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Very Low Altitude Remote Sensing of the Water Quality of Rivers

Analyses of data from surveys of the Ganga and Yamuna rivers indicate a high correlation of photographic optical density with turbidity and with biochemical oxygen demand.

Abstract: *Black-and-white photographs of the water surface were taken at sampling points along with a water quality survey in order to monitor the pollution parameters of the rivers. The data were analyzed and interpreted, and it was found that the photographic optical density could be correlated with turbidity and also with the biochemical oxygen demand. Models correlating photographic optical density with biochemical oxygen demand and with turbidity have been developed.*

Introduction

Wastewater discharge from such activities of man as domestic, industrial, agricultural, commercial, mining, etc., pollutes our water resources. The water quality of polluted water is expressed through the many conservative and nonconservative parameters, broadly grouped into physical (such as turbidity, color, and temperature), chemical (including inorganic and organic substances such as heavy metals, pesticides, detergents, and petroleum), and biological (Coliform MPN, Total Plate Count, species diversity indices, etc.).

In general, the most significant parameters are biochemical oxygen demand (BOD) and turbidity, which are commonly used to denote the pollution strength of many wastes.

Turbidity has been the parameter most easily and directly determined by means of the photographic technique of remote sensing. Scherz and Stevens (1970) and Gramms and Bailey (1971) noted that image densities read with a microdensitometer could be correlated to particle sizes along with their concentrations. Scherz and Stevens (1970) and Kiefer and Scherz (1971) demonstrated the feasibility of potential correlation between the suspended solids in a river and their photo images. Klooster and Scherz (1974) showed that turbidity correlated best to image brightness and used a microdensitometer to measure image brightness on films in order to determine turbidity.

In most cases, the BOD exerting material also imparts color to the water in addition to the turbidity. Color has also been interpreted directly from photographs. Though color photographs would indicate hue along with color intensity, black-and-white photographs have also been used successfully. Scherz and Stevens (1970), Gramms and Bailey (1971), and Word (1973) have placed emphasis on the use of volume spectral reflectance for water quality. Word (1973) was able to detect dye concentration as small as 0.05 ppm.

Methodology

Water quality surveys (Bhargava, 1977) of the two most important rivers of Uttar Pradesh in India, that is, the Ganga and Yamuna of the Indogangetic plain, were undertaken. The monitoring of several relevant parameters of water quality was carried out at a number of stations along the streams. Some of the parameters could be directly

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measured in the field. For others, samples were collected and analyzed utilizing Standard Methods (1971) in the temporary laboratories set up at different stations for the purpose. Black-and-white photographs of the river water were taken from a very low altitude (about 3 metres above the water surface) at each sampling station during the survey. The processed photographs were analyzed in the Institute using a DU-2 Beckman Spectrophotometer to determine if the results of such an analysis could correlate with any of the parameters of water quality.

Only black-and-white films were used in this study, because of the requirements for special laboratories and the enormous time and cost for making arrangements for color or color-infrared (IR) photographs. The study was therefore confined to the visible and near IR range. The camera, a Rolleiflex (Rollei, Honeywell-Franke and Heidecke, Germany-DBP, 2-8F, 2658518, DBGM), fitted with a lens of 80-mm focal length, and an exposure meter for setting the aperture of the lens and the shutter time for films exposure, were used in this study. Films were developed in the Institute laboratory, and diapositives were prepared from the negatives. A blank (transparent diapositive) was prepared for calibration purposes.

At selected points along the river where samples were collected for analysis, photographs of the river water were taken from a boat by holding the camera at a height of about three meters above the water surface. This represents the first attempt to use such low altitude photographs for the remote sensing of water quality.

The equation $A = a\ b\ c$ (Harley and Stephen, 1954), derived from Bear's Law, can be applied to diapositive films or negatives. That is, let A = Photographic Optical Density (POD), measured with a DU-2 Beckman Spectrophotometer; a = a constant depending on the exposed emulsion of the film as also the material in water causing the scattering or absorption of light and the frequency; b = the thickness of the emulsion layer and the film base; and c = the concentration of the pollutant which would affect the intensity of the imaging tone of the film. Thus, in the case where a and b remain nearly constant, A would be directly proportional to c, as in case of solutions (where Bear's Law is generally used).

The procedure for analyzing the film would involve the determination of the optical wavelength for maximum photographic optical density, as in solutions. A DU-2 Beckman Spectrophotometer, being readily available in the Institute Laboratory, was used in this study for this purpose, although Klooster and Scherz (1974) used a microdensitometer to determine image brightness. A photographic film (diapositive) was placed in the cell box of the DU-2 Beckman Spectrophotometer and the photographic optical density (POD) at a point in the film was determined for different wavelengths, from which the optimum wavelength was determined. At each time, the zero reading of the spectrophotometer was adjusted by using the blank diapositive. The photographic optical densities of other photographs taken at the various sampling stations were similarly determined at the optimum wavelength, which was found to be around 700 nm.

Observations and Interpretations

The observations of photographic optical density along with some other relevant parameters of water quality, made along Ganga and Yamuna rivers, are tabulated in Tables 1, 2, and 3, and the plots of the data are presented in Figures 1, 2, and 3.

From the plots in Figures 1 and 2, it is seen that photographic optical density shows some correlation to turbidity of the water. Similarly, from Figures 1 and 3, it is observed that photographic optical density can be correlated to BOD because, in the tested rivers, the BOD causing material generally manifests turbidity as well as greyish color, both of which affect the photographic optical density of the film. Non-color-causing soluble organic substances are, however, presumed to be negligible in such rivers. BOD, the most significant parameter of the pollution potential of any water, has been correlated for the first time with photographic imagery. It is also observed from the figures that the correlations and plots are consistent for both the winter and the summer data. There might, however, have been some errors in individual photographs, in spite of the best efforts.

Table 1. Photographic Study of the Ganga River in the Vicinity of Kanpur (Summer)

Point No.	Turbidity JTU	$BOD_{5-30°C}$ mg/l	Photographic Optical Density at 700 nm
1	40	4.9	0.55
2	50	13.9	0.95
3	40	12.0	0.80
4	44	8.9	0.69
5	30	13.0	0.82
6	23	8.0	0.58
7	37	12.7	0.68
8	37	10.5	0.43
9	50	28.0	1.30
10	48	24.1	1.20
11	39	11.0	0.68
12	36	9.5	0.70
13	40	11.0	0.80
14	42	9.0	0.85
15	50	8.0	0.90
16	40	12.0	1.00
17	47.5	6.2	0.70

TABLE 2. PHOTOGRAPHIC STUDY ALONG THE GANGA AND YAMUNA RIVERS (SUMMER)

River	Station		Turbidity JTU	$BOD_{5-30°C}$ mg/l	Photographic Optical Density at 700 nm
GANGA	Rishikesh	U	50	4.35	1.10
		D	50	6.65	0.95
	Haridwar	U	44	7.95	1.00
		D	46	7.20	1.20
	Narora	U	33	4.20	0.42
		D	29	7.20	0.67
	Kannauj	U	21	4.60*	0.32
		D	36	7.00	0.60
	Kanpur	U	44	10.00	1.00
		D	44	27.00	1.20
	Allahabad	U	26	6.00*	0.40
		D	23	6.80	0.30
	Varanasi	U	11	4.00*	0.28
		D	10	10.00*	0.64
YAMUNA	Dak Patthar	U	64	5.40	0.80
		D	13	2.60	0.30
	Delhi	U	30	5.20	0.40
		D	23	10.00	0.25
	Mathura	U	29	7.00	0.40
		D	35	12.00	0.53
	Agra	U	18	12.00	0.83
		D	27	14.00	0.71
	Hamirpur		11	5.90	0.30
	Allahabad	U	9	3.30	0.50

U = Upstream.
D = Downstream.
* Minimum turbidity values.

Probably, if an aerial photograph were taken to cover long stretches of a river, these errors would become minimized, and measurements of photographic optical density at different points along the river would assist in locating waste discharges and in assessing the pollution status of the river.

REGRESSION FOR CORRELATION

The observed POD values are an integrated effect of turbidity and BOD. The effect of other materials and causes is, however, assumed to be negligible.

Points of minimum turbidity values (marked with asterisks), where the POD would presumably be affected mostly by the BOD alone, are chosen from Table 2 for a possible correlation between the BOD and POD in the Ganga River. A regression analysis of these data yields a model,

$$(\text{BOD}) = -0.717 + 16.67\ (\text{POD}),$$

manifesting a Karn Pearson's correlation coefficient of 0.99 (with a probable error of 0.003), and a standard error of BOD estimation of almost zero

TABLE 3. PHOTOGRAPHIC STUDY ALONG THE GANGA AND YAMUNA RIVERS (WINTER)

River	Station		Turbidity JTU	$BOD_{5-20°C}$ mg/l	Photographic Optical Density at 700 nm
GANGA	Rishikeshh	U	8*	1.0	0.25
	Allahabad	U	33*	3.0	0.60
		D	23*	4.0	0.30
	Varanasi	U	18*	2.0	0.25
		D	20	8.0	0.60
YAMUNA	Mathura	U	27	3.0	0.26
		D	26	4.0	0.21
	Allahabad	U	16	1.9	0.20
		D	13	3.0	0.40

U = Upstream.
D = Downstream.
* Minimum BOD values.

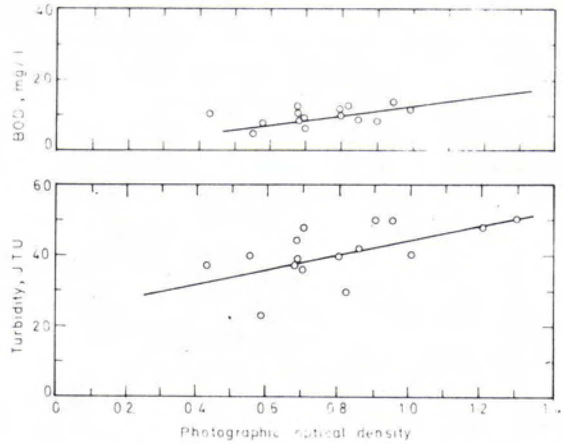

FIG. 1. Photographic optical density versus turbidity and BOD at Kanpur along the Ganga River (Summer).

value. The standard deviations of BOD and POD, respectively, show 2.5 mg/l and 0.01.

Similarly, the points of minimum BOD values (marked with asterisks), where the POD would presumably be affected mostly by turbidity alone, are chosen from Table 3 for a possible correlation between the turbidity and POD in the Ganga River. A regression analysis of these data yield a model,

$$(\text{Turbidity}) = -4.78 + 72.46\ (\text{POD}),$$

which shows a Karn Pearson's correlation coefficient of 0.86 (with a probable error of 0.084) and a standard error of turbidity estimation of around 25 units. The standard deviation of turbidity and POD are about 10 units and 0.29, respectively.

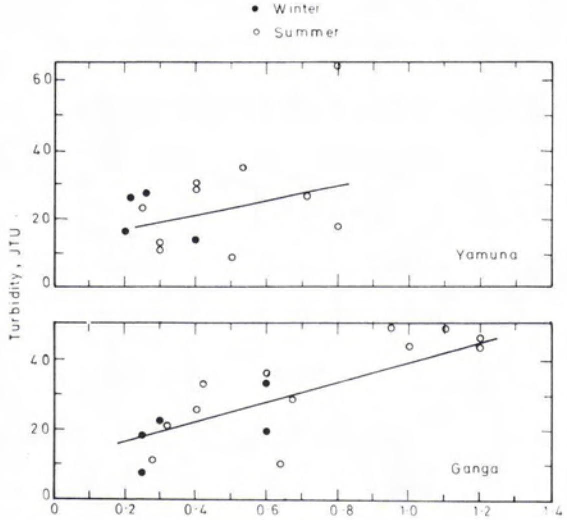

FIG. 2. Photographic optical density versus turbidity in the Ganga and Yamuna rivers.

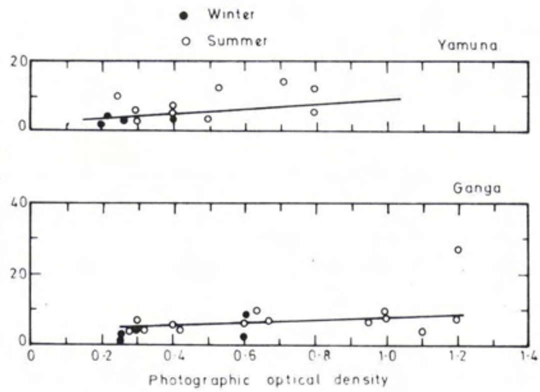

FIG. 3. Photographic optical density versus BOD in the Ganga and Yamuna rivers.

SUMMARY AND CONCLUSIONS

A water quality survey of the Ganga and Yamuna rivers of the Indogangetic plain in India was undertaken. The monitoring of several pollution parameters was done at a number of stations along the rivers. Photographs of the water surface were taken from the very low altitude of about 3 meters at the sampling points, and were analyzed at the Institute laboratory using a DU-2 Beckman Spectrophotometer to determine the photographic optical density (POD) of the film at the sampling points. The data were analyzed and interpreted. It was determined that the POD could be correlated to turbidity and also to BOD. Models correlating POD with turbidity and also with BOD have been developed. An aerial photograph covering a long stretch of a river would probably avoid most errors and compare the water quality of the river at different points satisfactorily.

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