Analysis of Lakes Over the Period of Time Through Image Processing

Sattam Ghosal, Abhishek Karmakar, Pushkar Sahay, and Uma Das

Abstract The Great Salt Lake, located in the state of Utah, is the largest salt water lake in the West and the eighth largest terminal lake in the world. The lake is a home for millions of native birds, shorebirds, and waterfowl, including the largest staging population of Wilson's phalarope in the world. Since 1847, there has been a constant decline in its area. Lake Powell is a lake near the Colorado River in the United States and serves as a major vacation destination for approximate 2 million people annually. However, because of successive droughts and insatiable requirement of water for human and agriculture, Lake Powell has fallen way below in terms of water, depth, and surface area. This study focused on the temporal changes of these two lakes using the multi-temporal Landsat images using Prewitt edge detection and the comparison of the result with other edge detection techniques. The results thus obtained reflect the constant decline in Lake Powell and the Great Salt Lake in terms of surface area in the period 1984–2018 and 1987–2018, respectively.

Keywords Delineation · Landsat images · Prewitt operator · Robert operator

1 Introduction

Lakes are generally located in the rift zones, mountainous areas, and areas with continuous melting of snow near glaciers. Some lakes are found along the courses

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of mature rivers. There are many lakes, in different parts of the globe, which were formed because of improper drainage systems. None of the lakes are permanent, as they will slowly get filled up with sediments or tip over the basin containing them. Many lakes are artificial in nature and have been constructed for serving the industrial or agricultural needs, or for hydro-electric power generation and domestic water supply, or for exquisite, recreational purposes, or some other activities.

Over the years, surface water bodies like lakes, ponds, reservoirs, etc. have been treated as a community resource. They were being nurtured, protected, conserved and managed by the major percentage of the local community without any code of conduct or rule. In turn, these water bodies have been catering the local human and livestock populations. In the modern times, after the introduction of water supply for the public and ground water usage through the hand pumps and wells, a dramatic shift in the attitude of the people towards these water bodies has been witnessed. Both the governments as well as the locals have begun ignoring this asset in the fad and fantasy of the introduced public water supply. They have just started neglecting and have really stopped being responsible for these community resources. Other than this, blooming urban and industrial development has changed the position of these water bodies from a public resource to just a dumping ground for construction debris, garbage, sewage, religious offering etc. These water bodies had fallen a prey to administrative and social atrocities. All this has put the existence of these water bodies on stake and has led to severe deterioration of their water quality. In the recent years, urgent need to restore these community resources has been realized by various countries. This is because mushrooming population and development activities have put immense strain on the public water supply and ground water extraction. This has widened demand–supply gap and has led to excessive depletion of ground water.

The present study deals with the narrowing of one of the major surface water bodies i.e. Lakes. Examining the changes in their overall structure and area done through the graphical analysis of the Landsat images with the help of our proposed framework.

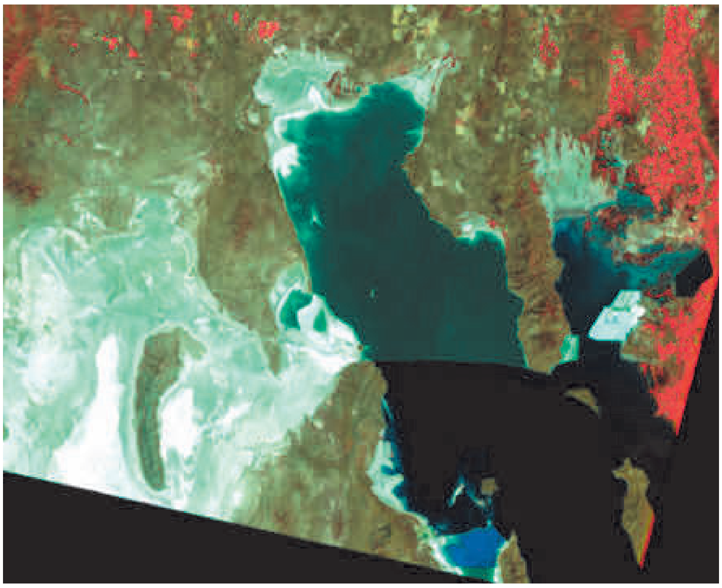
2 Materials and Methods

The basic methodology adopted for carrying out the present study is primarily by analyzing and interpreting the primary data along with the review on the available literature and media reference on the issue. Some of the finest works have been done for vegetation like [1] and [2] and for river extraction [3] but when it comes to using such algorithms for smaller water bodies like lakes and ponds, the noise overlapping is way too much. Primary data for the present study are the Landsat images which were gathered from https://www.earthexplorer.usgs.gov [4, 5] and the literature which was gathered from various sources. The segmentation based on threshold detection from hue histograms [6] and the NDVI method as discussed in [7] was very beneficial in finding out the vegetation or the cropped fields in a satellite image but when same technique is used for water bodies, the results aren't very promising. The various components of the methodology for the present study are as follows.

3 Great Salt Lake

The Great Salt Lake, located in the state of Utah, is the largest salt water lake in the West and the 8th largest terminal lake in the world [8]. In an average year the lake covers an area of around 1,700 square miles (4,400 km2). In 1988, the surface area was at its peak of 3,300 square miles (8,500 km2) but there has been a constant decline ever since. It is the largest lake in the United States, in terms of surface area coverage, which is not a part of the Great Lakes region. Great Salt Lake is salty because it does not have an outlet. Tributary rivers are constantly bringing in small amounts of salt dissolved in their fresh water flow. Once in the Great Salt Lake much of the water evaporates leaving the salt behind. These large changes in water levels is the result of years of human activities such as diverting the river water, which was supposed to fill the lake, for agriculture and industry. It is approximated that about 40% of river water is usually diverted from the lake. These activities, in addition to the ongoing drought in the Western hemisphere, have drained humongous volume of water from the historic lake. As a result, evaporation from the lake's surface is significantly faster than the river inflow. The wildlife habitat is also disappearing and the health of the two million people living in the surrounding area is threatened from airborne dust coming from the dried lake-bed (Figs. 1 and 2).

Fig. 1 Salt lake 1999



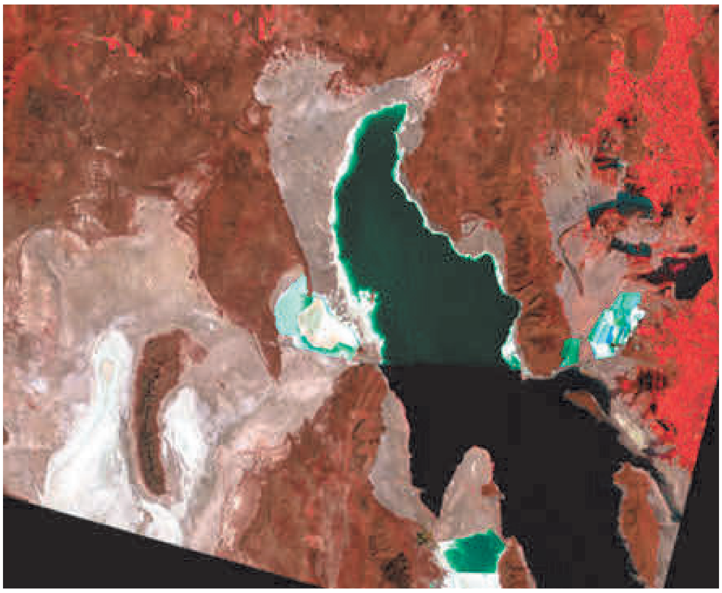


Fig. 2 Salt lake 2018

4 Lake Powell

Lake Powell situated near the Colorado river, is a lake bestriding the boundaries between Utah and Arizona in the United States [9]. Colorado River flows in from the east around Mille Crag Bend and is engulfed by the lake. At the west end of Narrow Canyon, the Dirty Devil River joins the lake from the north. It is a major vacation spot that around two million people visit every year. However, due to high water consumption for agricultural purpose and humans, and because of continuous droughts in the area, Lake Powell has fallen way below in terms of water, depth and surface area. The downfall was visible in the canyons on either side feeding the reservoir. By 2002, the water levels had dropped so much that the canyon walls, which were way too exposed, created a light- coloured outline all around the lake. Falling water levels and dry conditions are seen easily in the images of the 2000s. The side branches of the lake have all receded in comparison to the previous year's extents. In 2017, the rainfall and snowfall were as usual low, which resulted in long-term drought in the region (Figs. 3 and 4).

5 Delineation of Images

To convert an RBG image to grayscale, there are various methods to create a single value for each pixel to represents its brightness from the RBG values. One method is to take average contribution from the three channels. However, the thus obtained brightness is often influenced by the green component. To avoid that the images were delineated into RGB formats in order to analyze them individually.

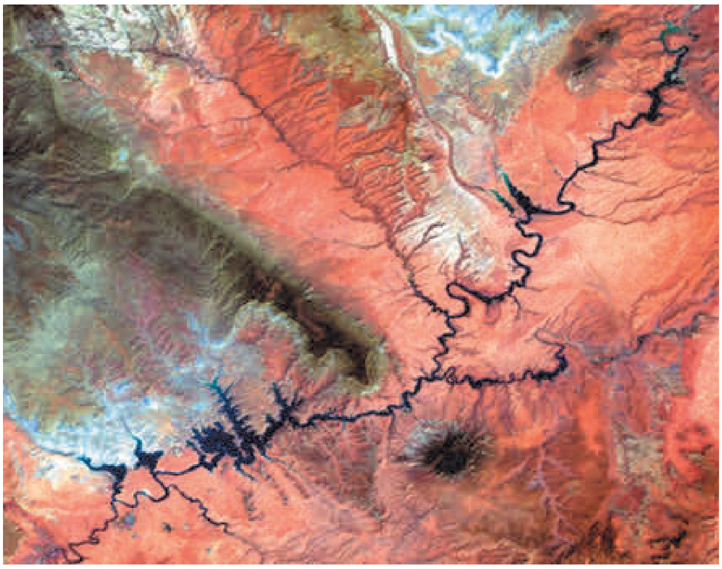


Fig. 3 Lake powell in 2018

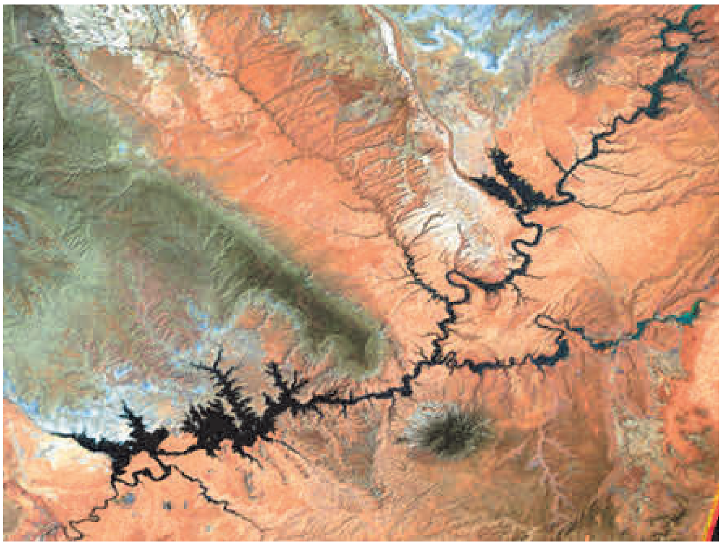


Fig. 4 Lake powell in 1984

6 Prewitt Method

Sometimes it happens that the lakes or other water bodies can't be extracted with great accuracy whereas the coastal boundaries segmentation as discussed in the paper [10] can be achieved using spatial attraction algorithm. This might be due to the noise present in the image or the blurriness in the image itself. That's why various edge detection algorithms were used to differentiate the edge of the lakes and the other uneven parts of the images but the Prewiit edge detection method gave the best output. The above mentioned operator is a discrete differentiation operator which computes the approximated values of the image gradient and its features. It is somewhat similar to Sobel operator. It has two 3×3 kernels. Mathematically, it uses the convolution of the original image with two 3×3 kernels to get the approximate values of the derivate, namely for the horizontal and the vertical changes. The 'A' being the original image, then Gx and Gy are considered to be the two images where the vertical and horizontal approximate derivatives are stored at each point. Upon convolving the resulting gradient is given by

$$G = \sqrt{(Gx * Gx) + (Gy * Gy)}$$

And the direction of the gradient is given by

$$\theta = a \tan 2(Gx, Gy)$$

7 Difference in the Images

Lastly two differences were taken for comparing the changes in the surface area. of the Lakes which happened over time. The differences are as follows:

- Difference in the original images (Lake Powell in 1984 and Lake Powell in 2018) to see the changes in the overall image.
- Difference in the images obtained after edge detection (rivers abstracted).

The average color of the zones and the brightness were used to compare two pictures for likeness. The basic approach for the same was as follows:

- Check dimensions. If different, then images are not the same.
- Check formats. If same, then perform precise comparison, pixel by pixel.
- If different formats do this: Compare Brightness as half the weight and compare color/hue as the other half. Calculate the difference in values and depending on'tolerance' value they are the same or they are not.

8 Results

8.1 Great Salt Lake

After calculating the differences in the original images and the images obtained after Prewitt detection were analyzed, the changes in the surface area was calculated over the years. The results were as follows:

- Change in the surface area from 1987 to 1999: –18.06%
- Change in the surface area from 1999 to 2011: –13.34%
- Change in the surface area from 2011 to 2016: –20.74%
- Change in the surface area from 2016 to 2018: –10.05%

The overall change observed from 1987 to 2018 was –53.07% (Figs. 5 and 6).

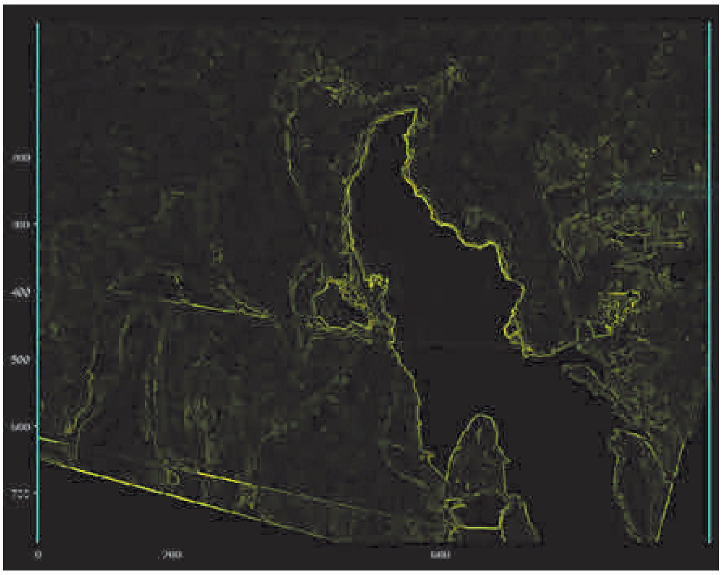


Fig. 5 Differences in the images after prewitt detection

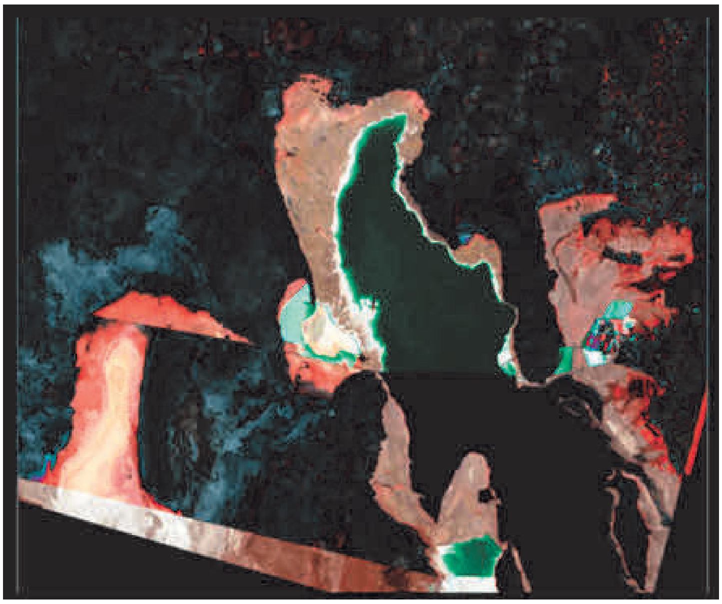


Fig. 6 Differences in the original images of 1987 and 2018

9 Lake Powell

After calculating the differences in the same way as described above, the results were as follows:

- Change in the surface area from 1984 to 1993: –12.47%
- Change in the surface area from 1993 to 1998: –26.36%
- Change in the surface area from 1998 to 2018: –35.65%

The overall change observed from 1984 to 2018 was –54.76% (Figs. 7 and 8).

According to an article by Denver Post [11] and Science Mag [12], the actual water level loss of Lake Powell was 52% and that of Great Salt Lake was 50%

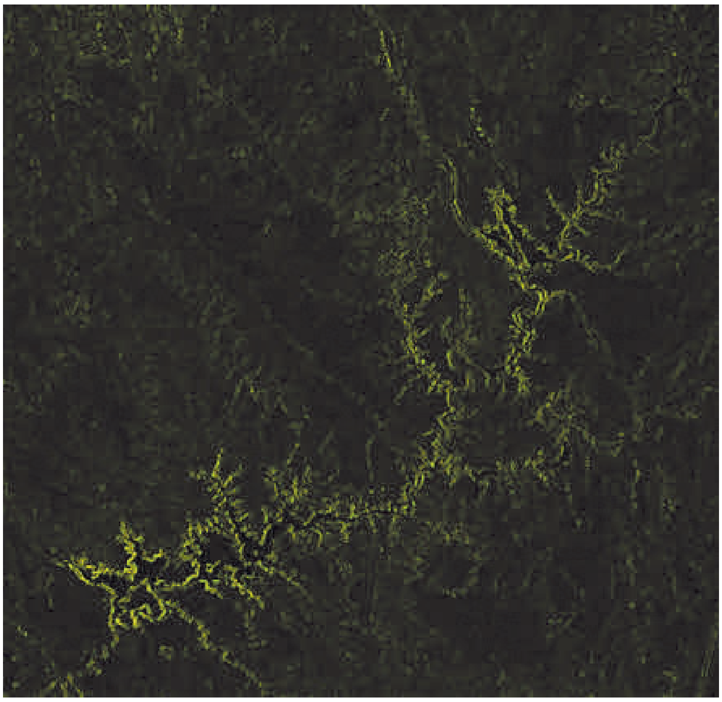


Fig. 7 Differences in the images after prewitt detection

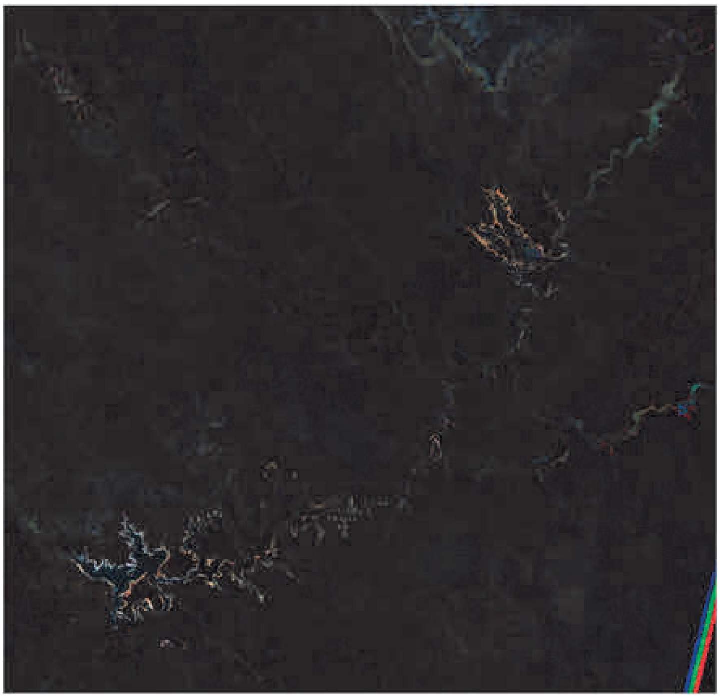


Fig. 8 Differences in the original images of 1984 and 2018

whereas our study showed it to be 54.76% and 53.07% respectively. The accuracy of our proposed framework was 94.69%. and 93.86% (Figs. 9 and 10).

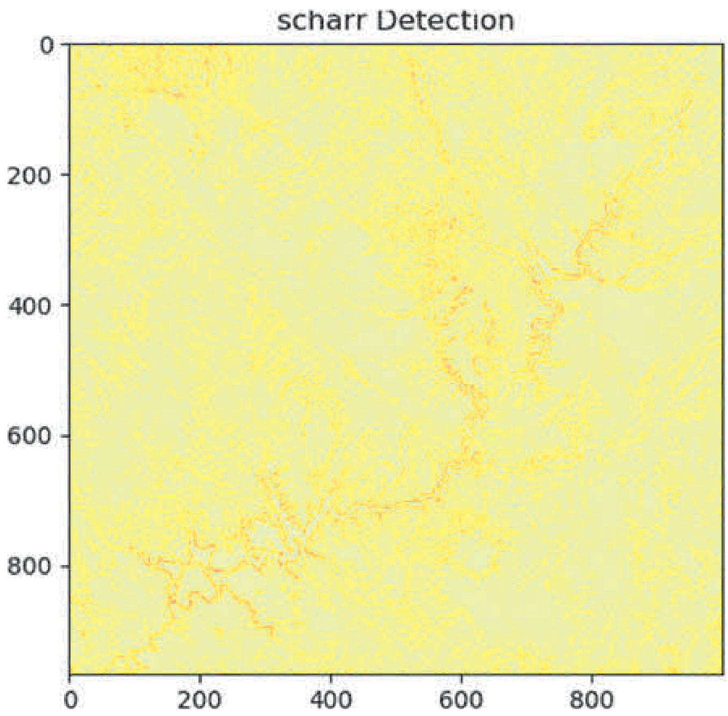


Fig. 9 Scharr detection

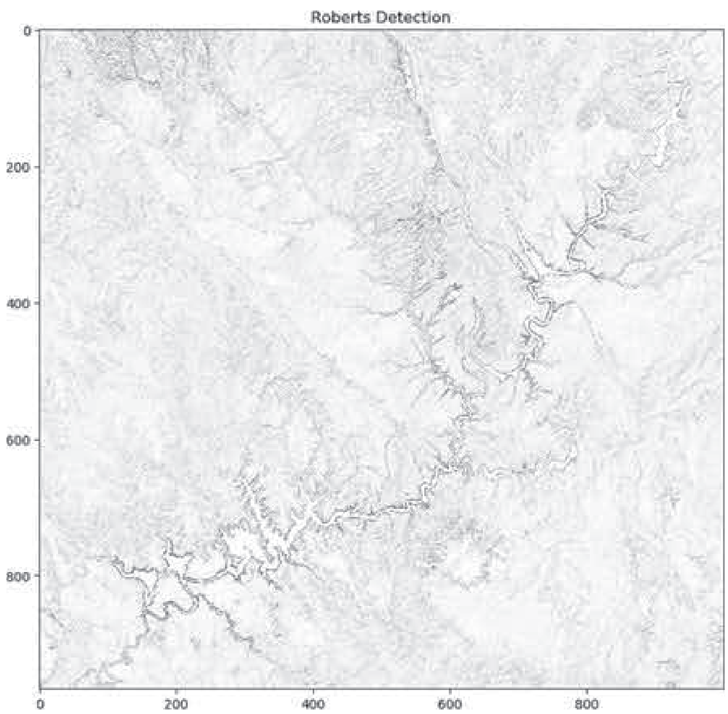


Fig. 10 Roberts detection

The decision to choose a particular edge detection technique played a vital role here. Comparisons of various edge detection techniques based on their outputs can be observed here (Figs. 11 and 12).

Fig. 11 Prewitt detection

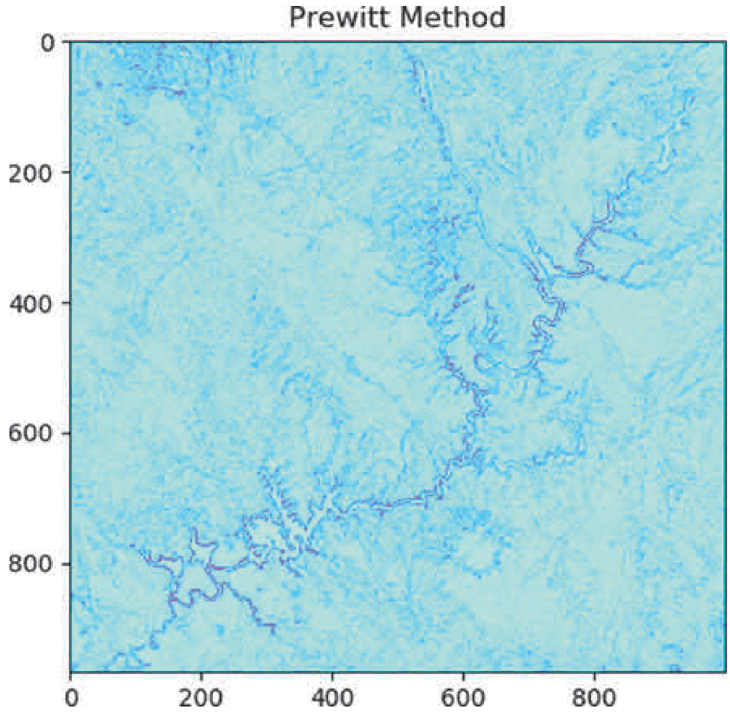
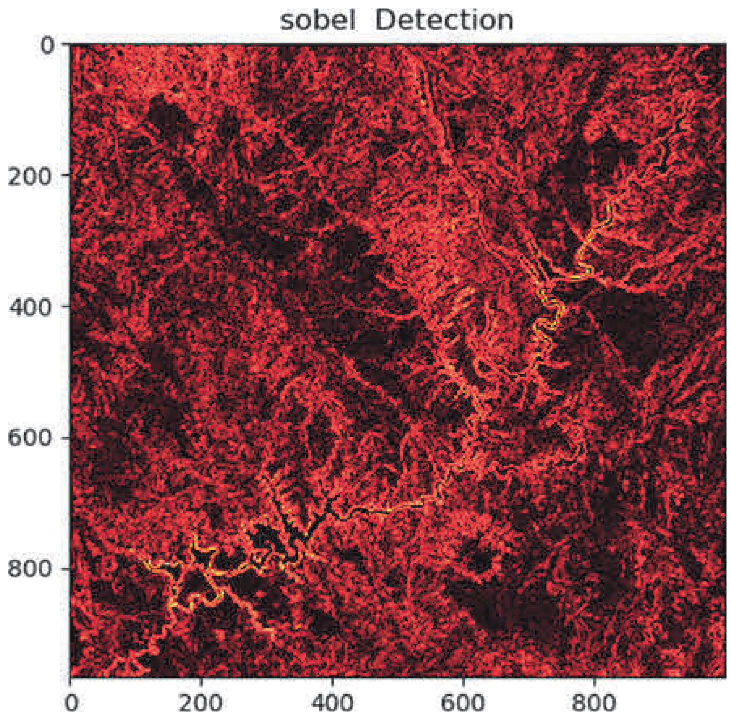


Fig. 12 Sobel detection



10 Summary and Discussion

Extracting water bodies from satellite images is a challenging task and has a few problems due to (1) merged water pixels, (2) scene dependent threshold levels, (3) background noise. Landsat imaging and water quality monitoring are of vital importance as it gives particular data about the quality and nature of the water bodies. In the current work we are thus able to detect the changes in surface water from images corresponding to different epochs.

As shown in the study, Lake Powell and Great Salt Lake lost more than half of this surface area in the period 1984–2018 and 1987–2018 respectively. If it continues in the same way, it is very likely that the lakes will lose all their surface area in the near future. This is very critical because the lakes provide many benefits for the society and the people living in their surroundings. Therefore, immediate and befitting measures should be taken by authorities to mitigate further decline of these lakes surface area and to restore the lakes to their original conditions. It is very clear that the construction of dams on the rivers flowing to the lakes, tremendous ground water usage, divergence of water sources to agricultural, industrial and domestic uses, and subsequent drought have all reduced the surface area of these lakes. Further, changes in watershed due to changes in rainfall and agricultural land use should also be investigated over the period of time.

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