Water Resour Manage
DOI 10.1007/s11269-007-9167-y

Spatial Assessment of Water Quality in Peripheral Rivers of Dhaka City for Optimal Relocation of Water Intake Point

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Received: 21 December 2005 / Accepted: 27 March 2007

Abstract In order to meet the ever increasing demand of drinking water, Dhaka Water Supply Authority (DWASA) of Bangladesh has installed a number of deep tube wells that tap the upper aquifers. However, in most parts of the city, the current groundwater abstraction exceeds the recharge rate, causing the groundwater to be mined systematically and be depleted of its reserve. Thus, there is an urgent need to alleviate the demand on the upper aquifers and explore more sustainable sources to augment the present water supply. This implies a conjunctive use of groundwater and surface water in order to maintain the balance between anthropogenic demand and water's natural availability. However, the surface water along these peripheral rivers is known to be highly polluted due to municipal and industrial untreated wastewaters that are discharged. This study analyzes the present water quality scenario along the surrounding rivers of Dhaka City pertaining to a 2-day field survey during the dry season of 2005. It uses a Geographic Information System (GIS) as a tool to arrive at a solution for relocation of the current intake point for surface water withdrawal. Derivation of water quality profiles (as a function of distance) along the downstream and upstream reaches of the current intake location indicated that a new location 12 km upstream of the present intake point could potentially be ideal for withdrawing surface water during the monsoon season. Such a proposed location was considered optimal due to the anticipated moderate construction costs of the transmission system that would be necessary to draw water to the current treatment plant. The study lays the foundations for the Dhaka City planners and designers to make a qualitative resource assessment of surface water. Such an assessment can eventually evolve to a long-term monitoring system of water supply sources for any city using GIS tools.

Keywords Water supply · Peripheral rivers · Conjunctive use · Surface water · Ground water · Industrial pollution · Spatial analysis · GIS tools

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1 Introduction

Today, there are many cities worldwide facing an acute shortage of water. Dhaka City (the Capital of Bangladesh) is one such city that is labelled as a mega city (i.e., cities with population exceeding 10 million; Haigh 2004; Karn and Harada 2001). The Dhaka Water Supply and Sewerage Authority (DWASA) is entrusted with supply of piped water in the Dhaka Metropolitan and its adjacent area. The present water supply coverage is 75%, out of which 83% is derived from groundwater sources using a network of 441 Deep Tubewells (DTW). The remaining 17% of the water is derived from surface water bodies comprising the peripheral rivers around Dhaka City (Fig. 1) which is treated by water treatment plants before entering the distribution system. Since 1971, the population of Dhaka City has grown from about 1 million to more than 12 million in 2005. In another 20 years, Dhaka is projected to have a population of about 20 million (Fig. 2; Bangladesh Bureau of Statistics 1998). This population increase would create an additional water supply demand of 42% which has to be met either from the surface water sources or by sinking additional DTWs.

In order to meet the ever increasing demand, DWASA has installed an increasing number of DTWs that tap the upper aquifers. However, this groundwater source is limited in supply. In most parts of the city, the groundwater abstraction exceeds the recharge rate, causing the groundwater to be mined systematically and be depleted of its reserve. The average groundwater depletion in most areas in the city is reportedly around 1–3 m/year. The present rate of depletion is alarming because it can potentially cause environmental hazards such as land subsidence, prolonged water logging, alteration in vegetation etc (Kabbour and Zouhri 2005; Karami and Hayati 2005; Haigh 2004). Thus, there is an urgent need to alleviate the demand on the upper aquifers and explore more sustainable sources to augment the present water supply. One potential solution is the conjunctive use of groundwater and surface water in order to maintain the balance between anthropogenic demand and water's natural availability for usage and recharge (Onta et al. 1991; Ejaz and Peralta 1995; Emch and Yeh 1998).

Searching for a sustainable solution can, however, be matter. Although Bangladesh is a riverine country, and Dhaka City is surrounded by rivers in its periphery, improper river water quality does not allow its convenient use. The surface water along these peripheral rivers is known to be highly polluted due to municipal and industrial untreated wastewaters that are discharged into these rivers (Subramanian 2004; Karn and Harada 2001; Kamal et al. 1999). The high level of water pollution consequently limits the capacity for water intake by the treatment plant from the existing point (Fig. 3). On the other hand, while alternative options for augmenting the water supply could be considered, such as, desalination of seawater from the Bay of Bengal; rainwater harvesting, ultra-pure treatment of spent water, these options would be costly from a financial and technical standpoint. Thus, optimal use of available water resources in Dhaka City has to depend on a spatial assessment the surface water quality along the peripheral rivers in order to identify a suitable alternative to relocate the intake point. Such a relocated point, where water quality within the tolerable limits for treatment, would allow sufficient flow rates for the water treatment plant and facilitate the conjunctive use of surface water and groundwater (Karn and Harada 2001).

This paper demonstrates spatially, using a Geographic Information System (GIS) tool, the existing level of some water quality parameters along the peripheral rivers around Dhaka City. A GIS-based assessment is undertaken to arrive at an optimal alternative for relocation of the current intake point for surface water withdrawal. Like many other

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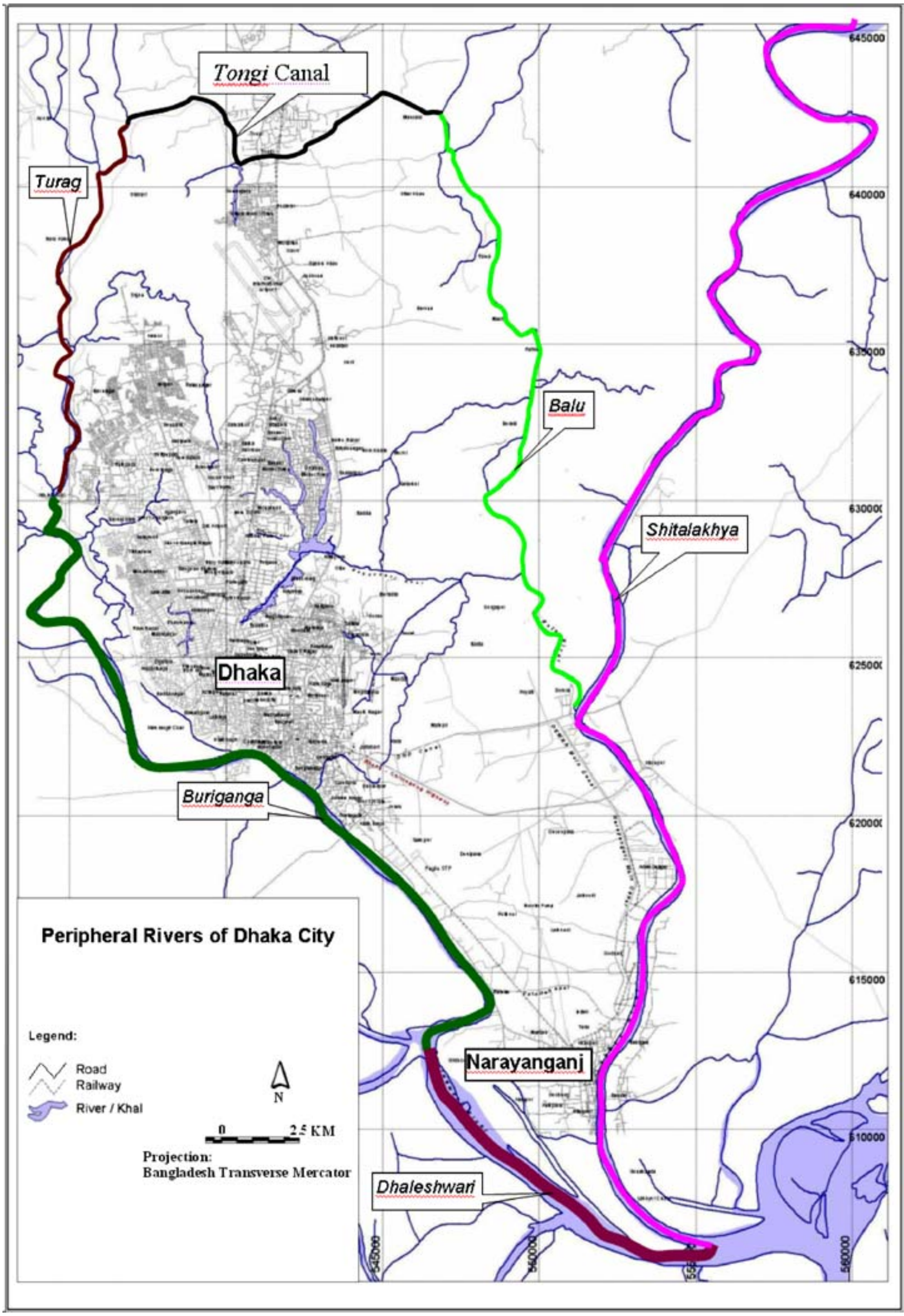

Fig. 1 Map of peripheral rivers around Dhaka City

environmental management projects, GIS is the most suitable tool for such a geo-spatial assessment and visualisation. The maps that can be created with sampled water quality data and relevant GIS tools can help both decision makers and general people to understand the present scenario. A visual display can also facilitate decision makers to

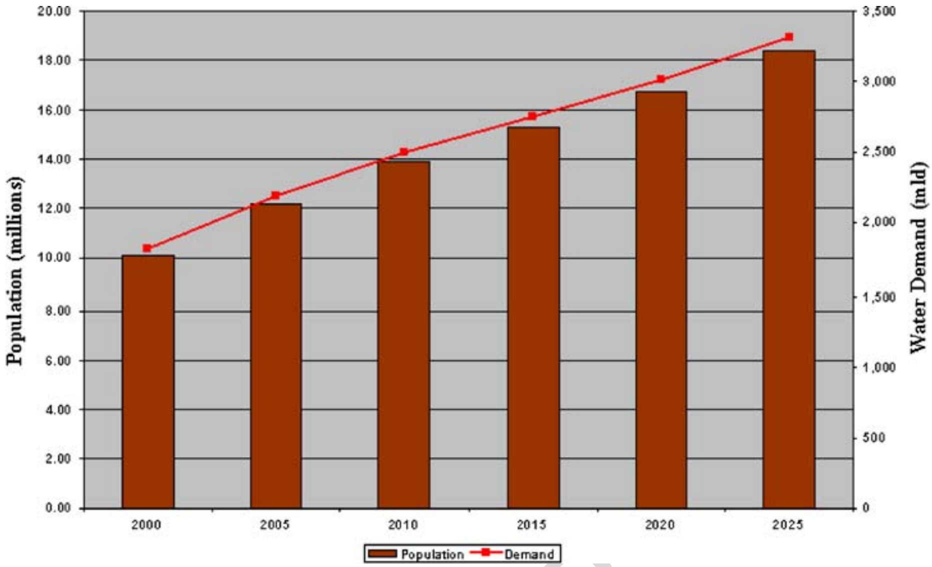

Fig. 2 Population and demand projection for Dhaka City. (Population data was taken from Bangladesh Bureau of Statistics 1998)

efficiently brainstorm a suitable alternative for intake point where the water quality is acceptable and therefore amenable to greater withdrawal to meet the anticipated additional demand.

The specific objectives of this study were therefore to:

- Develop a GIS based map of the study area showing the WQ sampling points
- Provide information on existing level of some major water quality parameters at those sampling points.
- Identify qualitatively a suitable location for the withdrawal of surface water using a graphical GIS interface.
- Develop a geographic information base on river water quality that can serve as a guiding tool for future projects by water resources managers and policy planners.

In particular, this study, through a GIS-based exploration of existing water quality, aims to demonstrate a possible strategy for water resources managers to lay the foundations for efficient qualitative assessment of surface water. Such assessment can eventually evolve to a long-term monitoring system of water supply sources for any city using GIS tools. The study can also facilitate water quality modellers select the proper water quality model and help in formulating the strategy for water abstraction and water supply.

2 Study Area

The Dhaka Water Supply and Sewerage Authority (DWASA), was established in 1963 with a broad mandate to provide water supply, disposal of domestic and industrial sewerage,

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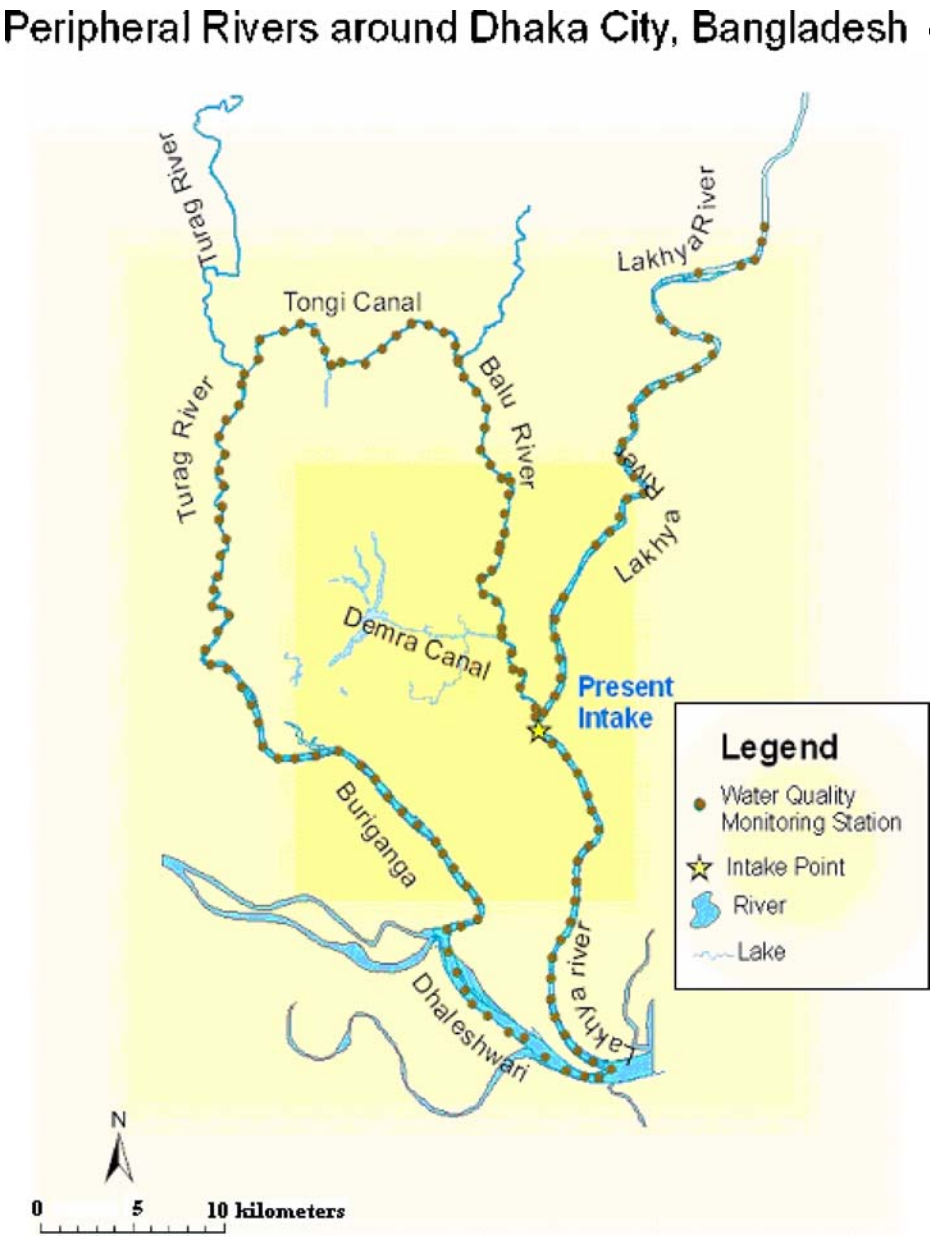

Fig. 3 Map of sampling locations at peripheral rivers of Dhaka City

storm water drainage and solid waste management for Dhaka City. However, DWASA has traditionally dealt with water supply and treatment and disposal of sewerage. The total area under the coverage of DWASA is 470 km^2. Management is divided into a total of seven zones (Fig. 4). Daily water supply/pumping for surface water and groundwater is 1,500 and

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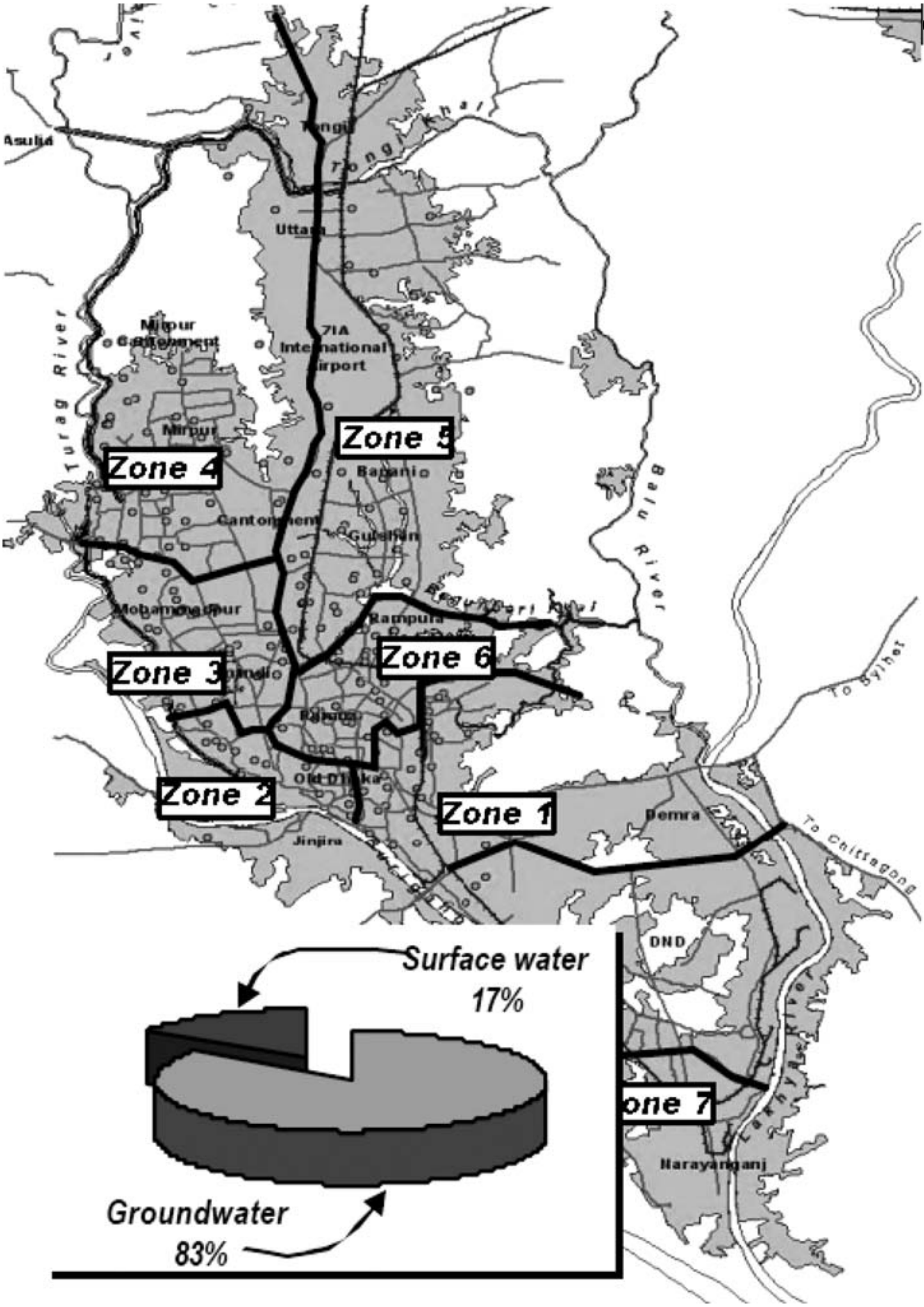

Fig. 4 Administrative zones of the Dhaka Water Supply and Sewerage Authority. Inset – the relative proportion of water supplied by DWASA from surface and groundwater sources

310 million liters per day (mld), respectively. Table 1 provides a summary of the current water supply system of Dhaka City that is maintained by DWASA.

Dhaka City is located between 23°35′ to 23°54′ North Latitude and 90°20′ to 90°33′ East Longitude and is encompassed by six water ways (five rivers and one canal; Fig. 1; Karn

Table 1 Summary of the water supply system of Dhaka Water Supply and Sewerage Authority (DWASA)

Areal coverage (km^2)	470
Number of connections	212,543
Total length of pipeline (km)	2,500
Surface water supply (mld)	310
Groundwater supply (mld)	1,500
Number of deep tubewells	441

and Harada 2001). These waterways constituted the following routes that were adopted for the water quality sampling of Dhaka's available surface water resources:

1. Tongi Canal–Balu river
2. Tongi Canal–Turag river–Buriganga river–Dhaleshwari river
3. Shitalakhya River

The study encompassed the entire reach of the Tongi Canal, partial reach of the Turag (from the confluence of Turag and Tongi Canal to the confluence of Turag and Buriganga rivers), partial reach of the Balu river (from the confluence of Tongi Canal and Balu river to the confluence of Balu river and Shitalakhya river at Demra), partial reach of the Dhaleshwari river (from the confluence of Buriganga and Dhaleshwari rivers to the confluence of Dhaleshwari and Shitalakhya rivers at Kalagachia) and finally, partial reach of the Shitalakhya river. Figure 1 summarizes the pertinent river routes studied in this project.

3 Methodology

As a preliminary step for initiating the project, a map of the study area showing Greater Dhaka and the peripheral rivers was first developed with the aid of existing GIS themes on Rivers, lakes and present intake point of water withdrawal from the rivers. In addition, sampling locations from GPS data needed to be digitized along with collected water quality (WQ) data. The water quality data was already available in digital format (carried out in 2005) but it needed to be interfaced with GIS. Hence, attribute tables were created with relevant water quality data for the spatial analysis of the study.

As a next step, the sampled water quality parameters were compared with the recommended (i.e., Bangladesh Government) water quality limits as a function of distance from the current intake point for the spatial assessment of the current scenario on surface water pollution. The distance from the current intake point serves as an important indicator of cost-effectiveness of any proposed relocation. Because the existing water treatment plant is situated at the current intake point, this distance would signify the length of transmission pipeline that would have to be constructed for withdrawing water from the relocated point.

After creating the GIS map for the study area, a geospatial analysis was performed on the basis of present scenario and with the help of GIS graphical interface. This analysis consequently facilitated a qualitative identification of a suitable (new) location for water withdrawal from surface water (discussed later in detail). For the purpose of data input and processing as well as plotting of water quality profiles, the common software of *Microsoft Excel*™ was used. Conversion of coordinates of the WQ sampling points as obtained from the GPS was performed using the Coordinate Calculator Utility available in the software *HydroPro*™. This software converted the WGS84 coordinate system (latitude, longitude) to the Everest 1830 system for projection on the Bangladesh Transverse Mercator (BTM).

Finally, the study used Environmental Systems and Research Institute (ESRI)'s software *ArcGIS*™ for all GIS analysis. *ArcGIS* allowed the creation of maps, geolocation of WQ sampling points on the map and spatial queries, among other applications.

4 Data Collection for Water Resources Assessment

The following data were collected for the study:

- The coordinates of the WQ sampling locations using GPS
- Level/concentration of the tested WQ parameters
- WQ Parameters:

  ➢DO (Dissolved Oxygen)
  ➢BOD (Biochemical Oxygen Demand)
  ➢COD (Chemical Oxygen Demand)
  ➢NO_3–N (Nitrate–Nitrogen)
  ➢PO_4 (Phosphate)
  ➢NH_3–N (Ammonia–Nitrogen)

These water quality parameters were selected because of their significance on aquatic life and human consumption (Pehlivan and Yilmaz 2005). This is elaborated in the section that follows (see Table 2 for Bangladesh Standards – taken from DoE 1991).

Dissolved Oxygen (DO) As oxygen is a necessary element for virtually all forms of life, adequate DO is necessary for ensuring water quality. When the dissolved oxygen levels drop too low, many aquatic species may perish. In addition, a healthy DO level (>3 mg/l) yields aesthetically pleasing quality in terms of smell and appearance. Low DO can result in foul-smelling water causing water to become septic in many cases. A low DO level is also an indication of elevated temperature that can alter the balance of aquatic life in the rivers.

Biochemical Oxygen Demand (BOD) A high BOD is an indication of abundant organic content in water originating from untreated sewage by industrial and municipal units. Typically, the BOD due to industrial sewage is many times that of domestic sewage. When

Table 2 WQ sampling of the peripheral rivers of Dhaka City

Sl. No.	Waterways surveyed	Surveyed length (km)	Number of testing samples					
			DO (in-situ)	BOD	COD	NO_3–N	PO_4	NH_3–N
	Safe Limits		>3 mg/l	0–3 mg/l	0–5 mg/l	0–1.5 mg/l	0–0.01 mg/l	0–1.5 mg/l
1	Lakhya	57	52	14	14	14	14	14
2	Balu	23	27	8	8	8	8	8
3	Buriganga	39	19	5	5	5	5	5
4	Turag	11	21	4	4	4	4	4
5	Tongi Khal (canal)	14	17	4	4	4	4	4
6	Dhaleshwari	12	11	4	4	4	4	4

sewage enters a surface water body such as river, micro-organisms begin to decompose the organic materials by consuming the DO of river water. This can quickly deplete the available oxygen and subsequently affect aquatic life. Also, when organic compounds decompose under low DO conditions, it can give rise to undesirable odors usually associated with septic or putrid conditions (Pehlivan and Yilmaz 2005).

Chemical Oxygen Demand (COD) COD is considered an indirect measure of the foulness of wastewater. Most applications of COD determine the amount of organic pollutants found in surface water (e.g. lakes and rivers), making COD a useful indicator of water quality.

Nitrate–Nitrogen (NO_3–N) Nitrate reactions [NO_3–N] in fresh water can cause oxygen depletion. Thus, aquatic organisms depending on the supply of oxygen in the stream can perish. The major routes of entry of nitrogen into bodies of water are municipal and industrial wastewater, septic tanks, animal wastes (including birds and fish) and discharges from car exhausts. Excessive amounts of nitrogen can speed up the eutrophication process, natural nutrient enrichment of streams and lakes and is responsible for the “algal blooms” of ponds, lakes, and reservoirs. As algae grow and then decompose, they deplete the dissolved oxygen in the water. This condition usually results in fish kills, offensive odors, unsightliness, and reduced attractiveness of the water for recreation and other public uses. But a certain amount of nitrogen is essential for any life to exist in water (Sundaray et al. 2005).

Ammonia–Nitrogen (NH_3–N) Ammonia is extremely toxic and even relatively low levels pose a threat to fish health. Excess ammonia increases the load on the nitrifying bacteria in water (Sundaray et al. 2005).

Phosphate (PO_4) Phosphate stimulates the growth of plankton and aquatic plants which provide food for larger organisms in the aquatic food chain. Initially, this increased productivity can cause an increase in the fish population and overall biological diversity of the system. But as the phosphate loading continues, the aging process of the surface water ecosystem can be accelerated. The overproduction of phosphate in lakes or rivers can lead to an imbalance in the nutrient and material cycling process. This overproduction due to nutrient can lead to a variety of problems ranging from anoxic waters (through decomposition) to toxic algal blooms (eutrophication) that eventually decrease aquatic diversity and cause habitat destruction.

All data were collected by the Institute of Water Modelling (IWM; http:// www.iwmbd.org) located in Dhaka, Bangladesh where it was preprocessed and quality controlled prior to use in this study. The period of WQ sampling spanned 26–27 February, 2005. This period is representative of the period of the dry season when flows are very flow. The low flow conditions in the rivers result in pollution trends to be at its highest levels due to non-existent runoff from rainfall that otherwise dilutes the pollutant concentrations (such as during the Monsoon season spanning July–September). Thus, the sampling period was considered ideal for the objectives of the study because it would further reduce the exceedance probability for the relocated point to experience a worsening of water quality. All samples were tested in Environmental Laboratory of Bangladesh University of Engineering and Technology (BUET; http://www.buet.ac.bd). The DO values were measured in-situ with the aid of digital DO meter. The coordinates of the sampling points were recorded with a hand-held GPS. The DO was measured approximately after every 1 km distance while samples for testing other WQ parameters (Table 3) were collected after every 5 km (Fig. 3). The relatively lower sampling Q2

Table 3 Comparison of WQ parameters at present and proposed intake points

WQ parameter	Acceptable limit[a] (mg/l)	Present intake (mg/l)	Proposed intake (mg/l)
DO	>3	1.66	4
BOD	<3	9.4	2.4
COD	<5	13	4.4
NH_3–N	0–10	2.3	0.11
NO_3–N	0–1.5	1.6	0.7
PO_4	0–0.01	4.8	0.74

[a] Acceptable limits are based on DoE (1991)

density for non-DO WQ parameters was dictated by issues of cost of testing at the laboratory in BUET, time and the care needed in carefully collecting the samples. Samples were collected at the immediate upstream and downstream of the confluence of rivers and canals (Fig. 3). Table 2 provides the total length sampled and number of samples taken for each river.

5 Results and Discussion

Six maps were first produced to geographically demonstrate the present water quality situation by considering the sampled WQ parameter values on DO, BOD, COD, NH_3–N, NO_3–N and PO_4 with the Bangladesh Standards for surface water. These maps are shown in Fig. 5 and were created on the basis of limiting range of water quality parameter according to Bangladesh standards. Red indicates water quality in sampled station that exceeds limiting range (i.e. dangerous or alarming) and Green indicates water quality to be within permissible limits. A preliminary review of these six maps reveal the following general outline on the current water quality scenario:

- Water quality at the existing intake location exceeds permissible levels for all WQ parameters except NO_3–N (indicated in red; Fig. 5).
- River reaches along the Tongi canal, Balu river, Turag river, Buriganga river and Dhaleshwari river are highly polluted.
- Though pollution is severe at the downstream end of Lakhya river, water quality appears comparatively more acceptable at the upstream end.
- NO_3–N is within permissible range along the entire reach of the peripheral rivers.
- Phosphate exceeds the limiting range along the entire reach of the peripheral rivers.
- Lakhya river appears ideal for relocation of the intake point because its upstream reach satisfies most of the WQ standards (DO, BOD, COD, NH_3–N, NO_3–N, with the exception of PO_4).

For a closer inspection, water quality profiles along the reach are shown in Fig. 6 for the Lakhya river using GIS tools. It becomes apparent from Fig. 6 that the present intake location is highly polluted. In addition, the reach downstream of the current intake point is also unsuitable for relocation of the intake point due to the high level pollution exceeding the permissible limits. This high level of pollution is attributed to the rampant discharge of waste originating from the industrial region on the eastern periphery of Dhaka City that is not regulated via treatment plants maintained by DWASA (Fig. 4). Pollution is also high at the confluence of Balu and Lakhya rivers. This can be explained from the fact that Balu river

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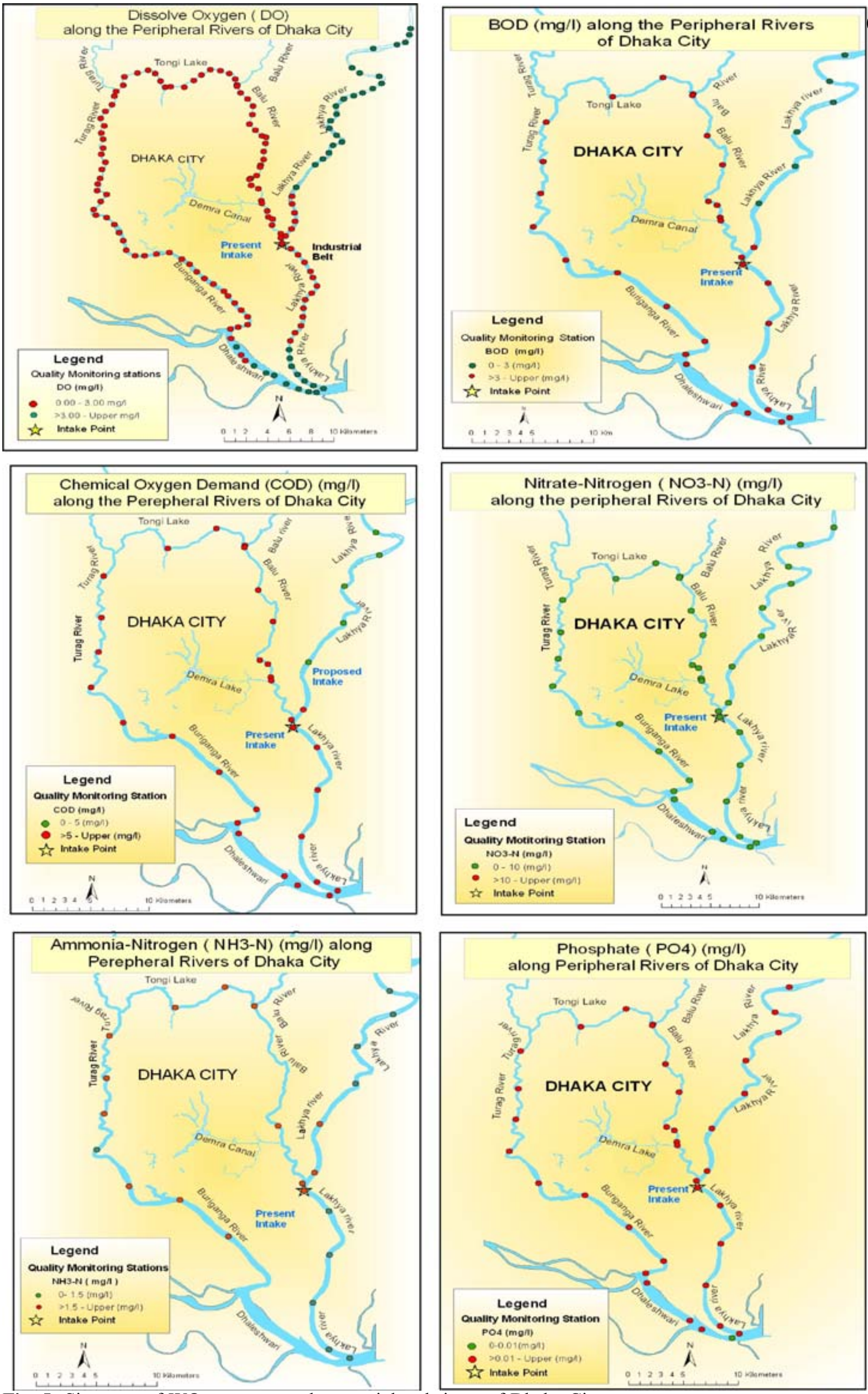

Fig. 5 Six maps of WQ parameters along peripheral rivers of Dhaka City

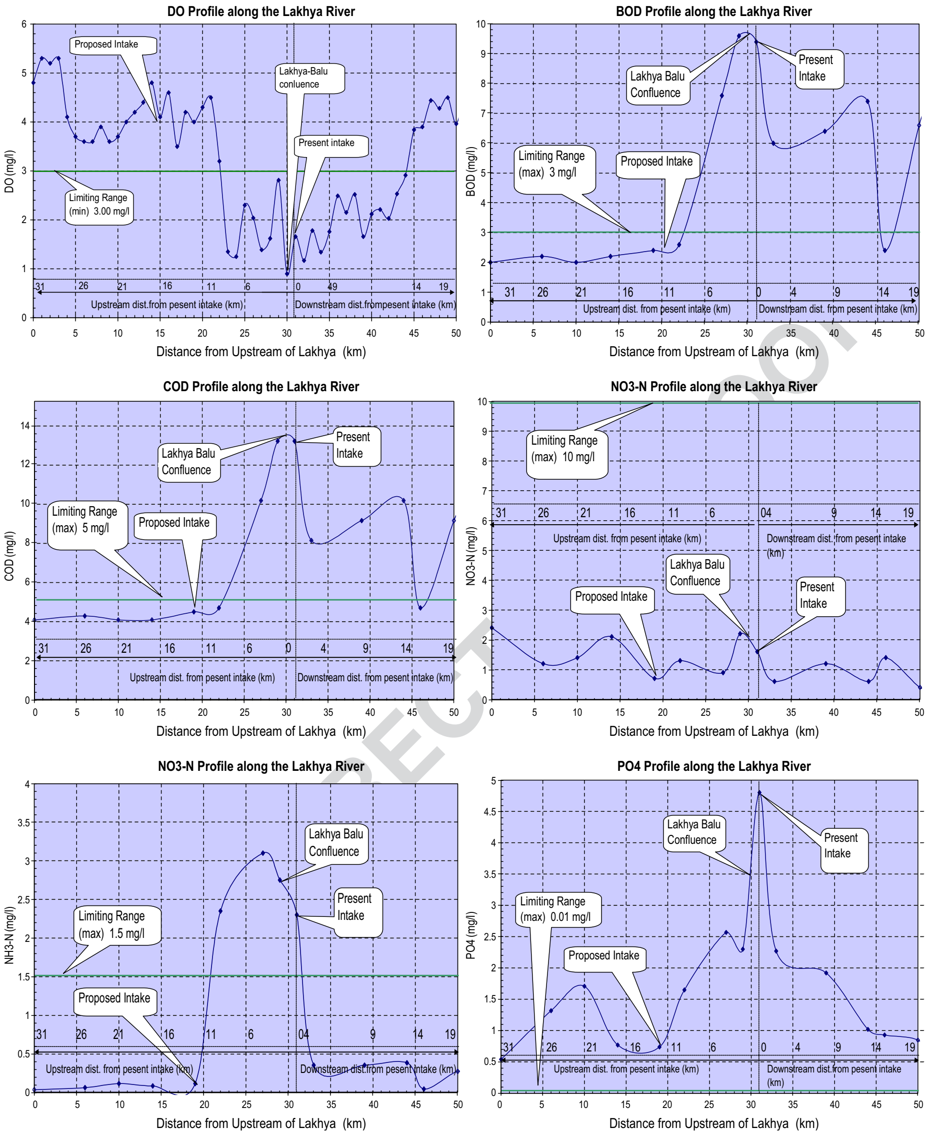

Fig. 6 Plots of water quality as a function of distance from present intake point

receives both domestic and Industrial wastes from Tongi (an industrial town in the northern periphery of Dhaka City) and Turag river leading to severe pollution at the confluence point. However, this pollution fails to spread to the upstream reaches of the Lakhya river because advective flow is always along the downstream direction.

Given the above assessment, the following three remedial measures could be considered:

1. Identify a suitable location for intake at the upstream reach of Lakhya river.
2. Regulate discharge of industrial waste in the Lakhya river.
3. Enforce treatment of industrial waste through wastewater treatment plants.

Due to the scope of the present study, only the first option was considered. A particular point to note herein is that the downstream reach of the Lakhya river can not be considered for relocation of the intake point for the additional constraint of temporally variable flow due to tidal effects from the Bay of Bengal. A subsequent query-based GIS analysis revealed a location 12 km upstream of the present intake location as a suitable point for future intake. This point is considered ideal from two standpoints: (1) the water quality is within acceptable limits (with the exception of PO_4); and (2) the cost of building the additional transmission system for withdrawing water from this relocated point to the current water treatment plant is unlikely to be prohibitive. These two factors jointly represent an acceptable compromise that is manifested in Fig. 6. In addition, GIS maps in Fig. 7 are shown below to demonstrate qualitatively the relative significance of the proposed intake point vis-à-vis other potential candidate points. Based on the analysis of Fig. 6 made possible by GIS, it is observed that most of the WQ parameters are within the safe limit at the proposed location. Table 2 provides a comparison of WQ parameter values for the present and proposed intake locations.

6 Conclusion

This study demonstrates the value of GIS as a tool to spatially analyse the water quality parameters along the peripheral rivers of Dhaka and thereby arrive at a solution for relocation of the intake point for surface water withdrawal under a severe pollution scenario. First, a map of the study area showing Greater Dhaka and the peripheral rivers was developed with the aid of existing themes on rivers, lakes and present intake point of water withdrawal from the rivers. Sampling locations from GPS data were then digitized along with collected WQ data. Attribute tables were updated with relevant water quality data for the proposed spatial analysis. Next, the WQ parameters at the sampled locations were compared with the Bangladesh standards to identify locations that appeared suitable for water intake. GIS analyses facilitated the derivation of water quality profiles (as a function of distance) along the downstream and upstream reaches of the current intake location. This helped to consider in the additional constraint for relocation of intake that will be imposed by the construction cost of the transmission system necessary to draw water to the current treatment plant. Additional GIS maps further helped to spatially visualise the relative significance of the proposed intake location among the pool of candidate solutions.

This GIS based study has made it apparent holistically that the peripheral rivers are currently not suitable as a source for water supply for Dhaka City in the dry season because of its deteriorating water quality. The analysis has also made it obvious that river waters could be used during the monsoon season (when the water quality is good due to dilution effects from runoff) and ground water during dry months. During the monsoon season, river flows typically increase anywhere from 50% to 90% due to substantial transboundary flow from upstream India (Hossain and Katiyar 2006). Therefore, under this conjunctive arrangement, the groundwater would be exploited optimally allowing it to be recharged during the rainy season for withdrawal in the next dry season that will follow. However, more detailed study involving flow duration curves and water quality modelling would be required to confirm that the both water quantity and quality available during the monsoon season would be adequate for a conjunctive and sustainable use. Overall, the work has laid the foundations for the Dhaka City planners and designers to make a qualitative resource assessment of surface water. Such an assessment can eventually evolve to a long-term monitoring system of water supply sources for Dhaka City using GIS tools. The study can

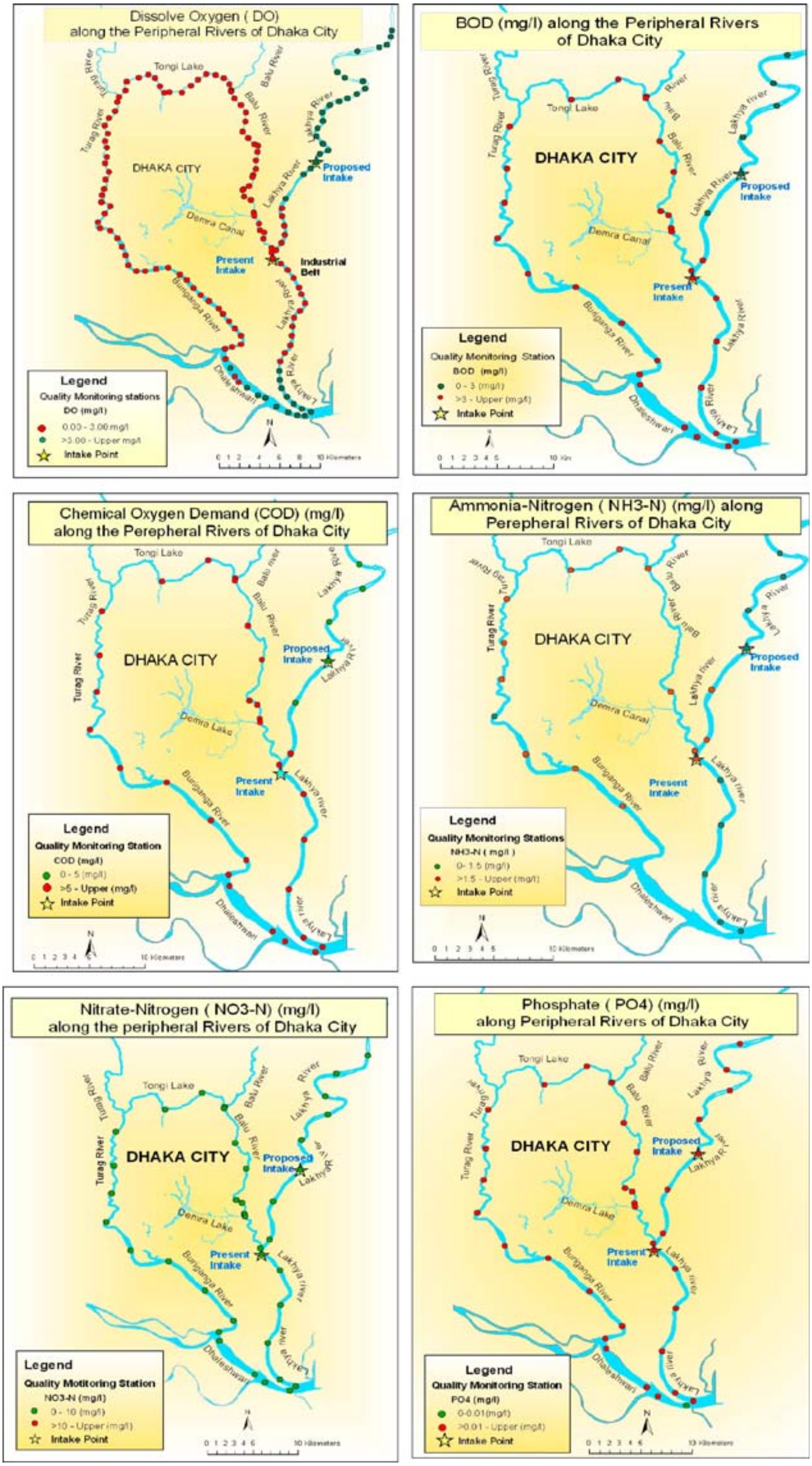

Fig. 7 Present and proposed intake point for withdrawal of surface water for Dhaka City

also facilitate water quality modellers choose the proper water quality model and help in formulating the strategy for water abstraction and water supply for Dhaka City.

Acknowledgement The authors wish to thank the Water Resources Planning Division of the Institute of Water Modelling (Dhaka, Bangladesh) for data on the peripheral rivers of Dhaka. In particular, support received from Mahbubur Rahman, Head of WRP Division is gratefully acknowledged. Support for this work was initiated with the 5-year Memorandum of Understanding between Tennessee Technological University and Institute of Water Modelling that took effect in 2006. The authors take sole responsibility for the views expressed in this work.

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