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ASSESSMENT OF POLLUTION OF THE RIVER BURIGANGA, BANGLADESH, USING A WATER QUALITY MODEL

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ABSTRACT

The River Buriganga, which runs past Dhaka City, is at present one of the most polluted rivers in Bangladesh. Dhaka City is very densely populated and will be one of the ten 'Mega Cities' by the year 2000. However, only a small fraction of the total wastewater being generated in the City is treated. Consequently, the amount of untreated wastes, both domestic and industrial, being released into the Buriganga is tremendous and is increasing day by day. Therefore, the objectives of this study were to investigate the status of the river water quality in terms of some cardinal water quality parameters, and to simulate the dissolved oxygen (DO) level using a water quality model. In order to fulfil the objectives, a comprehensive data acquisition programme - from both *in situ* and laboratory testing - was carried out. Then, a one-dimensional water quality model was developed for the Buriganga River system for a dry period of 1994-95. Different scenarios were tested to predict the most likely condition of the river. The results of the model simulations have replicated the alarming low DO level in the Buriganga. Option runs show that an integrated approach would be required to restore the river water quality with regard to biodegradable pollutants. © 1999 IAWQ Published by Elsevier Science Ltd. All rights reserved.

KEYWORDS

Dhaka City; River Buriganga; pollution; mathematical model; integrated approach.

INTRODUCTION

Background

The rapid expansion of population and industry in cities of Bangladesh, and the increased use of fertiliser and agrochemicals countrywide, have created an awareness of river water quality and a recognition of the need for environmental protection.

The River Buriganga running past Dhaka City, the capital of Bangladesh, is one of the most polluted rivers in Bangladesh. Greater Dhaka City is one of the most densely populated cities in the world, home to approximately nine million people of whom less than 25% are served by a sewage treatment facility. Many industries have set up in and around the City during the last decade, and the number of new industries is continually increasing. As a direct consequence, the amount of untreated wastewater being discharged into the Buriganga has risen steadily. That is why, in the lean flow period of the dry season (six months), the quality of water within the 17 kilometre reach of the river is much lower than required for the sustainability of aquatic life, posing a severe threat to the aquatic ecosystem.

Objectives

The principal objectives of the study comprised an assessment of the status of the water quality of the Buriganga River, and development of a mathematical model using a deterministic, fully-dynamic mathematical modelling system to aid planners and decision makers in the process of restoration of the river water quality.

DHAKA CITY AND THE RIVER SYSTEM

Dhaka City

Dhaka City is bounded by four rivers: Balu in the east; Tongi Khal in the north; Turag in the west; and Turag-Buriganga in the south, as shown in Figure 1. The drainage of the City mostly depends on the water levels of the peripheral rivers. The major drainage channels (locally known as khal) in the City are Dholai khal, Gerani khal, Segunbagicha khal and Begunbari khal, which collect catchment runoff as well as wastewater, and drain to the peripheral rivers.

River system

The Buriganga River system is located in the southeastern part of the North Central Region of Bangladesh, close to the confluence of the Padma (Ganges) and Upper Meghna Rivers (Figure 1). The Buriganga is a tributary to the Dhaleswari River, which, after the Old Brahmaputra River, is the largest river in the North Central Region. The Lakhya River joins the Dhaleswari, 11 km downstream of the Buriganga confluence. The Dhaleswari drains into the Meghna River, just upstream of the Padma confluence.

The Buriganga is fed mainly by the Turag River, which receives flows from local rainfall and spill flows from the left bank of the Jamuna River. The Lakhya River drains a large catchment lying between the central forested areas and the Old Brahmaputra. Additional inflows to the system originate from the Balu, which drains a small catchment to the west of the Lakhya, and from the Ichamati and Karnatali Rivers, which carry mainly spills from the Padma and Jamuna Rivers respectively.

The lower reaches of the Dhaleswari-Buriganga-Lakhya system are tidal during the dry season when upstream inflows are minimal. Saline intrusion, however, does not take place.

DATA ACQUISITION AND ANALYSIS

Existing water quality data collected by the Department of Environment (DOE), Bangladesh, was insufficient to meet the demands of developing a water quality model, which requires intensive measurements of water quality parameters for their calibration. Consequently, a comprehensive data acquisition programme was conducted. Activities encompassed identification of pollution sources, field measurements of pollution loadings, selection of water quality monitoring locations in the rivers, intensive measurement of relevant water quality parameters, e.g. dissolved oxygen (DO), temperature and light penetration depth (Secchi depth), and collection and testing of water and wastewater samples. Figure 1 shows the water quality monitoring locations, and pollution sources.

Wastewater flows in drains and khals (natural or man-made) discharging into the rivers were measured at numerous locations. The measured discharges together with the results of analyses of wastewater samples were used to compute pollution loadings ('wet method') to the rivers.

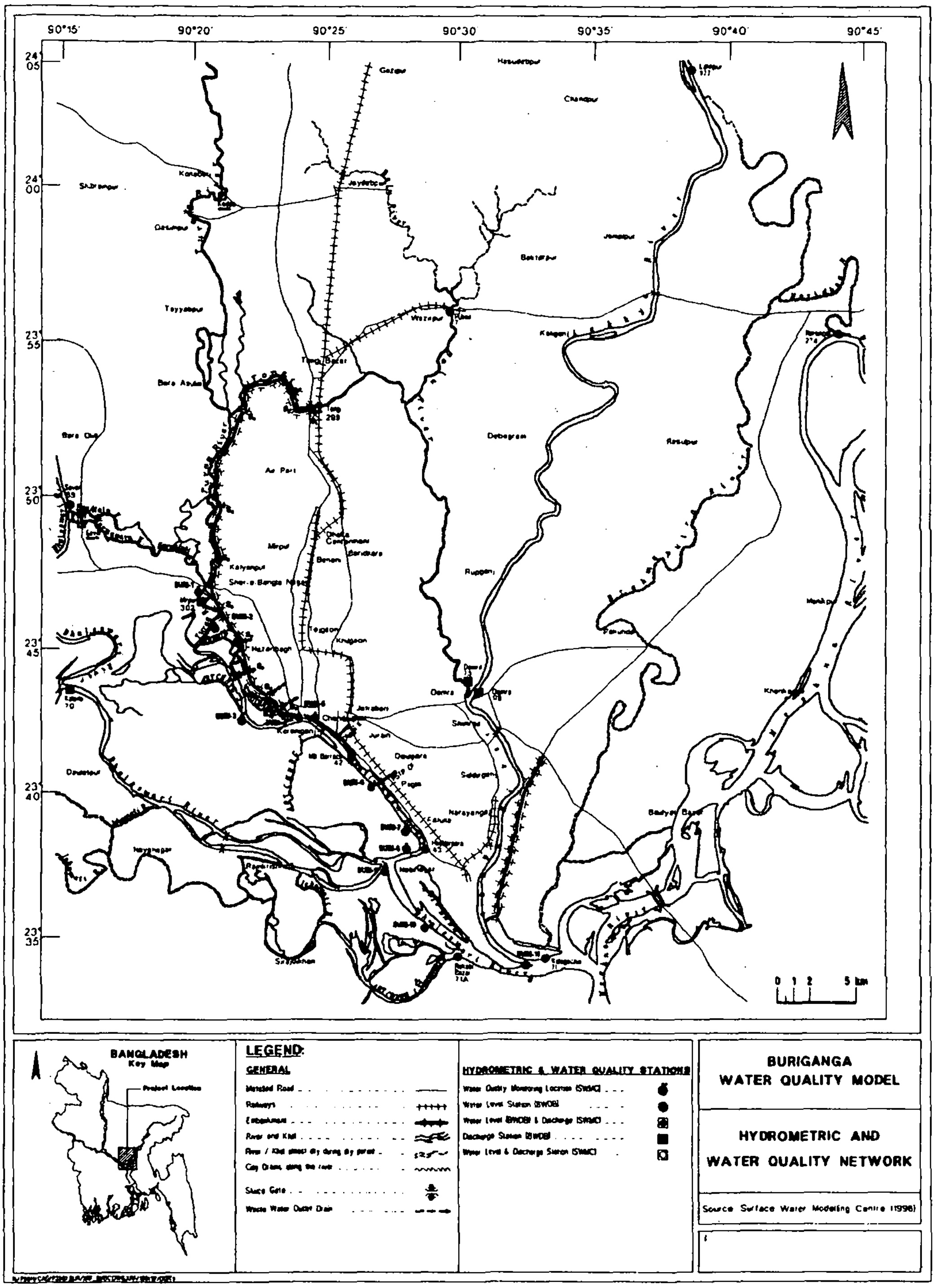

Figure 1. The Buriganga River system.

All the river water and wastewater samples were tested for the following parameters:

1. Biochemical oxygen demand, BOD_5 (at 20^0 C)
2. Chemical oxygen demand, COD
3. Ammonia as NH_3-N
4. Ammonium as NH_4^+-N
5. Nitrate as NO_3-N
6. *E. coli* (faecal coliforms)
7. Total coliforms
8. Total suspended solids (TSS)
9. Ortho-phosphate as PO_4-P
10. Chromium (Cr)

The testing was done at the laboratory of the DOE, Bangladesh. Table 1 represents a summary of data of water quality parameters for the Buriganga River system.

Table 1. Summary of water quality data for the Buriganga River system

Water Quality Parameter	Turag River			Buriganga River			Dhaleswari River		
	Min. Value	Max. Value	Data Range (mostly vary within)	Min. Value	Max. Value	Data Range (mostly vary within)	Min. Value	Max. Value	Data Range (mostly vary within)
DO	0.1	8.2	0.1-5.0	0.1	17.2	0.1-4.0	2.8	22.7	4.0-8.0
BOD_5	1	150	-	2.5	430	-	1	200	-
COD	4	382	-	8	540	-	4	530	-
NH_3-N	0	14.53	-	0	15.2	-	0	0.11	-
NH_4-N	0	109	-	0	114	-	0	0.76	-
E. coli	75	7500	-	10	55000	-	4	4000	-
Tot. Coli.	25	20000	-	125	80000	-	50	6500	-
TSS	9	80	-	10	42	-	10	35	-
NO_3-N	0	6.7	-	0	8.9	-	0	4.58	-
Orth.PO_4-P	0.06	5.36	-	0.45	15.22	-	0.78	11.54	-
Cr	0	0.016	-	0	0.014	-	0	0.01	-

Note: All values in Table 1 are in mg/l, except *E. coli* and Tot. Coli., which are in nos/100 ml.

Discussion on data analysis

With possible exceptions, the river water nowadays is not used directly for drinking. However, as a source of irrigation water, bathing, and washing of household items, river water is still used widely in Bangladesh. Comparing values of the measured/tested water quality parameters with the Environmental Quality Standards (EQS) set out by the DOE, Bangladesh (DOE, 1991), it is found that as sources of recreational, fishing and irrigation water, the Buriganga and the Turag Rivers hardly satisfy the EQS. Occasional high concentrations of DO or low concentrations of other parameters are mainly the result of fresh water inflow to these rivers, especially during the spring tide period, and local rainfall. Some very high concentrations of DO, recorded during daytimes, are suggestive of eutrophication, which is also not desirable for aquatic life.

POLLUTION LOADINGS OF BIODEGRADABLE WASTES

Estimation of pollution loadings by the 'wet method' has been described in the preceding section. In the 'dry method', pollution loadings were estimated based on the population density and areas of each drainage catchment from which discharges into the rivers occurred. Drainage network maps, population figures and unit loading figures were obtained from the Dhaka Water Supply and Sewerage Authority (DWASA), Dhaka Integrated Flood Protection (DIFP) Authority and JICA (1991), Browder (1992) and Henze. Additionally, BOD values and flow discharges of treated wastewater from the only sewage treatment plant situated at a place named Pagla (PSTP) were collected. The treated sewage is discharged into the Buriganga River.

Pollution loadings from industries in and around the City were extracted from the report of a study named 'Industrial Pollution Control Management' (BKH, 1994). It is to be noted that there are many non-point (diffuse) sources entering the Turag-Buriganga-Dhaleswari River system, originating either from industries or from domestic wastes. Waste loads from these innumerable indistinct origins cannot be measured precisely in the field through the direct flow measurement technique. Therefore, loadings from these non-point sources have been taken into account by increasing the loadings of nearby point sources. Finally, loadings from the wet and dry methods were compared to accept a reasonable figure. Table 2 shows finalised BOD loadings applied in the water quality model.

Table 2. Finalised BOD loadings to the Buriganga River system

	Point sources of pollutants										
Loading	S-4	S-5	S-6	S-7	S-8	S-9	S-10	Dholai K.	PSTP	City Drain	Kashipur K.
(kg/d)	1,470	3,480	1,080	21,080	1,860	220	1,380	29,980	6,000	7,950	365

MATHEMATICAL MODELLING

Modelling strategy

Due to foreseeable time constraints, the water quality modelling was restricted to one of the most important water quality processes, which is the well-known biochemical oxygen demand - dissolved oxygen (BOD-DO) interaction.

Water quality modelling using MIKE 11. The water quality modelling approach consists of the integrated Advection-Dispersion (AD) and Water Quality (WQ) modules in the MIKE 11 developed by the Danish Hydraulic Institute (DHI) of Denmark. The two modules simultaneously describe the discharge, transport and effects of pollutants in the river system. The AD module works based on the hydrodynamic description of water levels and flows calculated by the Hydrodynamic (HD) module in MIKE 11. The hydrodynamics of rivers depend, for the monsoon period, on the hydrological input, i.e. catchment runoff due to rainfall for which the Rainfall Runoff module (NAM) of MIKE 11 is to be used when needed.

Modelling software

Background of the MIKE 11 modelling system. The hydrodynamic (HD) module of MIKE 11 is based upon the equation of the conservation of mass and momentum (the Saint Venant equation) (DHI, 1995). However, in order to save computer time, MIKE 11 has the options of using the diffusive or the kinematic wave approximation, if the fully dynamic description is not required. For simulation of very long time series, a quasi-steady flow model can be applied. The hydrodynamic model is solved in a space staggered computational grid using an efficient numerical solution procedure (Abbott, 1979).

The advection-dispersion (AD) module of MIKE 11 is based upon the advective-dispersive transport equation for dissolved or suspended material (DHI, 1995). The module requires input from the hydrodynamic module in terms of discharges and water levels in time and space. The transport-dispersion equation is solved numerically using an implicit finite difference scheme, which in principle is unconditionally stable and has no numerical dispersion (Olesen *et al.*, 1989). A correction term has been introduced in order to eliminate the third order truncation error. This correction term makes it possible to simulate dispersion of concentration profiles with very steep fronts (Léonard, 1979).

The water quality (WQ) module of MIKE 11 consists totally of five partial differential equations describing (DHI, 1995): (i) Oxygen concentration; (ii) Concentration of BOD; (iii) Ammonium/ammonia concentration; (iv) Nitrate concentration; (v) Temperature.

The differential equations describing the processes are solved using a fourth order Runga-Kutta method (Press, 1986). The water quality module thus describes the oxygen conditions, which normally constitute the prime environmental parameter influencing the ecological state of polluted rivers.

Water quality modelling for the Buriganga River

Calibration of the hydrodynamic model. The Buriganga Water Quality Model was extracted as an independent sub-model from the North Central Region Model (SWMC, 1995). Modifications to the existing setup were necessary in order to improve the dry season calibration (SWMC, 1996). The river network adopted for the WQ modelling was chosen in such a way that the boundaries would not be directly affected by pollution discharges. The Buriganga River system was calibrated against measured water levels and tidal discharge for a period December 1994 to April 1995 (except January 1995 owing to unavailability of hydrometric data). Figure 2 shows sample calibration plots of hydrodynamic calibration.

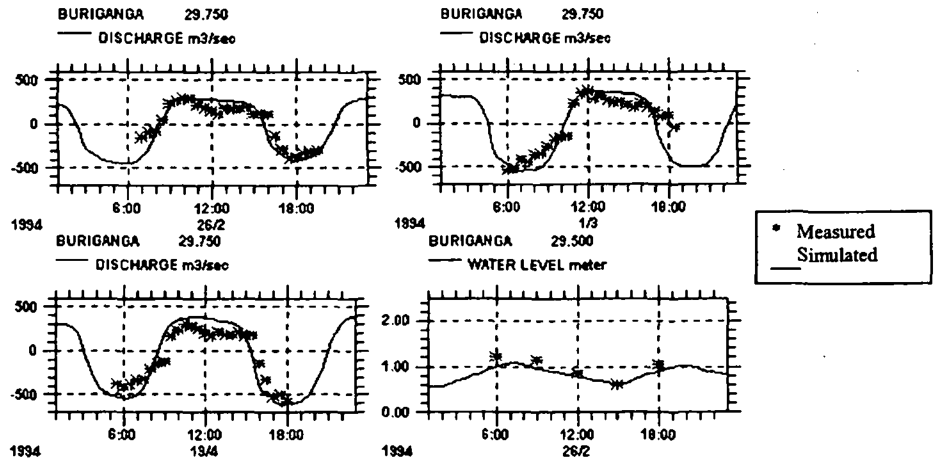

Figure 2. Sample plots of hydrodynamic model calibration.

Calibration of the water quality model. The water quality model was calibrated for the period 19-26 December 1994 against measured DO levels in the river system. The few BOD data, which were available, were used to check the levels simulated by the model. Calibration parameters included dispersion coefficients in each of the modelled rivers and process rate coefficients. Sample calibration results are shown in Figure 3.

Inferences from model results. The model simulated the measured DO levels in the river system reasonably well. The pattern and volume of tidal flow through the Buriganga River system remains the same throughout the dry season from November to April. Therefore, it is evident from the DO measurements that a considerable problem exists during the dry season in the Turag and Buriganga Rivers, the Buriganga being in the worst condition. Considering a critical DO level of 4 mg/l, only the Dhaleswari remains in an acceptable condition. As the model is so far not calibrated with respect to ammonia, nitrate, phosphates and heavy metals, no further comment can be made at this stage.

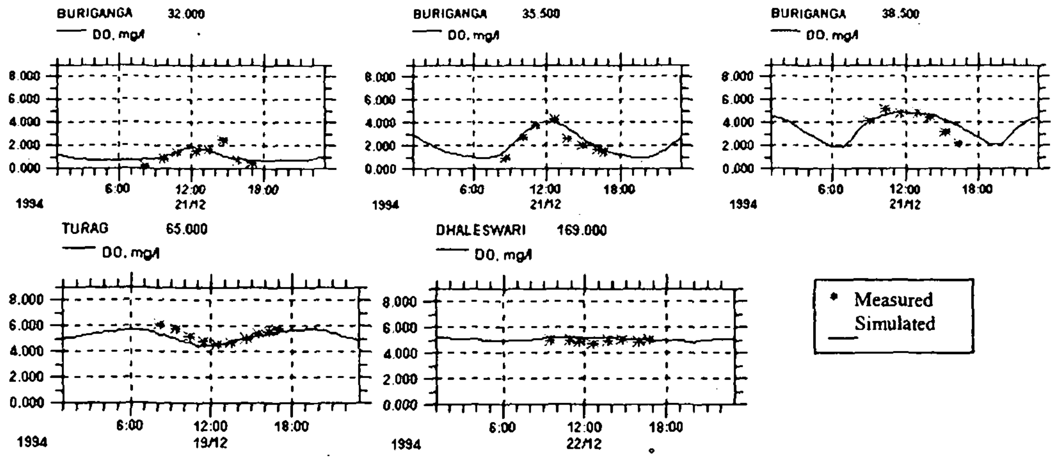

Figure 3. Sample plots of water quality model calibration.

Alternative Scenario Study. As the Buriganga River was found in an unacceptable condition with respect to the DO levels, alternative scenarios were tested to see how and when the river would be in acceptable condition with respect to DO. Table 3 describes the alternative scenarios, along with the improvement of concentration of DO in the Buriganga River following each of the scenarios. Here, the minimum DO values (mg/l) have been considered as a measure of comparison.

Table 3. Description of alternative scenarios

Scenario	Description	Min. DO
Base Condition	The calibrated model with the existing pollutant loadings	0.23
Scenario 1	No loading from tanneries (17,600 kg/d) through sluice S-7.	0.26
Scenario 2	Treatment of wastewater of S-7, City drains and Dholai Khal, with 60% BOD removal efficiency, prior to disposal	2.97
Scenario 3	All wastewater entering into Turag and Buriganga diverted to the end of Buriganga, treated with 60% BOD removal efficiency, and released into the Buriganga-Dhaleswari confluence	2.57
Scenario 4	All wastewater entering into Turag and Buriganga diverted to the confluence of Dhaleswari-Lakhya, treated with 60% BOD removal efficiency, and released into the Dhaleswari	5.14
Scenario 5	No BOD loading from sluice S-7	0.28
Scenario 6	No BOD loading from the Dholai Khal, the highest polluting outfall	1.70
Scenario 7	No BOD loading from the City drains	0.32
Scenario 8	All BOD loadings from S-7, Dholai Khal and City drains discontinued	4.23

Discussion on model results

Through the series of alternative scenario simulations using the calibrated water quality model, it is found that discontinuation of any of the major point sources of pollutants, e.g. the Dholai Khal or S-7 (Hazaribagh tannery area) may not be adequate for the improvement of the minimum DO level in the Buriganga River (Scenarios 5, 6 & 7). Also, discontinuation of these wastewater sources is hardly possible physically. Again, it is also apparent that establishment of treatment plants at the sites of the major point sources of pollutant may not be adequate for the improvement of the minimum DO level (Scenario 2). On the other hand, a dramatic improvement of the minimum DO level in the Buriganga River has been observed if all the major pollutant sources are treated for biodegradable materials and disposed of at a location further downstream of the Dhaleswari River (Scenario 4). It indicates that an integrated approach would be required to restore the water quality of the Buriganga River.

CONCLUSIONS

As a planning tool, mathematical models are now widely recognised having proven efficiency. With the advent of very fast computing facilities, it has become very easy to study alternatives to optimise many physical problems. Therefore, use of mathematical models needs to be incorporated in planning sectors to assess measures to be taken up to minimise a physical problem like pollution in rivers.

Water quality modelling is a new field of application in Bangladesh. The Buriganga Water Quality model in its present state is suitable for application in impact assessment studies at pre-feasibility level. Lack of data and time constraint have restricted the model verification process in this study. In addition, other water quality parameters such as ammonia, nitrate, phosphate and coliforms were not modelled. Thus, the model needs to be further developed and refined with additional resources when the same may be used as an environmental management tool by different development authorities.

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