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DEVELOPMENT OF MATHEMATICAL MODEL FOR ASSESSMENT OF ENVIRONMENTAL DAMAGES AROUND THE SHITALAKHYA RIVER IN BANGLADESH

K. M. H. Kabir[1], M. K. Uddin[2] & A. Khair[3]

Abstract

For the assessment of environmental damages around the study area, the related environmental parameters have been identified and subsequently data were gathered through focus group discussion, questionnaire survey, key informant's information along with two case studies. Out of two Case Studies (CS); in Case Study-1 (CS-1), the gross income of a family was reported to be TK. 80,071.00 in 2005, TK. 71,261.00 in 2006 and TK. 63491.00 in 2007. In Case Study-2 (CS-2), the gross income of the respondent in 2005 was TK. 51,162.00 and in 2006 and 2007 were TK. 51,820.00 and TK. 59,034.00 respectively. The opportunity loss of the respondent at polluted area were TK. 43,270.00, TK. 45,680.00, TK. 50,075.00 during the year 2005, 2006 and 2007 correspondingly which was higher than the respondent of CS-1. The pollution load and chemical characteristics of water of the Shitalkhya River was rated as very low quality i.e. Water Quality Index was 17.89. Out of polluted river water the surrounding inhabitants of the study area are suffering from opportunity loss and subsequent increased expenditure with comparison to non- polluted area. Eventually the basic outcomes of information has been expressed in following mathematical model for assessment of environmental damages for a particular case:

$TL \propto \sum (DL+IL+EL)$ or, ----------Equation-1
$TL = K \sum (DL+IL+EL)$ ----------Equation-2

Where,
TL- total loss, DL- direct loss, IL- indirect loss, EL- environmental loss,

Keywords: Environmental Pollution, Case Study, Mathematical Model

Introduction

The river Shitalakhya is navigable throughout the year and having economic and ecological importance for Dhaka and adjoining cities. Presently a number of small, medium and heavy industries including several clusters of textile industries have been established on the banks of the Shitalakhaya river which are located at Demra, Godnail, Narayanganj Pourashava, Rupganj, Sonargaon etc. under Narayanganj district those are creating severe pollution problem with increasing trend (Alam *et al.*, 2006).

About 36,000 metric tons of fabrics dyes are being used at textile industries in Bangladesh

*Corresponding author. E-mail: Dr Kazi Muhammad Humayun Kabir, Department of Environmental Sciences, Jahangirnagar University, Dhaka-1342, Bangladesh. Email: as.kabir@gmail.com, (corresponding author)[1]. Dr Md. Khabir Uddin, Professor, Department of Environmental Sciences, Jahangirnagar University, Dhaka-1342, Bangladesh. Email: khabir88@yahoo.com[2], Dr Abul Khair, Professor, Department of Botany, Jahangirnagar University, Dhaka-1342, Bangladesh. Email: ju_khair@yahoo.com[3]

(Global Dye Chem. Expo-2007) which are being eventually released as partial or un-treated textile effluent in the rivers of Bangladesh so the rivers are losing their dilution capacity and ecological viability specifically during lean period which resulting in serious health & environmental hazards and causing problems to aquatic lives including water-dependent food chain. The Dissolve Oxygen (DO) level, EC values, TSS, BOD and COD are also reported to be higher than that of acceptable limit for river water quality. The Shitalakhya river is reported to be second most polluted river in Bangladesh (Hossain, 2012; Alam *et al.*, 2006; DoE, 2008, Kabir *et al.,* 2010a,b, 2013).

The minimum available flow during extreme dry condition was 127m^3/sec (IWM, 2008), which was quite viable for environmental growth of that area, the temperature of the river water of the Shitalakhya river varied approximately from 20 ^{0}C to 31 ^{0}C except at the textile industrial discharge points. The optimum temperature is desirable for successful growth of tropical fishes ranges from 22-27 ^{0}C, water temperature of the Shitalakhya river is within acceptable limit but due to some other factors (pollution) the growth and breeding of tropical fishes are under stress (Jobling, 1981). It is also important to assess the tidal effects and dilution capability of particular section of river to get the advantages of natural phenomena and dilution aptitude of the Shitalakhya river to avoid over pollution (Jones and Jirka, 1996) and overstressing of flora and fauna (Benedict *et al.*, 2011; Kabir *et al.,* 2010a,b) and to put off the loss of river system.

On the other hand estimating the benefits through river restoration program is complicated, because of all the resources are not marketed goods. Since the environmental damages depend on cross cutting issues. On the basis of the collected information from the interviewee including various compensation theories and parameters of assessment were explored to assess the damages and opportunity lost around the study area. Through the study and considering the economic growth rate of the specified area the following geometric expression e.g., $Y_t = Y_0 (1+ r)^t$ (Weisstein, 2011; Abramowitz *et al*., 1972) was found to be dependable factor for development of mathematical model for assessment of environmental damages.

MATERIALS AND METHODS

Development of working map

A relatively small-scale base/site map was developed depicting the project area, sampling locations, and major water bodies, land, and road characteristics.

Questionnaire development and survey

For the development of questionnaire and survey of socio-economic data the methods of Kothari (1992) and Syed Ali Naki (1987) were followed.

Location of the CS area

Two settlements have been taken for case study one at relatively less polluted area at Roghur Char (23^{0}36’00.56” N and 90^{0}34’20.55” E; CS-1), under Hossaindi union at Gazaria upazila of Munshiganj district adjacent to Meghna river and other one is at heavily polluted area at Nayamati (23^{0}44’05.27” N and 90^{0}29’33.88” E; CS-2), under Demra thana of Dhaka metro along the bank of Balu river which is also adjacent to the Shitalakhya river.

DATA COLLECTION METHODOLOGIES

Focus Group Discussion (FGD: FGDs have been conducted at the randomly selected study areas with different groups' of respondents, namely; (i) mixed group at Painari Gram under Narayanganj Sadar, (ii) business men at Godnail Bazar under Narayanganj Sadar, (iii) shop keepers and traders at Kanchpur Bridge area under Sonargaon upazila of Narayanganj district, (iv) male workers of different industries at Demra Ghat area under Demra thana of Dhaka Metro, (v) female worker at Jatramura under Araihazar, of Narayanganj district, (vi) shop keepers and traders at Nayamati under Demra thana of Dhaka Metro, (vii) farmers at Patira, under Gulshan thana of Dhaka Metro, (viii) mixed groups at Parabarta, under Gulshan thana of Dhaka metro, (ix) mixed groups at Rupganj Sadar, under Narayanganj district, (x) mixed groups at Roghurcahr village under Hossaindi union of Gazaria, Munshiganj district and (xi) mixed group at Gazaria Sadar under Munshiganj district.

Key Informant's (KI) Interview : The 09 key informants have been interviewed at different places namely; (i) Bandar at Narayanganj, (ii) Siddhirganj at Narayanganj, (iii) Rupganj at Narayangang, (iv) Gazaria at Munshiganj, (v) Hossaindi union at Gazaria, Munshiganj, (vi) Female ward commissioner at Siddhirganj, Narayanganj, (vii) Adamjee Nagar at Siddhirganj, Narayanganj, (viii) Member of Narayanganj Chamber of commerce and (ix) Godnail at Narayanganj.

CS-1: (Clean area/non polluted area) : Socioeconomic condition was studied of a farm house having family member of 05 under village- Roghurchar, union-Hossaindi, upazlila- Gazaria, District- Munshiganj.

CS-2: (Polluted area): Socioeconomic condition was studied of a farm house having family member of 05 under village- Nayamati of Derma, District- Dhaka.

Analysis of collected data: The data have been analyzed using statistical package (SPSS 11.5). The results of case study has been calculated and mathematically computed, the results have been plotted graphically including possible regression analysis.

Development of a Mathematical Model

On the basis of those two case studies the yearly income-expenditure and projected loss of agro-fisheries, health, job and opportunity etc. of 2005 to 2007 were recorded. The outcome of the result has used to develop mathematical model (Brouwer, 2000; Garrod and Willis, 1999; ECLAC, 1999).

The qualitative and quantitative figures and facts were transferred at Ex-cell spread sheet and from the statistical analysis a linear expression was established, where a simple geometric expression was included i.e. $Y_t = Y_0 (1+r)^t$ (Weisstein, 2011 & Abramowitz, 1972) for dependable factor.

RESULTS AND DISCUSSION

It was revealed during river water flow study that the Shitalakhya river has very limited tidal effect (only 12 inches during high tide). The Jones and Jirka (1996) model was found to have limitations due to huge surge of pollution from point and nonpoint sources around the study area. The pollution load and chemical characteristics of water of the Shitalkhya river was rated as 17.89 using the model of Brown *et al*. (1970) and this model was subsequently

updated in 2001. The water quality of the Shitalakhya river was reported to be very of low quality: pH- 11.88, Temperature- 29.6, salinity- 4.5, DO- 4.03. Turbidity- 85, Phosphate- 0.35 and Nitrate- 0.03 and fecal coliform- 25/100 ml. Pearce *et al.* (2002) also used the same tools for rating the river water quality for developing countries.

Findings of FGD participants' at less polluted (CS-1) area

The villagers located at Hossaindi union of Gazaria upazila (CS-1) presently enjoying good environment. They are catching fishes from the Meghna river and maintains healthy livelihood. At this area the peoples are maintaining their own original profession along with other part time jobs. Due to less developed communication system the government health services or hospital in the vicinity of this area is also absent. The generated house hold and kitchen wastes are not creating any problem at this stage, but waste management system requires to be developed in this area for future sustainable development.

Findings of FGD participants' at polluted (CS-2) area

The aquatic, terrestrial ecology and agricultural activities of that area are being severely deteriorated. Few residents of that polluted area already migrated to a safer place for better living environment. During lean period the water further deteriorates and the large fishes of that area migrate to safer places e.g. at Meghna river for their survival and subsequently during monsoon relatively small amount of fishes are being usually caught at the study area. The unplanned invasion of industrial activities has changed the land use pattern including livelihood. These manmade activities are negatively influencing the sustainable development of the study area.

Key Informant's (KI) Interview

The key informants have been interviewed at different places namely; Bandar, Siddhirganj, Rupganj under Narayangang, Gazaria, Hossaindi union, under Munshigang, teachers and political leaders including female community leader were interviewed.

Findings of the KI

Most of the interviewee expressed their concern about the growing pollution of the Shitalakhya river water, which are ultimately affecting the vegetation of that area, the aquatic and terrestrial ecology are also at stake. It was learnt from interviews that, during the previous decades there were abundance of large fishes like carp fishes, cat fishes, etc. Other aquatic lives including freshwater dolphins (S*husuk*), water monitors (*Guishap*), snakes, leeches, snails, crabs, turtles, frogs, *kuicha* etc. were also found at that area. Presently those species are gradually losing their habitat. The adults and children are suffering from various types of bronchial and skin diseases due to increasing pollution at the study area.

CS-1: (Clean area/non polluted area)

The location of the case study is shown in figure 1. This outcome of this case study reveals that, gross income of the CS-1 family was Bangladeshi TK. 80,071.00 in 2005, TK. 71261.00 in 2006 and TK. 63491.00 in 2007. The expenditure were TK. 71,245.00

in 2005, 59,874.00 in 2006 and 61,650.00 in 2007 and subsequently the opportunity loss was calculated to be TK. 0.00 during 2005, 2006 and 2007. To keep the present clean condition of that area a comprehensive river management including awareness program is of deem necessary. The cost for management of a small section of river i.e. approximately 01 km up and downstream from the specific settlement (CS-1) was calculated to be as TK. 17, 250.00 in 2005, TK. 13,000.00 in 2006, and TK. 11, 500.00 in 2007 (Figure 2).

The respondent of this case study expressed that, the above mentioned cleaning program may be useful form for better environmental management for future sustainable development. The following are the graphical representation of the income expenditure, opportunity lost etc. which were depicted by log 10 based scales through using primary vertical axis (Figure 4a, 4b, 4c). The graph shows the gradual decline in gross income at CS-1 area and subsequently the expenditure also decreased. The Gross income of CS-2 area gradually increased to some extent. The expenditure also increased at CS-2 area. It was reported that for CS-2 both the income and expenditure were lower than that of CS-1. The family of CS-1 area is reluctant to migrate from their village house to other places, but the family members of CS-2 already migrated to the nearest growth center and limited shifting has started from their primitive agricultural profession to small business and others professions.

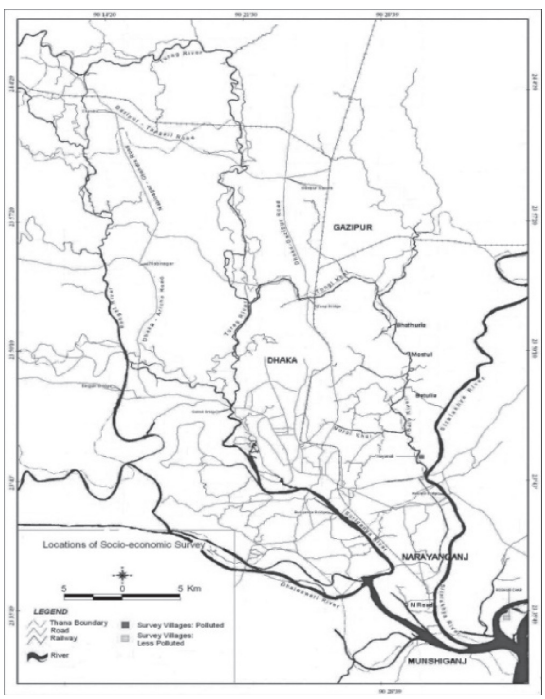

Fig. 1. The figure showing the Case study-1 (Roghur Char, Munshigang) & - Case study-2 (Nayamati, Dhaka) area adjacent to the Shitalakhya river

CS-2: (Polluted area)

The result reveals that the gross income of the case study-2 respondent in 2005 was TK. 51,162.00 and in 2006 and 2007 were TK. 51,820.00 and TK. 59,034.00 respectively (Fig. 2). The expenditure of that CS-2

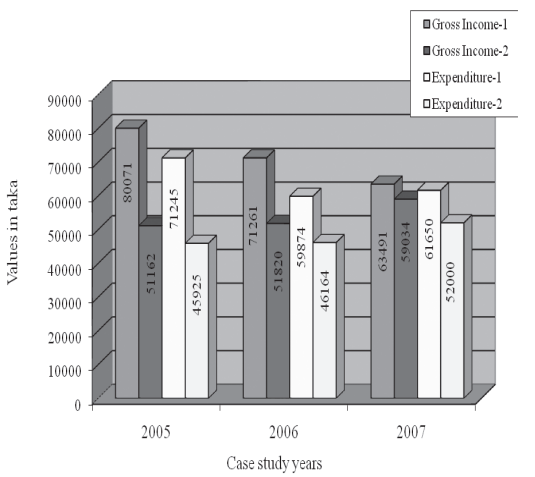

Fig. 2. Gross income and expenditure at two case study areas (Case study-1 & 2)

respondent were TK. 45,925.00 in 2005, TK. 46,164.00 in 2006 and TK. 52,000.00 in 2007 subsequently the opportunity lost were TK. 43,270.00, TK. 45,680.00, TK. 50,075.00 during 2005, 2006 and 2007 respectively. Depending on the collected data during CS-2 it was revealed that, to clean and develop awareness for 01 Km up and downstream of the river from the position of CS-2 respondent would be TK. 4,17,34550.00, TK. 26,20,500.00 and TK. 7,22,500.00 in 2005, 2006 and 2007 respectively. From the CS report it was shown that, if the local community/government invest that amount of money in return the stakeholder (community and government) residing adjacent to this river will get more return with comparison to spent money. The following are the graphical representation of the income expenditure and opportunity lost for the specific CS.

The opportunity lost for CS-1 area is much lesser than the CS-2 area. Likewise the river and water ways cleaning cost of the CS-2 area (Fig. 3) is higher than that of CS-1 area. The cleaning cost of CS-2 area will be gradually decreased and subsequently income will be increased. From the study it was found that, the cleaning cost is suggested to be collected through the following arrangements: (i) the surrounding community may be involved for successful cleaning program of the Shitalakhya river either giving money or labor, (ii) the neighborhood may be involved for policing for the follow up cleaning/ restoration and maintenance program, (iii) the project activities and increased income can be distributed according to the proportion of shared expenditure by the respondents around the project area and (iv) the local elected members, Member of National Parliament and local administration should have involvement and commitment for the cleaning and income generation program in accordance with lawful accountability to the community.

Through CS it has been found that after accomplishment of cleaning program, the possible income generation avenues is expected to be as follows: (i) Fish and Oyster culture will be increased including their breeding, (ii) amateur fishing licenses may be sold to the anglers, (iii) attraction of tourists in the project area, (iv) water cost for irrigation and industries at the surrounding areas for water users and (v) polluters will be charged for specific cases along with possible heavy penalty following the Common and Environmental laws which are in place.

Development of Mathematical Model

Direct losses are usually calculated in Bangladesh for assessment of environmental damages and for subsequent compensation. Usually for this type of damage assessment requires to be adjusted through the integration

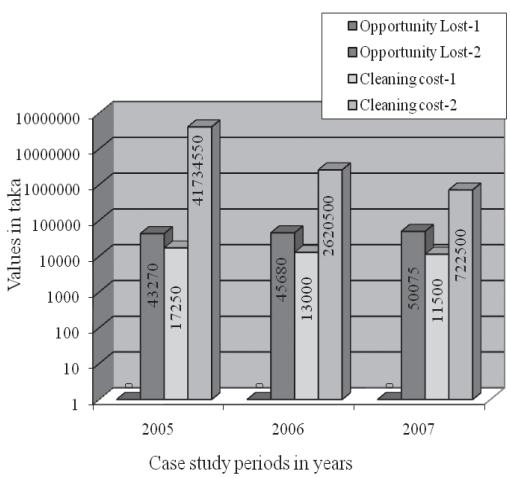

Fig. 3. Opportunity lost and cleaning cost at two case studies areas (Case Study-1 & 2)

of non-market benefits and nonuse values, which are often overlooked as for example; aesthetical values, landscape values, heritage and traditions, opportunity lost and time values. These components need to be calculated in association with other direct assessment of Environmental damages in the study area for comprehensive damage assessment (Alam *et al.*, 2006).

Under the above circumstances, a suggested Mathematical Model has been developed using the data of two case studies. This model can assess environmental damages in terms of TK. and the assessed fine out of that environmental damages can be charged to the point and non-point polluters around the study area. Through the above mentioned ways the restoration of the Shitalakhya river ecology can be accomplished for economical sustainable return (Ahammed and Harvey, 2004; Derek, 2004). Besides, in 2009 the Shitalakhya River has been declared as Ecologically Critical Area (ECA) but still the trend of pollution is becoming unstoppable.

On the basis of those two CS at polluted and non-polluted area, the yearly income and projected loss of agro-fisheries, health, job and opportunity etc. were recorded for 2005 to 2007. The natural damages, agro-fishers, health etc. were plotted in statistical model which was resulted as a linear expression and graphs have been presented in a deviation with 5% error (Figure 4a, 4b, 4c). The analyzed R^2 value indicates the dependent variables can be predicted through independent variables in this study (Figure 4a). In CS-1 the difference between income and expenditure are gradually decreasing. In the CS-2 it appears from the R^2 value that the dependent variables can also be predicted by independent variables. In CS-2 the income and expenditure both are showing increasing trend due to incidental expenses.

The comparison between income of CS-1 and CS-2 are shown in the figure 4c and the dependent variables for both studies are positively related with independent variables which materialize from the R^2 values. The regression equation and the corresponding R^2 values for CS-1 & CS-2 are given in the following table (Table 1).

On the basis of the statistical analysis the following mathematical expression has been established for the assessment of environmental damages. The following suggested model has been computed through trial and error:

Total loss (TL) $\propto$ (DL+IL+EL) or,---Equation-1
TL = K (DL+IL+EL) ---------- Equation-2

Where,
TL= Total Loss
DL= Direct Loss
IL= Indirect loss including recreational and aesthetic values
EL= Environmental Losses
K (Constant) =1, in this particular case

Direct loss (DL)-

$$DL = \Sigma (D_1 + D_2 + D_3 + ...D_n) \text{ ------ Equation-3}$$

Indirect loss (IL)-

$$IL = \Sigma [I_1(1+X_i/100)^{y1} + I_2(1+X_i/100)^{y2} + I_3(1+X_i/100)^{y3} + ...+ I_n(1+X_i/100)^{yn}]$$
---------- Equation -4

Environmental loss/ damage (EL / ED)-EL/

$$ED = \Sigma[(E_1(1+X_i/100)^{y1} + E_2(1+Xi/100)^{y2} + E_3(1+Xi/100)^{y3} + ...+ E_n(1+Xi/100)^{yn}]$$
----------Equation-5

Table 1. The regression equation and the corresponding R^2 values

Study Area	Variables	Regression Equation	R^2 values
Case Study-1, (Clean Area)	Gross income	y = -8290x +2E+O7	0.998
	Expenditure	y = -4797x +1E+O7	0.615
Case Study-2, (Polluted Area)	Gross income	y = 3936x -8E+O6	0.812
	Expenditure	y = 3037x -6E+O6	0.779

Development of Computer Software: Using the above mathematical expression a computer software has been developed using visual basic language (Figure 5). This computed mathematical expression can be used by the entrepreneur for Environmental Impact Assessment (EIA), Social Impact Assessment (SIA) and Disaster Impact Assessment (DIA) prior to establish any industry at the study area or other locality in Bangladesh. Through using this model the prediction of environmental, agro-fisheries, health other damages can be assessed.

Conclusion

The present study concludes that the river water of the study area was highly polluted so, the river water of study area is not suitable for fish culture, irrigation, household uses and recreational purposes. Inhabitants living around the project area are also suffering from continuous pollution, diarrheal diseases, skin diseases and food poisoning related cases which are ultimately forcing them to migrate from their original possession. The catch fishes from the Shitalakhya river are also not safe for consumption.

For assessment of environmental and associated damages the developed Mathematical Model may be used at decision making level. Out of reclaimed river system the environmental and economic benefits may be shared among the contributing members of community people residing around the polluted area. This model may be professionally used in other parts of Bangladesh for further sustainable industrial development. The findings and knowledge gathered from this study including the Mathematical Model may be shared for further improvement of the river water and reclamation mechanisms to promote earnings out of reclaimed river. On the other hand for restoration of the polluted river water, the exact amount of assessed fine may also be charged to the point and non-point polluters of the study area and for other polluted river systems in Bangladesh. A portion of this collected fine may also be distributed to the aggrieved community as upfront compensation.

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