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WATER QUALITY MODELS WITH DIFFERENT FUNCTIONS OF EXOTECH RADIOMETER BANDS

K.R. RAO, R. KRISHNAN, A.K. CHAKRABORTY,
B.L. DEEKSHATULU

National Remote Sensing Agency
Secunderabad, India

I. ABSTRACT

Surveillance of water quality by remote sensing technique can be persued with advantage. An attempt has been made in this paper to obtain regional models of water quality of inland tanks and lakes. Stepwise multiple linear regression analysis between water quality parameters and several functions of Exotech radiometer band reflectance values, namely, bands alone, bands and their ratios, and, bands and their products are evaluated with respect to performance of the regression parameters. It is seen, that, the pairwise product of the reflectance in different bands is better correlated than the bands and their ratios. A possible explanation for this could be the higher order non-linear relation between the water quality parameters and the spectral bands.

II. INTRODUCTION

1. Environmental implication of water quality has assumed much importance in recent times. With increasing industrial activity, agricultural practices and man's increasing use of the land and the environment, waters which were once considered safe and most easily available commodity on Earth, are no longer there for the present and future generations. The increasing concern for availability of safe and enough water for drinking, industrial use, irrigation needs, recreational purposes and aesthetic reasons reflects the problem of dimension both in developing and developed countries of the world. The United Nations has realised the urgency of it and declared 'Eighty' as the 'Drinking Water and Sanitation Decade'.

2. Evaluation of water quality of inland tanks and lakes on a regional scale is a time consuming and costly means by conventional ground survey methods. Since quality of water is an intricate and variable natural or man-made phenomena, it requires periodic survey and monitoring for evaluation of safe and acceptable water and for implementation of corrective measures, if required. Effective management and accurate prediction of water quality on a regional scale thus need a superior device for numerical modelling which may satisfactorily answer unforeseen happenings at a future date. Recent advances in remote sensing data acquisition technique and digital processing of environmental data may help in this respect.

3. Many studies have indicated that reflected radiation from a water body in different bands of the visible and infrared portions of the electro-magnetic spectrum have strong correlations with several water quality parameters[1]. In these studies, Landsat and airborne multispectral scanner data have been correlated with the water quality parameters. Computer implemented pattern recognition technique using supervised classification procedure like the maximum likelihood algorithm[2] and stepwise multiple linear regression analysis[3] have been commonly used in these studies. The regression equations derived for sample areas have been utilised to produce water quality maps over the entire water body and to enable prediction of water quality over non-sampled areas using supervised classification of the space acquired data. In regression analysis between water quality parameters and remotely sensed data, reflected mean values alone or reflected mean values and their ratios of the Landsat MSS or airborne M^{2}S bands have been employed on[4,5,8] several water quality parameters.

However, the usefulness of other functions of the band values, say, pairwise products of the mean reflectance of the bands have not been investigated yet.

4. Secondary to this aim is to attempt regional models of water quality. Since, one of the great advantages of the remotely sensed data from space, such as Landsats, is the ready availability of the near-surface environmental data on a regional scale and on a repetitive basis, this situation could be used with advantage to construct regional models of water quality of inland tanks and lakes by considering data of different water bodies and of different dates. However in this study, groundbased Exotech radiometer observation has been used as a first step in that direction.

III. METHODS AND MATERIALS

1. In connection with another study of resources survey in Bundelkhand region of Uttar Pradesh State in India, Water Quality of four selected reservoirs were taken up for examination. These reservoirs are of small sizes and managed by the State Irrigation Department for irrigation and drinking purposes. Ground data collection were conducted for these reservoirs between 16th October and 4th November, 1979. These data collections were of two types: (i) Exotech radiometer measurement of surface water reflectance for each of these reservoirs at two or three different locations, (ii) water sample collection from each of these locations for subsequent laboratory analysis of water quality parameters.

2. Exotech (sometimes called the Landsat ground-truth radiometer) is a four band portable instrument which can be used in hand-held mode. The four bands are the same as the Landsat bands, i.e., band 4 (0.5 - 0.6 μm), band 5 (0.6 - 0.7 μm), band 6 (0.7 - 0.8 μm), and band 7 (0.8 - 1.1 μm). The instrument measures per cent radiation back-scattered (% reflectance) from any object with respect to solar incident radiation. Laboratory analysis of water samples determined 10 water quality parameters. These were: pH, Conductivity (micro-mhos), Turbidity, Total solids (mg/l), Dissolved Solids (mg/l), Suspended Solids (mg/l), Total Hardness (mg/l), Ca-Hardness (mg/l), Chloride (mg/l), Total Alkalinity (mg/l). Besides, surface water temperatures were recorded by Precision Radiation Thermometer (Model PRT-5).

IV. ANALYSIS

1. The stepwise regression model is employed in this analysis. The classical multiple linear regression problem is that of estimating the coefficients,

$$\beta_i,\ i = 0, 1, \ldots, t.$$

In the linear model,

$$\hat{Y} = \beta_0 + \sum_{i=1}^{t} \beta_i X_i + e \ldots\ldots (1)$$

based on a set of n responses, Y, to various values of the input variables, Xi, in the presence of errors. In the present problem, Y corresponds to the water quality parameter and Xi represent the spectral bands or some functions of the bands. In many cases, a subset of size 's' of the original 't' input variables will be adequate to describe the data. The stepwise regression algorithm selects this subset (optimal in the mean square sense) and evaluates the Bi's as follows: First, the most correlated variable is chosen by considering the correlation coefficients. The correlation metrix is updated to account for the variable (s) entering the regression; the next highly correlated variable is chosen, based on the new matrix and so on. The procedure terminates, when the required level of significance is reached. At each step, a check for deciding whether, a variable already in regression has become redundant or not, is performed and, if found redundant, is discarded.

2. In this study, stepwise regression analysis were carried out between water quality parameters and several functions of Exotech 4 band radiometer reflectance values. Here, water quality parameter is the response variable and Exotech values are the independent variables. Only eight water quality parameters, viz. depth, temperature, pH, conductivity, turbidity, Ca-hardness chloride and total alkalinity are found to be correlated with Exotech readings and therefore, taken up for further investigation in this paper. The following three models were investigated:

i) Regression of water quality parameters on the 4 exotech band values.

ii) Regression of water quality on the 4 Exotech bands and their ratios (viz. 4/5, 4/6, 4/7, 5/6, 5/7 and 6/7)

iii) Regression of water quality on the 4 Exotech bands and their products (viz. 4x5, 4x6, 4x7, 5x6, 5x7 and 6x7).

3. One of the aims of this investigation is to obtain regional model of water quality. For this purpose, data for all the four reservoirs were lumped together and used in the regression analysis. The input data used in the regression models are presented in Table1.

V. DISCUSSION OF RESULTS

1. Out of eleven water quality parameters taken up for examination, eight parameters, namely, depth, temperature, pH, conductivity, turbidity, Ca-Hardness, chloride and total alkalinity were found to be well correlated using all the three models. Even though the observed data of several water bodies and different dates were lumped together, the regression models were not impaired as can be seen from Table 2. For evaluating the performance of the regression models and for comparison, the regression test parameters chosen were: Exotech band as well as their ratios and products in regression as entering variables (E.V.), the F value, the standard error of estimate (s.e.e.) and the multiple correlation coefficient (r).

2. The resultant water quality models are tabulated in Table 3. Comparing the three models, it is observed that the model using pairwise products of band values gives better performance in terms of lower standard error of estimates and higher F values than the other two models. It is suggested, that, one of the reasons for this could be a higher order non-linear relation between the water quality parameters and the bands. This can be explained as follows:

Suppose that the water quality parameter

$$Y = \beta_1 . X_4 . X_5 + \beta_0 + \ldots.. + e \quad (2)$$

where X_4 and X_5 represent the bands 4 and 5. Since, the bands themselves are correlated, we can assume that,

$$X_4 = \beta_2 . X_5 + \beta_3 + \ldots\ldots.. + e' \quad (3)$$

Now, substituting for X_4 in eqn. (2), we get

$$Y = \beta_1 (\beta_2 . X_5 + \beta_3 + e') X_5 + \beta_0 + \ldots. + e \quad (4)$$

$$= \gamma_1 . X_5^2 + \gamma_2 . X_5 + \ldots\ldots + \beta_0 + \ldots.. + e \quad (5)$$

Eqn. (5) shows that Y is a quadratic function of X_5.

VI. CONCLUSION

Regional models of water quality may be attempted by considering remotely sensed data of different water bodies and of different dates. Further, in water quality studies using regression model, besides the bands and their ratios, other functions, such as, pairwise product of bands may also be useful and these need to be further investigated.

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Table 1. Water Quality And Exotech Radiometer Data For Reservoir in Bundelkhand Region.

Reservoir	Observation Site	Date	Depth (metre)	Temp. °C	pH	Conductivity (micro mhos)	Turbidity	Ca-Hardness (mg/1)	Chlorides (mg/1)	Total Alkalinity (mg/1)	Exotech Radiometer Measurements band 4	band 5	band 6	band 7
Pahuj	1	17.10.79	1.00	18.00	7.3	250.0	1.0	16.03	32.49	108.0	2.06	2.73	1.27	0.47
	2.	17.10.79	4.90	16.50	7.5	250.0	3.0	14.43	32.49	100.0	3.27	3.30	1.18	1.05
	3	26.10.79	4.81	17.00	7.8	250.0	6.0	14.42	34.99	108.0	2.73	2.70	1.18	0.62
Parichha	1	26.10.79	7.60	18.50	7.7	170.0	0.0	24.05	9.99	100.0	2.98	2.28	0.80	0.41
	2	26.10.79	8.09	18.50	7.77	170.0	0.0	27.25	7.49	104.0	2.78	2.28	0.80	0.40
	3	26.10.79	6.94	19.00	8.0	180.0	0.0	22.43	9.99	108.0	3.13	2.21	0.63	0.29
Kamlasagar	1	25.10.79	1.00	18.50	7.8	260.0	10.0	16.03	19.55	96.0	4.94	4.76	1.50	0.77
	2	25.10.79	6.25	18.00	8.0	240.0	6.0	28.86	17.49	120.00	5.60	4.76	1.33	0.69
	3	25.10.79	4.90	17.00	8.2	230.0	2.0	28.86	17.49	124.00	5.67	4.69	1.25	0.69
Govindsagar	1	18.10.79	2.23	17.50	7.2	160.0	2.0	14.43	19.99	100.0	1.31	2.21	1.20	0.60
	2	18.10.79	7.05	18.50	7.4	170.0	2.0	16.03	19.99	96.0	1.23	2.37	1.20	0.48
Mean			4.98	17.91	7.69	211.82	2.91	20.26	20.18	105.82	3.25	3.12	1.12	0.59
Standard Deviation			8.10	2.53	0.99	129.47	10.05	19.27	30.10	29.05	4.91	3.44	0.83	0.67

Table 2. Results Of Stepwise Regression Analysis
(Number of observations = 11)

Response Variable, Y_1	Regression test parameter chosen for comparison	Exotech Bands only. No. of variables = 4	Exotech bands and their ratios. No. of variables = 10	Exotech bands and their products. No. of variables =10
Depth	F	8.6396	8.6396	8.6396
	r	0.700	0.700	0.700
	s.e.e.	1.9279	1.9279	1.9279
	E.V.	6	6	6
Temperature	F	11.7042	11.7042	11.7042
	r	0.752	0.752	0.752
	s.e.e.	0.5564	0.5564	0.5564
	E.V.	7	7	7
pH	F	8.7056	40.3185	9.8342
	r	0.922	0.904	0.927
	s.e.e.	0.1362	0.1416	0.1318
	E.V.	4,5	5/6	4,5 x 7
Conductivity	F	8.1909	8.1909	10.8941
	r	0.690	0.690	0.740
	s.e.e.	31.2273	31.2273	29.0283
	E.V.	5	5	5 x 7
Turbidity	F	11.5805	11.5805	14.7609
	r	0.750	0.750	0.788
	s.e.e.	2.2143	2.2143	2.0608
	E.V.	6	6	5 x 6
Ca-Hardness	F	8.0715	12.6428	14.8631
	r	0.827	0.764	0.882
	s.e.e.	3.8323	4.1431	3.2130
	E.V.	4,7	4/6	4,6 x 7
Chloride	F	4.6320	5.8689	3.8114
	r	0.583	0.628	0.839
	s.e.e.	8.1526	7.8062	6.1962
	E.V.	6	4/7	6,4 x 7, 5x6
Total Alkalinity	F	6.0086	6.0086	6.0086
	r	0.633	0.633	0.633
	s.e.e.	7.4973	7.4973	7.4973
	E.V.	4	4	4

Table 3 Water Quality Models

Water quality	Exotech Bands	Exotech bands and their ratios	Exotech bands and their products
Depth	12.6167 - 6.8082 (band 6)	12.6167 - 6.8082 (band 6)	12.6167 - 6.8082 (band 6)
Temperature	19.5781 - 2.8376 (band 7)	19.5781 - 2.8376 (band 7)	19.5781 - 2.8376 (band 7)
pH	7.4294 + 0.3332 (band 4) - 0.2630 (band 5)	6.4977 + 0.4266 (band5/6)	7.1606 + 0.2649 (band 4) - 0.1680 (band 5 x band 7)
Conductivity	130.8351 +25.9788 (band 5)	130.8351 + 25.9788 (band 5)	161.7434 + 25.5494 (band 5 x band 7)
Turbidity	-7.2471 + 9.0533 (band 6)	-7.2471 + 9.0533 (band 6)	-1.8116 + 1.2848 (band 5 x band 6)
Ca-Hardness	19.8616 + 3.3212 (band 4) -17.6530 (band 7)	9.9727 + 3.4249 (band 4/ band 6)	17.4344 + 3.6289 (band 4 -12.9103 (band 6 x band 7)
Chloride	-3.4716 + 21.0808 (band 6)	32.9890 - 2.1881 (band 4/ band 7)	-28.9072 + 66.4023 (band 6) + 7.3843 (band 4 x band 7) - 10.9877 (band 5 x band 6)
Total Alkalinity	93.6620 + 3.7456 (band 4)	93.6620 + 3.7456 (band 4)	93.6620 + 3.7456 (band 4)

1. K.R. Rao. Graduated in science from University of Mysore in 1945, obtained post-graduate diploma in electrical and communication engineering from Indian Institute of Science in 1948 and Masters' degree in electrical & Control engg. from Cranfield Institute of Technology, U.K. in 1962. He has held several important appointments in the Indian Air Force, Department of Atomic Energy, Indian Space Research Organisation. He was a member of the U.N. International Team of Experts for preparing the document on Training of Users of Outer Space Technology, Senior Consultant/Remote Sensing Adviser for a short term UNDP assignment. He was the recipient of World Telecommunication Day Award in 1973. Since 1975, he is the Director of the National Remote Sensing Agency, India. He is a Fellow of the Institution of Engineers (India), member, American Society of Photogrammetry, President, Indian Society of Photo-Interpretation & Remote Sensing, President, Association of Exploration Geophysicists, India and Founder Member, Indian National Cartographic Association.

2. R. Krishnan. Graduated in electrical engineering from University of Madras in 1970, obtained Masters' and Doctorate degrees in electrical engineering from University of Madras and Indian Institute of Science in 1972 and 1977 respectively. Since 1977, he is working as Software Engineer at National Remote Sensing Agency, India. His main area of Interest are Pattern Recognition & Image Processing.

3. A.K. Chakraborty. Graduated in Civil Engineering from University of Burdwan in 1968, obtained Masters' degree in Advanced Hydraulic Engineering from Indian Institute of Technology, Kharagpur in 1970. He was engineer, Irrigation & Water-Ways Department, Government of West Bengal. Since 1975, he is a scientist (Water Resources) at National Remote Sensing Agency, India. He is a member, Indian Association of Hydrologists and Indian Society of Photo-Interpretation and Remote Sensing.

4. B.L. Deekshatulu. Graduated in electrical engineering from Banaras Hindu University in 1958, obtained Masters' and Doctorate degrees in electrical engineering from Indian Institute of Science. He was a Faculty Member, Electrical Engineering Department, Indian Institute of Science in 1964-1976 and became Professor in 1970. Since 1976, he is Head, Technical Division at National Remote Sensing Agency, India. He is a Fellow of the Institution of Engineers (India), Fellow, Indian Academy of Sciences, Member, Computer Society of India, Member, Biomedical Engineering Society of India, Member, National Academy of Biophysics, Member, International Association for Pattern Recognition, Sr. Member, IEEE, Fellow, IETE. He has several research publications to his credit.