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LANDSAT DIGITAL DATA FOR WATER POLLUTION AND WATER QUALITY STUDIES IN SOUTHERN SCANDINAVIA

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ABSTRACT

Spectral diagrams,illustrating the spectral characteristics of different water types,were constructed by means of simple statistical analysis of the various reflectance properties of water areas in southern Scandinavia as registered by LANDSAT-1.There were indications that water whose spectral reproduction is dominated by chlorophyllous matter (phytoplankton) can be distinguished from water dominated by non-chlorophyllous matter.Differences between lakes,as well as the patchiness of individual lakes,concerning secchi disc transparency could be visualized after classification and reproduction in black and white and in color by means of Line Printer, Calcomp Plotter (CRT) and Ink Jet Plotter respectively.

1.INTRODUCTION

Water quality studies were carried out by densitometer analysis of LANDSAT diapositives within different wave length bands at the Remote Sensing Section, Department of Physical Geography,University of Lund in 1974 (Helldén 1975). Thereby it proved possible to trace pollution plumes in the Öresund off Copenhagenhagen and to obtain relative measures of the concentration distribution and circulation in the polluted water under different conditions.The results obtained also clearly indicated that there is probably a relation between the grey-tones of lakes within different spectral bands in LANDSAT imagery and secchi disc transparency of the same lakes.It was considered valuable for the continued work in this field to test the information bulk in LANDSAT CCT for the appraisal of water qualities by automatic data processing.Parts of Scania and the Öresund were chosen as test areas.The data used for the investigation were registered by LANDSAT-1 on Aug. 8, 1973 (1400-09410).

2.ERRORS AND THEORY

According to spectral investigations presented by Fitzgerald (1972) water pollutions and inorganic suspensions are characterized by a reflectance maximum in 0.6-0.7 microns (MSS 5) and then the reflectance falls rapidly with increasing wave length,while the spectral characteristics of phytoplankton are more complex. Generally speaking chlophyll in water in the form of plankton absorbs effectively within the band 0.4-0.5 microns while reflectance is most intensive in the band 0.5-0.6 microns (MSS 4) with a secundary minimum in 0.6-0.7 microns (MSS 5) and a secundary maximum in 0.7-0.8 microns (MSS 6). The pre-requisite for a secondary maximum in MSS 6 is that the chlorophyll concentration reaches a lowest critical value in the water layers closest to the surface since the electromagnetic radiation in the near IR is almost entirely absorbed by the water molecules in the uppermost centimeters of the water body.

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The radiation that is recorded by the satellite borne sensor system cannot be related to the radiation properties of the water exclusively,but the spectral properties of the atmosphere must also be taken into consideration.According to Farrow (1975) about 9%,on an average,of the radiation that reaches the atmosphere from the sun is back-scattered into space on a cloudless day. Of course,great deviations from this value may occur due to variations in solstice and composition of the atmosphere.Provided that 75% of the radiation emitted from the sun reaches a water mass on a cloudless day and that the water re-radiates 10% of the radiation,i.e. 7.5%,via the atmosphere into space,it is evident that the atmospheric radiation into space is of great importance since it makes up more than half of the radiation registered by the satellite.The atmospheric scattering,which is partially dependent on wave length (Rayleigh scattering) is most intensive in short wave lengths and, then, gradually decreases with increasing wave length.Thus,the atmospheric noise is strongest in MSS 4 where it can sometimes reach values that are equivalent to the re-radiation of the water,while it may be considered neglible in the near IR bands (MSS 6 - MSS 7)(Farrow 1975, NASA 1974).

In the present investigation no attempt has been made to quantify the effect of the atmosphere or solstice on the radiation recorded by LANDSAT-1 since the study is based on analyses of one LANDSAT scene only.When studying water quality, using LANDSAT data,over long periods and at registrations from different times during the year, these factors should be taken into consideration.

3.DATA AND METHODS

3.1.DIGITAL PROCESSING OF MULTISPECTRAL DATA

Basic research regarding digital processing of pictorial information has been carried out at the National Defence Research Institute (FOA) since the 1960s and in 1973 this activety was extended to comprise multispectral data.

The computer processing has been carried out at the Stockholm Computer Center, using an IBM 360/75 and also using a PDP-11/40 at FOA. As a necessary complement to the image processing the FOA computer has special equipment for input and output of image data, for example three-colour TV, ink jet plotter and instruments for converting a transparent film to a digital image or,vice versa.

FOA have several routines for the conversion of data.These routines are all part of the process to convert data of different original types and from different storage medium to a form which can be used as a standard routine.

An important part of the digital processing also consists of manipulations of separate spectral bands,e.g. when transforming digital data in order to improve the image.Amongst other things it is interesting to investigate the amount of picture elements with a certain digital value and to present them in the form of histograms or to present pixel by pixel of the digital values registered.Other manipulations which may be used are,for example,writing only one or a few selected digital levels with one of the image recorder units available, including line printer,colour coding of the digital levels in a spectral band or, in advanced processing to use Fourier transformation technique for the analysis of any regular geometric forms in the image.Routines for all this manipulations, and others,are implemented,or can be included as intergrated parts of the program system for the processing of multispectral digital data at FOA,even if its main purpose is simultaneous processing of several'image layers'.True multispectral processing must also be based on knowledge of the statistical characteristics of image data.In this case routines are required for the calculations of,for example,mean values,variances,co-variances and correlations,generation of scattering diagrams etc..Where generation of images is concerned,colour images can,naturally, be created where separate spectral bands can be given separate colours and also composite images in the form of the difference or the quota or more complicated mathematical relations between the pixels which correspond to the same ground point.Special forms of statistical pre-processing are required for automatic classification,i.e. the determination of which "class" the pixel belongs to according to rules known in advance and in relation to known type objects or in relation to groupings of similar pixels which are determined during the course of the calculation.These processing routines are also implemented in the program system in question.A detailed examination of the available processing routines are beyond the scope of this report. Please refer to separate reports for the description of this program system and its application (Gustafsson and Åkersten 1976, Orhaug and Åkersten 1976 a, b, Orhaug et al. 1976).

3.2.METHODS OF EVALUATION

After the selection of subscenes and the definition of extensions by determination of corner co-ordinates (line number and pixel),the statistical grey-tone distribution for the spectral bands MSS 4 - MSS 7 could be presented in the form of histograms and symbol coded plots.The distribution of pixels over digital grey-tone levels (DGL) for different types of water was automatically evaluated and represented in diagrams.Mean values and standard deviations were calculated at the same time. The latter formed the basis of the construction of spectral diagrams for the study of spectral characteristics of different water qualities.

In order to visualize differences in water quality grey-tone maps (line printer plots), Calcomp Plots (CRT) and color plots (Ink Jet Plotter) were produced. Using the line printer for production of grey-tone plots up to nine different grey-tones can be reproduced simultaneously,while up to 15 grey-tone levels can be reproduced at the same time in a calcomp plot. The ink jet plotter has the capability of producing color images directly on ordinary paper.By forcing ink under high pressure through a fine nozzle,small drops of ink are produced. A suitable voltage charges the drops which can be modulated by a control electrode. With three ink systems having different colours (magenta,yellow and cyan) color images can be produced. The one available at FOA can be fed directly from the computer or from a tape drive.It plots six pixels per millimeter in the colors mentioned independently modulateable to 15 intensity levels.Current output format allows a 1024 x 1536 pixels image to be plotted on a drum in about 90 seconds.

4.RESULTS

4.1.THE COPENHAGEN AREA

Today most of Copenhagen's waste water is discharged unpurified by two pump stations into the Eastern part of Kongedybet at a depth of 6-10 m. The pump station situated in the North discharges about 14 mill. m^3 waste water per annum,while the corresponding quantity for the pump station in the South is about 40 mill. m^3/year (Dackman et al.1971).Besides the sewers mentioned two day-water sewers start from Strandvaenget,which,on Aug.27,1973,served as sources of the waste plume furthest to the North registered by LANDSAT-1 (Helldén 1975). The extension of the plumes and presumed concentration distribution are shown in Fig. 1. The iso-lines,which are supposed to be a relative measure of the particle concentration of the discharge plumes,were drawn with the help of a symbol coded line printer plot in MSS 5.The grey-tone distribution in the water areas near the coast on all plots reflects not only the varying particle concentration of the water but probably also the varying depth of water (Fig. 2-3).

4.2.LAKES RINGSJÖARNA

As investigation area and subscene number two the lakes Östra Ringsjön,Västra Ringsjön and Sätoftasjön were chosen.

The differences in water quality between and within the three lakes were visualized by production of plots of the above mentioned types (Fig. 5-6).The plots can also be said to illustrate the extent to which a measurement of the secchi disc transparency carried out in situ in any one of the lakes is representative of the lake in question.In other words,the applied methodology may be useful for obtaining an idea of the patchiness of lakes regarding their secchi disc transparency.The great variations in reflectance in the different bands,within and between the registered lakes,can probably be referred to algae blooming.The light strakes,which are most distinct in Lake Östra Ringsjön in MSS 6 and MSS 7, are interpreted as accumulations of blue-green algae in the most superficial water layers.

4.3.THE LAKES NW YSTAD

As investigation area and subscene number three the Lakes Krageholmssjön, Ellestadsjön,Snogeholmssjön and Sövdesjön were chosen.The spectral description and varying water quality of the lakes are dealt with under the following heading.

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4.4.COMPARATIVE SPECTRAL ANALYSES

Spectral diagrams were constructed for the respective investigation areas in order to carry out comparative studies of the spectral characteristics of different water qualities (Fig. 7-8).

4.4.1.THE COPENHAGEN AREA

The spectral functions of the water masses outside Copenhagen are characterized by having the highest DGL values in MSS 4 falling with a relatively steep gradient to MSS 5.In MSS 5 the gradient becomes more gentle and assumes a permanent value between MSS 5 and MSS 7. The position of the functions in the y-direction is supposed to provide a measure of the transparency of the water and consequently the digital grey-tone levels,especially in MSS 5,are supposed to give a relative measure of the particle concentration in the water.High values of DGL correspond to high particle concentrations.The spectral functions concerning the standard deviations of the waste plumes, on the whole display the same characteristics as corresponding functions for DGL mean values.The mutual positions of the functions are supposed to reflect the varying homogenity (patchiness) of the different water masses regarding transparency and particle concentration.

4.4.2.LAKES RINGSJÖARNA

All the functions are characterized by assuming the highest DGL values in MSS 4 from where they fall to MSS 5 in relatively steep gradients.However,between MSS 5 and MSS 6 the gradients decrease and in one case even changes sign,but between MSS 6 and MSS 7 they resume values that are equivalent to the course of functions between MSS 4 and MSS 5.An embryo of a secondary maximum is thus seen in MSS 6 concerning A,B and C, a secondary maximum which is a reality for the function D; the latter reflects spectral characteristics of an accumulation of superficial plankton (algae) in Lake Östra Ringsjön.The above mentioned embryo or occurrence of a secondary maximum in DGL in MSS 6 is supposed to characterize chlorophyllous water.The appearance and mutual position of the functions are thereby thought to give information about varying algae concentrations and transparencies between the lakes.

The spectral functions concerning standard deviations are characterized by a minimum in MSS 5 and a maximum in MSS 6. The mentioned max. and min. are probably characterizing chlorophyllous and,where phytoplankton distribution is concerned,heterogenous waters.The mutual positions of the functions reflect the varying homogenity,patchiness, of the waters concerning transparency and algae concentration.All the functions diverge noticeably from the spectral functions of the Copenhagen area.

4.4.3.THE LAKES NW YSTAD

As in the case of the spectral functions of Lakes Ringsjöarna,the characteristics of the lakes (A),(B),(C) and(D)are supposed to be a result of the presence of chlorofyll (phytoplankton) in the water bodies. However, the presence of chlorphyll in (B) seems to be almost zero. The presence of chlorophyll gives rise to increased reflectance values in MSS 6.Matter not containing chlorophyll in water does not give rise to such an increase (Cf the spectral diagrams of the Copenhagen area).The appearance and mutual positions of the functions are supposed to reflect varying algae concentrations and secchi disc transparencies between the four lakes.

The spectral functions regarding standard deviations are,as in the case of Lakes Ringsjöarna,characterized by a minimum in MSS 5 and a maximum in MSS 6. The min. and max. mentioned are supposed to characterize chlorophyllous and, regarding phytoplankton distribution,heterogenous waters.

5.CONCLUSIONS

The secchi disc transparency of the above-mentioned lakes was measured in situ between Aug. 8 and Aug. 27,1973 by means of a secchi disc.The registrations were carried out by the County Administration of Malmöhus (Nilsson 1974).Since the variations in secchi disc transparency in six of the seven lakes only amounted to 35 cm and there is little investigation material,it was not considered appropriate to present any correlations between in situ measurment and DGL.The reliability of the secchi disc transparency values can also be questioned as the measurements were taken in only one place in each lake,part of which were apparently very heterogenous concerning particle concentration and secchi disc transparency.Consequently it is uncertain to what extent the registrations carried out in situ were representative of the respective lakes.

In spite of the small variations in secchi disc transparency between the lakes in question,it is evident from the results obtained that very small differences in water quality can be detected by analysis of LANDSAT digital data. The results also suggest possibilities of distinguishing chlorophyllous water from water whose secchi disc transparency is above all dependent on suspensions of nonchlorophyllous matter.In addition,certain conclusions can be drawn about quality conditions at different depths of water at the same time as a measure of the patchiness of different water masses can be obtained regarding transparency and particle concentration.

In order to determine the statistical relations between different types of spectral functions and water qualities the collection of ground truth data from about 200 lakes for comparision with satellite data is in progress.For further investigations laboratory analyses by spectrometer are probably necessary in order to determine how the spectral properties of water vary with different algae species and with different concentrations and to what extent minerogenic suspensions can affect the results.

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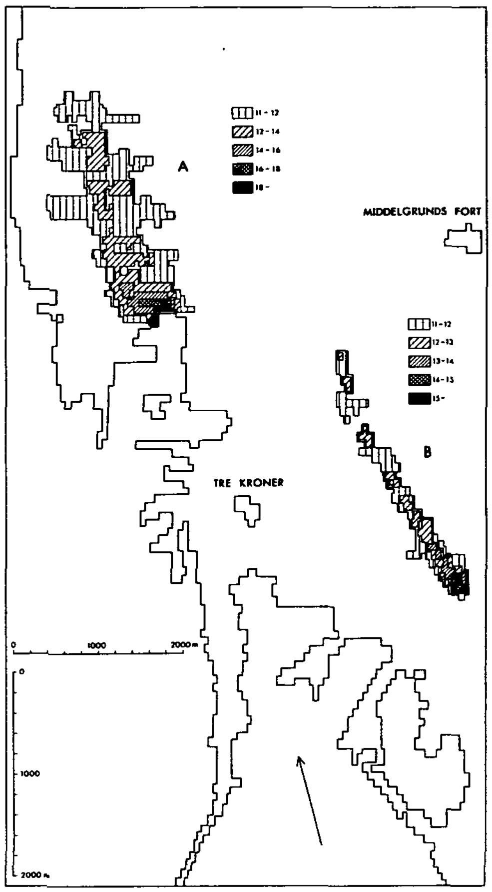

FIG.1. COPENHAGEN WASTE PLUMES.The extension and presumed concentration distribution of the Copenhagen pollution plumes according to analyses of LANDSAT CCT(27/8-73).The iso-lines were drawn with the help of a symbol-coded line printer plot in MSS 5.A=278,B=96 pixels.

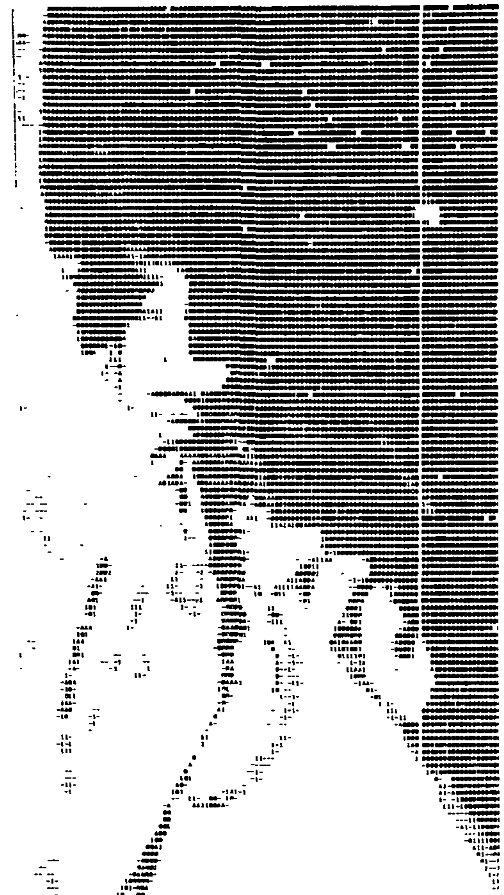

FIG.2. COPENHAGEN WASTE PLUMES. Grey-tone plot (line printer) covering the Copenhagen area (MSS 5, 27/8-73).

FIG.3. COPENHAGEN WASTE PLUMES. Calcomp plot in MSS 4 - MSS 7.

FIG.4. COPENHAGEN WASTE PLUMES.The extension and relative concentration distribution of the Copenhagen pollution plumes generated by Ink Jet Plotter (MSS 5 and MSS 7,27/8-73).Green= land.The image is filtered for the LANDSAT line scanner noise.

MSS 6

FIG.6. LAKES RINGSJÖARNA. Calcomp plot in MSS 4 and MSS 6.

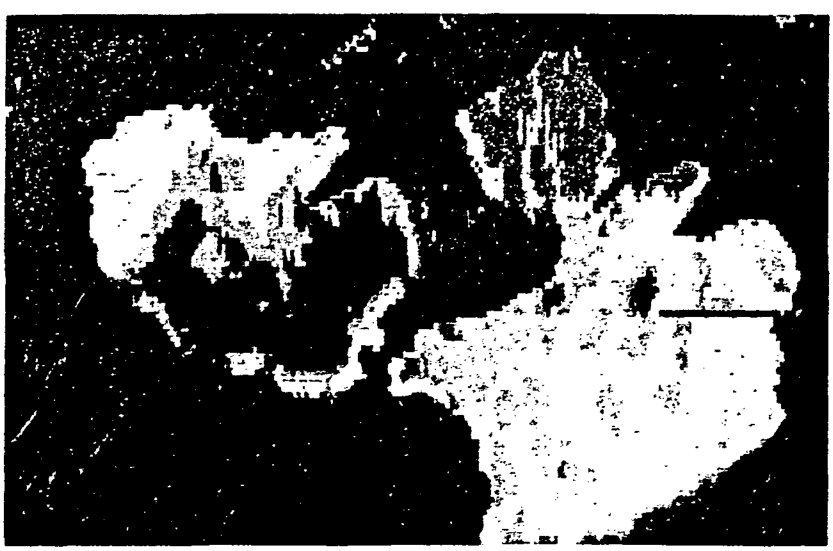

FIG.5.LAKES RINGSJÖARNA, generated by Ink Jet Plotter in MSS 4 and MSS 7 (27/8-73).The image is filtered for the LANDSAT line scanner noise.Green=land, dark blue=highest transparency and lowest particle(phytoplankton) concentration.Dark red =lowest transparency and highest particle concentration.

The left lake is Västra Ringsjön,the right lake is Östra Ringsjön and the uppermost part of Östra Ringsjön is Lake Sätoftasjön.

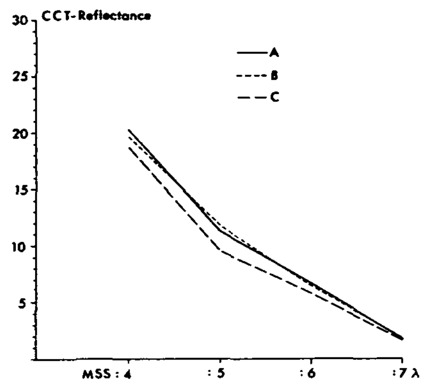

FIG.7.a. SPECTRAL DIAGRAM for the pollution plumes A and B and for "clean" water off Copenhagen.

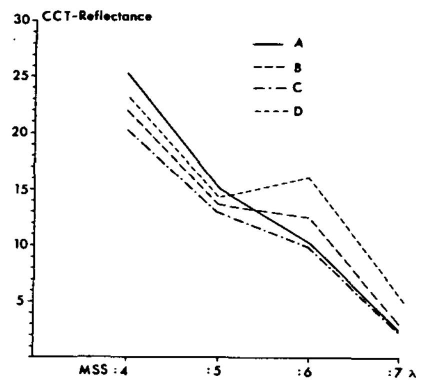

FIG.7.b. SPECTRAL DIAGRAM for the Lakes Västra Ringsjön (A),Östra Ringsjön (B), Sätoftasjön (C) and an algae strake in Lake Östra Ringsjön (D).

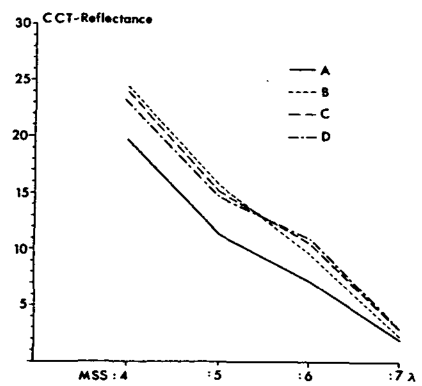

FIG.7.c. SPECTRAL DIAGRAM for the Lakes NW Ystad.A=Krageholmssjön, B=Ellestadsjön,C=Snogeholmssjön and D=Sövdesjön.

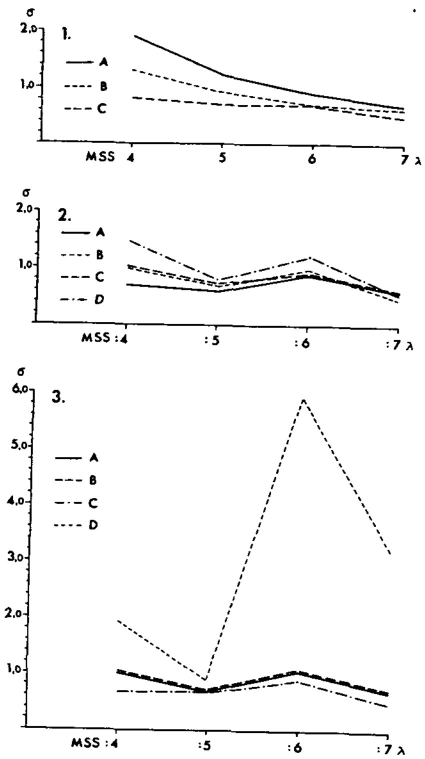

FIG.8. SPECTRAL FUNCTIONS regarding standard deviations of digital grey-tone levels. (1) The Copenhagen area, (2) The Lakes NW Ystad, (3) Lakes Ringsjöarna. The functions are named in the same way as in Fig. 7a-7c.