

THE APPLICATION OF AN ATMOSPHERIC CORRECTION AND CHLOROPHYLL ALGORITHM ON A TM IMAGE OF CENTRAL LAKE TANGANYIKA : TECHNIQUES AND OBSERVATIONS

P. I. VANOUPLINES

INTERUNIVERSITY POST-GRADUATE PROGRAMME IN HYDROLOGY,
FREE UNIVERSITY BRUSSELS, BELGIUM.

FORMERLY : ROYAL MUSEUM FOR CENTRAL AFRICA (KMMA/MRAC),
TERVUREN, BELGIUM.

ABSTRACT

Firstly, some general ideas on remote sensing of water are presented. These strict rules are the basis of the processing techniques being applied in this paper. After destriping, an atmospheric correction is performed in order to obtain radiances as they would have been measured at ground level. These radiances allow estimates of the chlorophyll concentration in surface waters. The application of the proposed processing techniques on an image of Central Lake Tanganyika shows chlorophyll strips. The possible origin of these strips is discussed. A short geological investigation shows a relationship with heat sources at the bottom of the lake.

INTRODUCTION

The study of water surfaces with the help of satellite images is very promising. Much research has been done with the Coastal Zone Colour Scanner (CZCS) on board of the Nimbus-7. This sensor has many advantages, such as an interesting choice of the spectral bands, and a high frequency of image registration. An important disadvantage is its ground resolution of 825 m. Landsat Thematic Mapper might have a worse choice of the spectral bands for water quality investigations, and a frequency of image registration of only 16 days, but its ground resolution is only 30 m. This capability must be explored. Some interesting results are obtained even before complete calibration of the chlorophyll algorithm.

1 SOME GENERAL IDEAS ON REMOTE SENSING OF WATER

Remote sensing images covering water are special in two ways. Firstly, these images show a small dynamic range in all spectral bands. Secondly, they are extremely sensitive to all kinds of external influences, due to the low reflectance in all spectral bands. These external influences are sensor deficiencies and atmospheric interference. The sensor deficiencies are responsible for the striping, always being more prominent over water surfaces, and an effect that could be called inertia of the sensor : near a coast line slightly higher digital values are observed when the scanning goes from the land surface towards the water surface. It is as if the sensor somehow retains some of its higher saturation recorded over the land when it scans the first water pixels. The atmospheric interference is severe and variable in time and space. This means that images cannot be compared with each other, because firstly, the atmospheric conditions may be different for two adjacent images, and, secondly, two images of the same area, but recorded at different days may show completely different atmospheric influences.

The image processing technique discussed in this paper accounts for both striping and atmospheric influences. The effect of sensor inertia

disappeared by the clustering of four by four pixels. This clustering increases moreover the signal/noise ratio by a factor four.

Image processing techniques must be chosen with extreme care. The target is to obtain radiances as they would have been measured at ground level. Complicated techniques are dangerous because the user can easily apply them on a computer, but loses track of what really happens with the image. The result is an unreliable and thus invaluable image (although it might be a beautiful picture).

2 IMAGE PROCESSING TECHNIQUE

2.1 Preprocessing

A Landsat TM subscene of 2048 by 2048 pixels was selected. The preprocessing consists of two main steps. The first step is the application of a destriping algorithm. A very simple algorithm can be used, since the dynamic range is small over the image representing a part of Lake Tanganyika (Tanzania). Land as well as some smoke plumes from local bush fires occur in the right part of the image. The left half of the image (1024 by 2048 pixels) is used for calibration. A mean radiance value is calculated for the left side. Then a mean radiance is calculated for the 1024 first pixels of each scan line. The difference between these two means is subtracted from each of the 2048 pixels of the scan line under consideration (see Fig. 1 and 2).

Four by four pixels are clustered in order to reduce the rather high signal/noise ratio of Landsat TM. This is done by taking the average value of the sixteen pixels, thus reducing to a 512 by 512 image. Each pixel represents a surface of 120 by 120 m. The preprocessing is executed on an IBM mainframe. Next, the image is transferred to the image processing system (see Fig. 3).

2.2 Atmospheric correction

The atmospheric correction being used is described in VANOUPLINES (1986,1988). Here, the algorithm and its application are only reviewed without focusing the mathematical background. The technique allows correction of the first four spectral bands of Landsat TM (in the visual and near infra-red part of the spectrum).

The most important feature of the correction is the use of the meteorological range (or horizontal visibility). STURM (1981) used the same approach, but for the CZCS on board of Nimbus-7. The meteorological range allows to compute the aerosol optical thickness, without extra field measurements when the image is being recorded. The variable is regularly measured at airports and meteorological observatories. This means that the algorithm can be applied for most images.

The final form of the correction is a linear relationship between the radiance received by the sensor and the radiation at ground level. This allows applications on almost any image processing system because a program

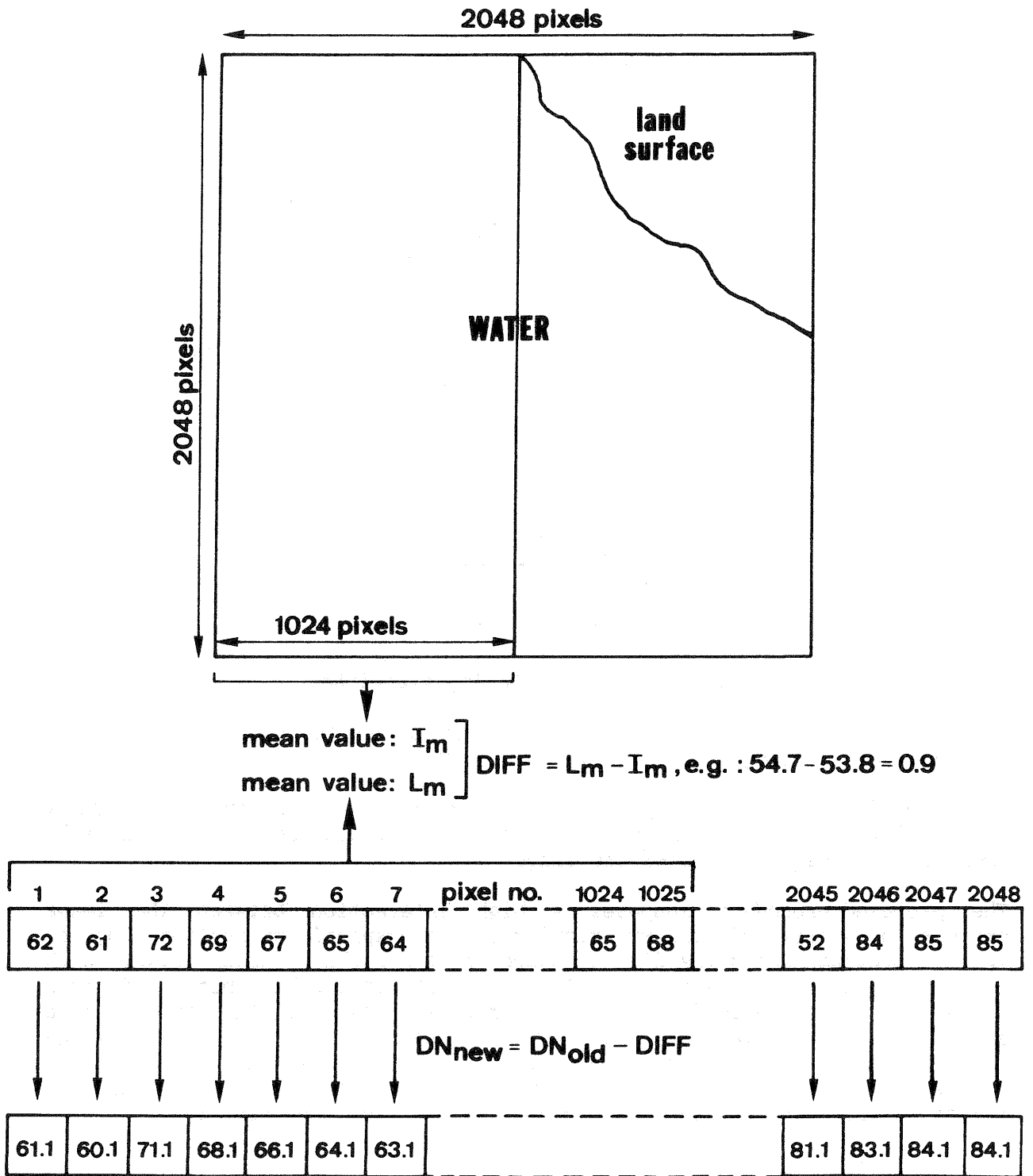


Figure 1. The destriping algorithm

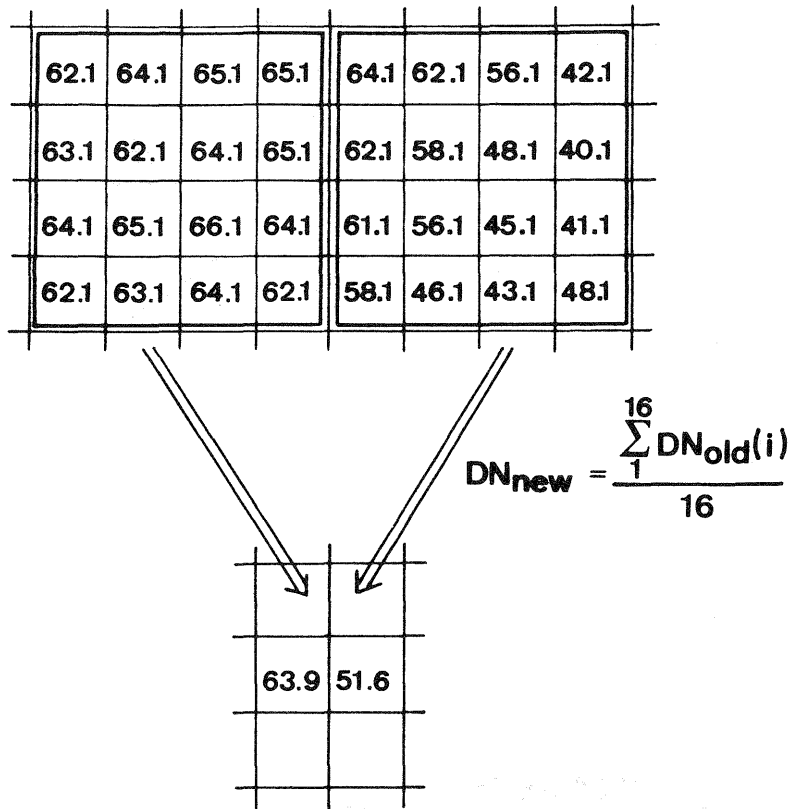


Figure 2. The clustering algorithm

on a PC can compute the corresponding parameters for a linear stretch on the basis of the image characteristics (see Fig. 3).

It is evident that this approach is only valid for sensors with a small field of view, such as Landsat TM, since optical thicknesses will gradually increase towards the edges of the image.

The proposed procedure supposes a high interaction between the image processing system and the PC running the atmospheric correction program. The PC program needs the digital number of the darkest (water) pixel in TM spectral band 4, since the GORDON (1978) assumption has been used. This value can be retrieved from the image processing system. Other inputs, such as the date of image registration, geographical latitude of the image centre, meteorological range and solar zenith angle, may as well be retrieved by using an image processing system able to decode the header and tailer files, or being supplied directly by the user (see Fig. 3).

2.3 Postprocessing

It can be supposed now to have a radiation for each pixel (of 120 by 120 m), having a value very close to what would be measured at ground level. A subjective test was elaborated. A colour composite was produced with the first three corrected spectral bands. Spectral band 1 was represented in blue, band 2 in green, and band 3 in red. The colours appearing on the screen were very realistic : blue water, yellowish savannah, green-brownish bushes and red-brownish naked soils. This result could never be obtained with uncorrected spectral bands : if the water was blue, then the colours

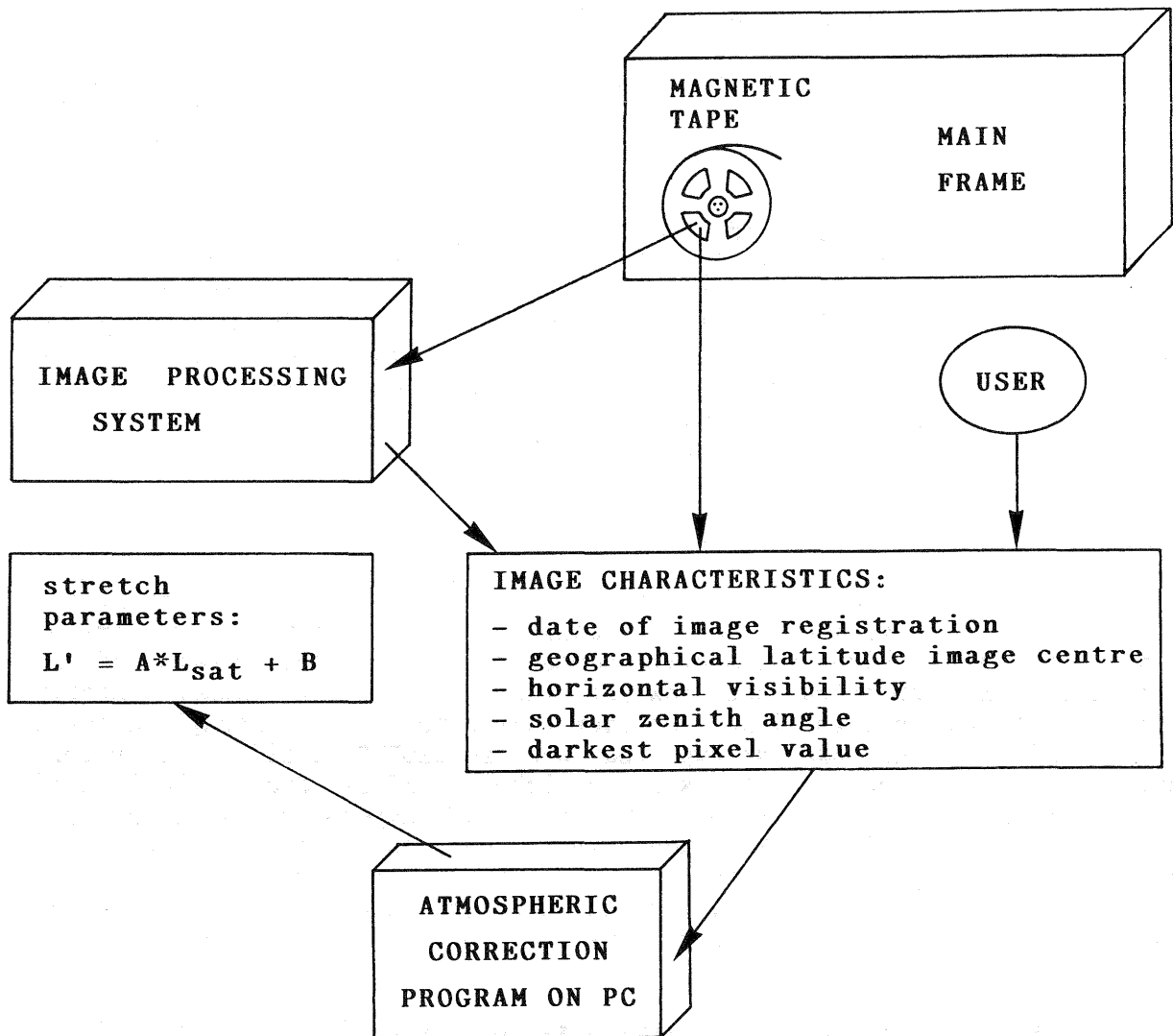


Figure 3. The procedure for the atmospheric correction

of the land surface were unsatisfactory; and when the land surface colours became acceptable, the water remained black. There is evidence that only this combined radiometric - atmospheric image processing technique provides true colour composites.

After this intermediate result the research was focused back on the real target : retrieval of water quality. In contrast with CZCS applications it is possible to obtain water quality estimates of chlorophyll and sediment concentrations with a high ground resolution. It was established in VANOUPLINES (1986) that comparable radiometric results could be obtained for Landsat TM with a ground resolution of 120 m. This is an advantage over the CZCS ground resolution of 825 m.

Many chlorophyll retrieval algorithms have the form :

$$C = a(L_1/L_2)^b$$

where C is the chlorophyll concentration, L_1 and L_2 are the radiances in two spectral bands (here respectively TM1 and TM2), a and b are two

calibration coefficients. These coefficients need calibration, depending on the sensor characteristics. Since this calibration is not yet executed, it was decided to accept the quiet reasonable estimate of $b = -2$. The value of a is not critical under these assumptions because this value will be modified by the linear stretch parameters, used to produce a readable, uncalibrated colour image.

A final smoothing was applied. This smoothing does not influence the interpretation of the image, it only served to improve the general outlook of the image. However, it must be stressed that the expressions 'low', 'medium' and 'high' chlorophyll concentration in Fig. 4 do not imply any linear relation. It is possible that e.g. the 'high' concentration is 100 times bigger than the 'medium' concentration, and that the 'medium' concentration only 3 times bigger is than the 'low' concentration. This is due to the uncalibrated power coefficient b , not being known at this moment.

3 RESULTS

The processing techniques are applied on a Landsat TM image covering the central part of Lake Tanganyika. An unusual image appeared. There are no smooth zones with high chlorophyll concentrations at the borders of the lake and lower concentrations towards the middle, but rather sharply defined strips across the lake. The fact that almost no chlorophyll appears in the middle of the lake was expected, because DEGENS et al. (1971) report very low nutrient concentrations at the lake's surface, due to the lack of upward flows and mixing in general. The dissolved oxygen on the other hand, is near saturation level. This means that, under the excellent temperature conditions, an explosive algae growth may be expected with the slightest nutrient input. Such an input is present near the border of the lake, where indeed high chlorophyll concentrations are indicated by the processed TM image.

A simple explanation for the observed strips is difficult to find. It is amazing that the strips form more or less the prolongation of two major geological faults, present on the land surface. Two rivers are situated along these rivers. They normally do not carry water in September, when the image was recorded. Spectral analysis of the image does not confirm the presence of any water: the reflectances are too high in all spectral bands (except in the thermal band 6) along the river beds.

The strips seem to find their origin in geology. DEGENS et al. (1971) presented some disperse heat flow flux measurements. A slightly higher heat flux was observed near one of the strips (see Fig. 4). A heat source at the bottom of the lake might be responsible for a steady upward current, carrying nutrients from the sediment rich bottom towards the surface.

If this is a valid hypothesis, then these image processing techniques may be a valuable tool for the geologist, looking for the continuation of recently active faults over the bottom of deep lakes without horizontal currents. Further research on other images of Lake Tanganyika is scheduled. This research must bring more clarity in the processes playing a part in the formation of the chlorophyll strips, because DEGENS et al. (1971) reported heat fluxes up to three times as high as the ones on this image. These high fluxes are moreover in the neighbourhood of the prolongation of geological faults over the bottom of the lake.

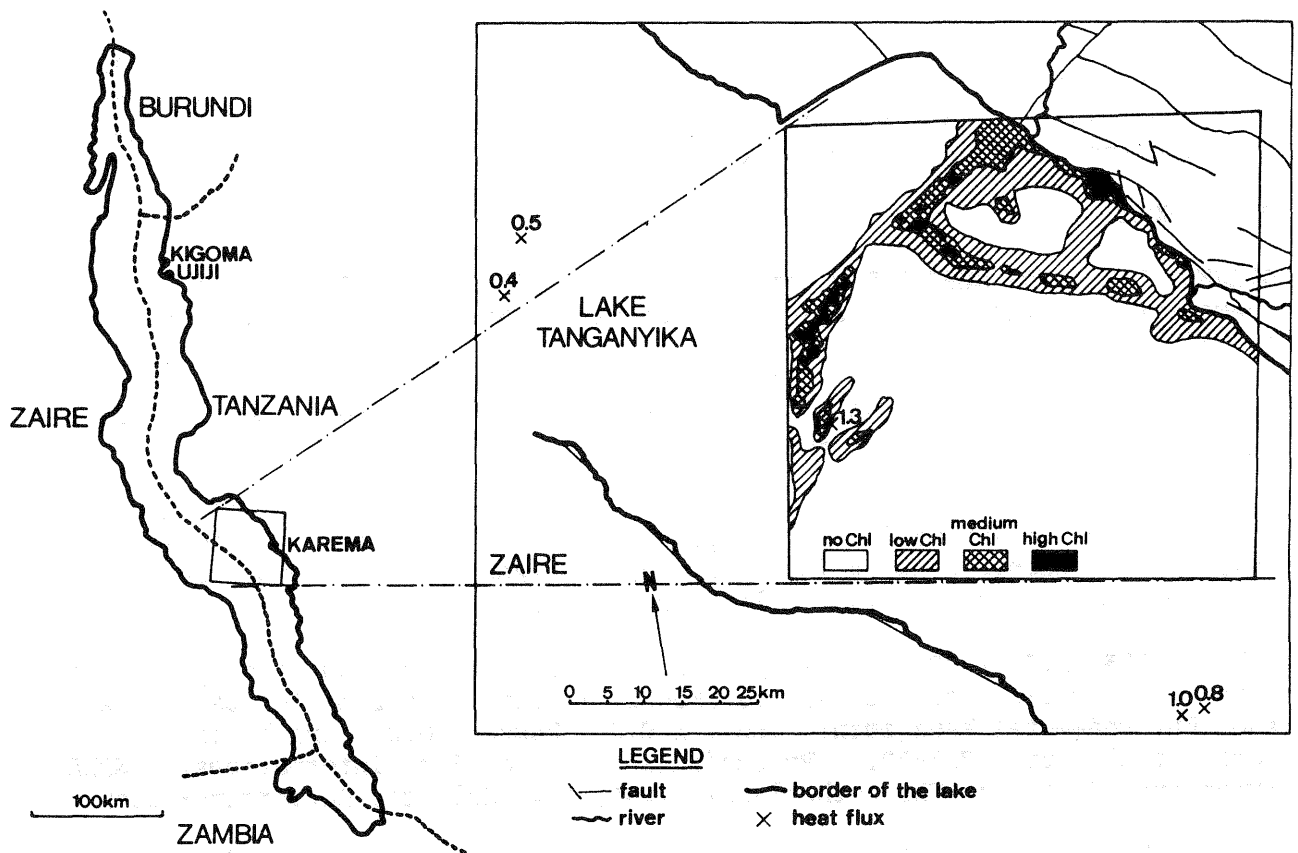


Figure 4. Localization of the processed image and schematic representation of the results (data and faults : geological map of Tanzania and fieldwork; heat flux data : DEGENS et al., 1971).

CONCLUSION

The proposed processing techniques, providing the possibility of using Landsat Thematic Mapper's high ground resolution, proved to be valuable for the retrieval of chlorophyll concentrations in surface waters. Further investigation on Lake Tanganyika is required to prove the hypothesis that vertical currents exist in this lake. The calibration of the chlorophyll algorithm will lead to an interesting tool for the water quality specialist who wants to retrieve chlorophyll concentrations in small water bodies, such as rivers, water reservoirs and lakes.

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