{(b3 - b5)}{(b3 + b5)} \quad (1)$$

Where  $b3$  and  $b5$  are the SR values of green and NIR bands respectively. The SR products of the chosen lake dataset with the corresponding NDMI results for water extraction have been shown in Figures 3(a) and 3(b).



**Figure 3 (a).** SR Product of Sambhar Lake.



**Figure 3 (b).** NDMI Water Extraction.

## 2.2 Influence of Image Filters

The water extraction results of Sambhar lake on eight different dates have been applied for analyzing the influence of image filters for choosing the most suitable filter to achieve better water contour extraction has performed a similar comparative analysis on different image filters for image denoising<sup>27</sup>. The image filters are generally applied for suppressing the high frequencies for smoothing and low frequencies in order to sharpen the image. The image filtering can be done either in spatial or frequency domain. In spatial domain filtering, the image gets convolved with the filter function of a chosen kernel size (often it is  $3 \times 3$  in size) for being filtered as shown in the following Equation 2. Where  $h(x,y)$ ,  $g(x,y)$  and  $f(x,y)$  are Output, Input images and filter function respectively. In general, convolution is termed for a mathematical operation in which two arrays of same dimensions has been multiplied to produce the

**Table 1.** Properties of Image Filters

Image Filter Type	Description	Filter functions /Working procedure
Median	Noise Removal of an image using the median of neighborhood	$f(x, y) = \text{median}\{g(s, t); (s, t) \in h_i\}$  where, $h_i$ denotes the corresponding sub-region of image, (i.e) neighborhood pixels.
Adaptive Median Filter	Overcome the limits of fine details loss while noise removal using median filter.	Localizes the pixels having affected by noise through considering neighborhood pixels on pixel wise comparison by adjustable neighborhood size.
Averaging Filter	Image Smoothing and Noise Reduction through averaging the neighborhood and results in slight blurring.	It is a linear image filter that spreads the noise through averaging to reduce the noise effect, rather than removing noise as median filters.
Harmonic mean	Performs noise reduction based on harmonic mean computed from corresponding neighborhood.	$f(x, y) = \frac{mn}{\sum_{(s,t) \in h_i} \frac{1}{g(s, t)}}$
Contra Harmonic mean	Performs noise reduction in images.	$f(x, y) = \frac{\sum_{(s,t) \in h_i} g(s, t)^{Q+1}}{\sum_{(s,t) \in h_i} g(s, t)^Q}$ where, Q be the order of the filter.
Adaptive Wiener Filter	Optimum Sharpening filter that achieved minimum mean square error.	As adaptive filter, it considers the image characteristic that varies in different neighborhood hence works well in increasing edge sharpness and noise removal.
Gaussian Filter	Effective noise removal filter.	The Gaussian filter is effective in noise suppression that depends on the weights chosen according to the corresponding Gaussian function.

output of same dimension which can also be stated as a neighborhood operation where each output pixel is produced as the weighed sum of neighboring input pixels.

$$h(x, y) = g(x, y) \circledast f(x, y) \tag{2}$$

To evaluate the influence of image filters on the water extraction results, the predominant image filters are chosen from the literature as shown in Table 1, <sup>28,29</sup>.

### 3. Results and Discussion

The relative influence of the chosen filters are quantitatively assessed using familiar image quality measures like Peak Signal Noise Ratio (PSNR)<sup>30</sup> and Structural Similarity Index (SSIM). The PSNR measure is defined to be the ratio of maximum power of a signal and the power of noise that leads to signal distortion. The corresponding equations are shown in Eq. 3 and Eq. 4.

$$PSNR = 10 \cdot \log_{10} \frac{MAX^2}{MSE} \tag{3}$$

Here, MAX is the maximum possible image pixel value and the power of noise is calculated using Mean Square Error (MSE) where I and K are images before and after preprocessing.

$$MSE = \frac{1}{M N} \sum_{i=1}^M \sum_{j=1}^N [I(i, j) - K(i, j)]^2 \tag{4}$$

The SSIM metric computes the structural similarity between two images considering their luminance, contrast and structure<sup>31</sup>. The performance evaluation of seven image filters (numbered as 0 to 6) on multi-temporal dataset has been carried out and the influence of filters has been tabulated in Table 2 and the plot in Figure 4 also shows the effectiveness of Adaptive Wiener and Gaussian filters as in Figures 5(a) and 5(b). From the evaluation of image filters on chosen dataset, the adaptive wiener and Gaussian filter are the two filters that outperform all the other filters in sharpening and smoothing respectively. Hence, these suitable filters with relatively good per-

formance are chosen for carrying out the processing of contour extraction model.

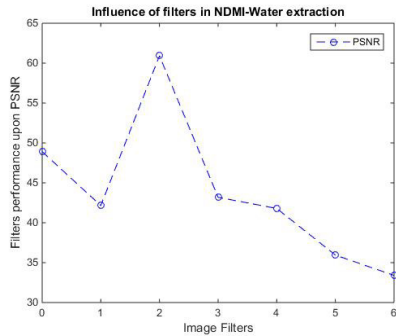


Figure 4. Influence of Image Filters.

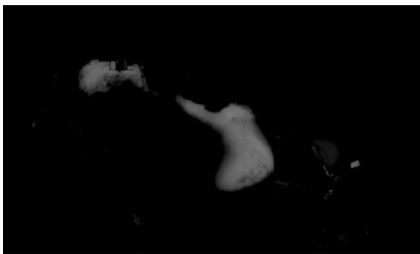


Figure 5 (a). Adaptive Wiener Filtering on NDMI.



Figure 5 (b). Gaussian Filtering on NDMI.

Table 2. Evaluation of Influence of Image Filters

No	Image Filters	Image 1		Image 2	
		PSNR	SSIM	PSNR	SSIM
<b>Sharpening Filters</b>					
0	Adaptive Median	48.9092	0.9954	51.8044	0.9972
1	Median	42.1553	0.9896	46.4691	0.9935
2	<b>Adaptive Wiener</b>	<b>60.9195</b>	<b>0.9991</b>	<b>68.0100</b>	<b>0.9998</b>
<b>Smoothing Filters</b>					
3	<b>Gaussian</b>	<b>43.1874</b>	<b>0.9916</b>	<b>47.4922</b>	<b>0.9951</b>
4	Contra Harmonic Mean	41.7888	0.9890	46.1683	0.9935

5	Average	35.9457	0.9825	40.8281	0.9902
6	Harmonic Mean	33.3988	0.9586	36.9993	0.9693

The water contour extraction models are generally used for localizing the enclosed boundary of the water body so that these contours can be applied in image based surface area assessment models<sup>32</sup>. In case of water contours, the irregular polygons of water bodies need to undergo a sequence of image processing operations to acquire a closed contour of a water body. The NDMI based water extraction results that are acquired for the chosen dataset be applied with the two best image filters found from the above empirical analysis listed in Table 2. Initially the Gaussian filter has been applied for smoothing since the actual water extraction result from the SR product is seemingly uneven due to rationing. Then for improving the boundary discrimination, the adaptive wiener filter which is found to be better amidst all the sharpening and smoothing image filters has been applied. Followed by the edge preservation, the image contrast needs to be improved for effective binarization. Normally, the brightness enhancement will be carried out by adding or reducing a constant from the luminance values of an image using image adjustment functions like gamma correction or histogram equalization methods<sup>33,34</sup>. In this model, the Contrast Stretch Limit method has been applied considering the high and low values of the image gray levels for dynamically stretching the image<sup>35</sup>. The enhanced images are then applied with binarization to get divided into foreground and background pixels. Here, Bernsen thresholding which is a local thresholding method based on the local contrast value of an image has been used for binarization of an image<sup>36</sup>. The maximum contrast values of image acquired from the bernsen threshold function has been applied for tracing the maximum boundary of the water body.

The delineation of water body with respect to both maximum and minimum contrast values of the pixel can be visualized in the bernsen thresholded image. Thus shape based filtering is possible through using either maximum or minimum contrast values, here maximum value based contrast filtering has been applied to prevent loss of boundary information. It has been followed with the morphological closing operation using disk operator.

The morphological close operation assures the enclosure of the region. Then contour extraction has been

applied with range filter which finds the contour through ranging throughout the neighborhood for values between maximum and minimum values. This proposed combination of bernsenthresholding and range filter found to be an effective combination for contour detection. The contour extraction results of the proposed model and the other edge extraction methods are shown in Figures 6 (a) to 6 (c). It is evident from the sobel and canny operators that even though close operation has been performed, these contours are still without a proper enclosure<sup>37</sup>. In order to quantify the results achieved through the proposed pipeline of contour enhancement, the combination of average filter and adaptive median filter which has relatively good performance from the above empirical analysis also has been tried and the results are shown in Figures 6 (d) to 6(f). The contours are highly smoothed and the areas with less water concentration are missed out in this combination.



**Figure 6 (a).** Gaussian and Adaptive Wiener Based Contour using Sobel.



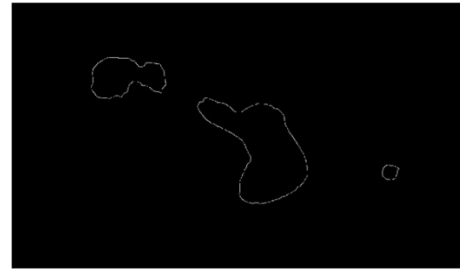
**Figure 6 (b).** Gaussian and Adaptive Wiener based Contour using Canny.



**Figure 6 (c).** Proposed Gaussian and Adaptive Wiener Based Contour.



**Figure 6 (d).** Adaptive median and Average filter based contour using Sobel.



**Figure 6 (e).** Adaptive Median and Average Filter Based Contour using Canny.



**Figure 6 (f).** Adaptive Median and Average Filter Based Contour using Proposed Model.

Hence, it is more evident that the proposed model with combination of Gaussian and Adaptive wiener filter chosen from the empirical analysis performed could bring out an effective water contour extraction in satellite images. These extracted closed contours of a water body can be used for tracing the long term changes in water body monitoring models and also in area estimation of water bodies using satellite images.

## 4. Conclusion

Thus empirical examination performed over image filters in satellite images is found to be efficient both in noise removal and image details preservation. The highly influenced image filters from the above analysis that are examined further through contour extraction model bring closed contours successfully. This proposed con-

tour extraction model is relatively simpler than level sets or any other approximation based edge detection models. Hence it can be more useful in building change monitoring models for water bodies. This model is also found to be stand alone and can be applied with moderate resolution satellite images of any water bodies. Further, this contours based object localization and recognition can also be extended in medical data and computer vision fields of research.

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