Nadia Binte Jamil[1]
Kazi Matin Ahmed[1*]

Vulnerability Assessment and Groundwater Resources Planning for Tongi Industrial Area, Bangladesh

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[1.] *University of Dhaka, Dhaka-1000.*
[*] ***Corresponding author***
E-mail: kmahmed@du.ac.bd

Abstract

Groundwater pollution risk assessment from industries has been conducted in order to prepare a water resources management plan for Tongi, the largest and oldest industrial area of the country. Most of the over 200 industries located there discharge untreated solid and liquid wastes into lowland or open water bodies posing serious threats to water resources. DRASTIC model has been used to assess groundwater pollution risk of the study area and Geographical Information System (GIS) overlay procedure has been used for producing various maps. A Groundwater Vulnerability Map (GVM) has been prepared on the basis of seven hydrogeological parameters of DRASTIC model for identifying low, moderate and high vulnerable zones. The high vulnerable zone encompasses the low lying areas along the water courses whereas the central relatively elevated part has been found to be least vulnerable. Potential Hazardous Activity Map (PHAM) and Hot-spot Map have been prepared to show the point sources of pollution located at different risk zones. Finally, a Groundwater Resources Planning Map (GRPM) has been produced based on DRASTIC vulnerability index. The GRPM exhibits that the low lying area near riverbanks as the high risk zone which should not be used for polluting industries. However, industrial activities may take place within the low risk zone confined to the central elevated area. This approach can be applied for other industrial areas of the country for preparing groundwater management plans.

Keywords

Groundwater vulnerability, DRASTIC model, GIS, Tongi Industrial Area, Bangladesh.

Introduction

According to UNESCO, groundwater provides about 50% of current potable water supplies over the world and has been considered as an important source of water supply due to its relatively low susceptibility to pollution in comparison to surface water and its large storage capacity (US EPA 1985). Groundwater is the first and foremost source of water supply in urban and rural areas of Bangladesh and its demand has spiraled out of control with increasing population and industrial growth. Intensive extraction, direct industrial disposal, lack of adequate sewerage system and inadequate management of solid waste disposal are the main threats to groundwater pollution. In contrast with surface water pollution, subsurface pollution is difficult to detect and even more difficult to control (Todd 2001). Spatial variability and data constraints prohibit groundwater monitoring and make remediation activities expensive and often impractical. Prevention of contamination is therefore the most effective measure for groundwater management. Proper management and protection of this resource need determination of areas where groundwater may be more defenceless to contamination due to anthropogenic activities at or near the earth's surface. Once identified, these areas can be targeted by careful land-use planning, intensive monitoring and by contamination prevention of the underlying groundwater. This study will attempt to assess groundwater pollution risk and water resources management in Tongi Industrial Area, Bangladesh. Several methods can be used for vulnerability mapping, however based on type, quality and amount of available data, this study will use DRASTIC model, the empirical model of the U.S. Environmental Protection Agency (US EPA 1985) with combined use of geographical information system (GIS). Vulnerability assessment prioritizes areas for further investigation, protection, and monitoring, thus has become an important element for sensible resource management and land use planning. Vulnerability assessments are also powerful educational tools for raising public awareness of groundwater protection issues, which is an on-going need (Nowlan 2005).

Concept of Vulnerability

The concept of groundwater vulnerability was first introduced in France by the end of the 1960s to create awareness of groundwater contamination (Vrba and

Zoporozec 1994 and Margat 1968) was the one who first used the term 'vulnerability' in Hydrogeology; thereafter the concept was adopted worldwide. (Albinet and Margat 1970; Haertle 1983; Aller et al. 1987; Foster and Hirata 1988; Adams and Foster 1992; Drew and H"otzl 1999; Zwahle 2003).

Groundwater vulnerability can be defined as the possibility of percolation and diffusion of contaminants from the ground surface into the groundwater system. Vulnerability is usually considered as an "intrinsic" property of a groundwater system that depends on its sensitivity to human and/ or natural impacts. "Specific" or "integrated" vulnerability, on the other hand, combines intrinsic vulnerability with the risk of the groundwater being exposed to the loading of pollutants from certain sources (Vrba and Zoporozec 1994).

The potential for contaminants to leach to groundwater depends on the following factors:

* Presence and nature of overlying soil
* Presence and nature of overlying drift deposits
* Nature of solid geological strata in the unsaturated zone
* Depth to groundwater table
* Recharge rate
* Environmental factors influencing the potential for biodegradation

Approaches to vulnerability assessment

Up to date, many approaches have been developed to evaluate groundwater vulnerability but there is not any recognized and accepted common definition developed yet (Samey & Gang 2008). Comprehensive reviews of vulnerability assessment methods can be found in Vrba and Zoporozec 1994, Lindström and Scharp 1995, Gogu and Dassargues 2000, Magiera 2000, Zwahlen 2003 and Hans et al. 2000.These methods can be classified in three main classes and each class has its characteristics strength and weakness that affects its suitability for particular applications. They include process based methods, statistical methods, and overlay and index methods (Tesoriero et al. 1998).

* **The process based methods** use simulation models to estimate the contaminant migration but they are constrained by data shortage and computational difficulties (Barbash and Resek 1996).
* **Statistical methods** use statistics to determine associations between spatial variables and actual occurrence of pollutants in the groundwater. Their limitations include insufficient water quality observations, data accuracy and careful selection of spatial variables.
* **Overlay and index methods** combine factors controlling the movement of pollutants from the ground surface into the saturated zone resulting in vulnerability indices at different locations. Their main advantage is that some of the factors such as rainfall and depth to groundwater can be available over large areas, which makes them suitable for regional scale assessments (Thapinta and Hudak 2003). However, their major drawback is the subjectivity in assigning numerical values to the descriptive entities and relative weights for the different attributes (Babiker *et al.* 2005)

DRASTIC Model

The DRASTIC model was developed by the U.S. Environmental Protection Agency (EPA) to evaluate groundwater pollution potential for the entire United States (Aller et al. 1987). It is the most widely used method all over the world that uses a relatively large number of parameters for the assessment of vulnerability index which ensures the best representation of the hydrogeological setting. It is based on the concept of hydrogeological setting that is defined as composite description of all the major geologic and hydrologic factors affecting and controling the groundwater movement into, through and out of an area (Aller et al. 1987). DRASTIC method is one of the PCSM (Point Count System Method) subgroup and focuses on the intrinsic factors. DRASTIC is an acronym for the seven parameters used in the model which are: Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and hydraulic Conductivity.

DRASTIC model uses a numerical index derived from weights, ratings and ranges which are three significant part of the model.

* Weights: Each factor has a fixed relative weight that reflects its relative importance with respect to the others in terms of vulnerability. The values allotted to the weights ranging from 1, given to the least significant factors to 5, allotted to the most significant factors (Tab. 4).

* Ranges: Each factor had been divided into either ranges or significant media types based on its impact on pollution.
* Ratings: A value 1 to 10 is assigned to each factor based on local conditions. High values correspond to high vulnerability. (Samey AA; Gang 2008).

The DRASTIC Index (Di) is calculated from the following formula:

DRASTIC Index, Di= Dw Dr + Rw Rr+ Aw Ar+ Sw Sr + Tw Tr + Iw Ir + Cw Cr - - - - - - (1)

Where, w= weight and r = rating.

Study Area

Tongi Pourashava lies in between latitude 23.88˚N to 23.94˚N and longitude 90.34˚E to 90.44˚E (Fig. 1). It is located to the North of Dhaka Mega city and South of Gazipur district. Total area is 32.36 sq. km. There are 12 wards within the Pourashava boundary. According to the local census the present population is approximately 6,50,000 (www.tongimunacipality.com)

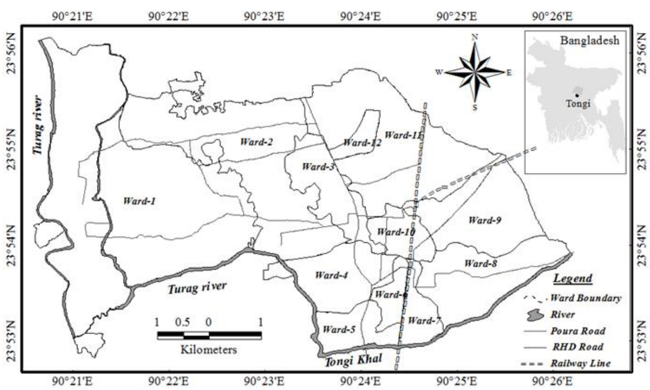

Figure1: Location map of the study area

Tectonically, Tongi area comprises the southern extension of the Madhupur Tract (under Madhupur-Tripura Threshold). Madhupur Tract is an uplifted Pleistocene Terrace bounded by the Ganges-Meghna flood plain in the east, the Brahmaputra flood plain in the north, the Jamuna flood plain in the west. The elevation of the Tract varies from 2 to 14 m above mean sea level (amsl) (Fig. 2).

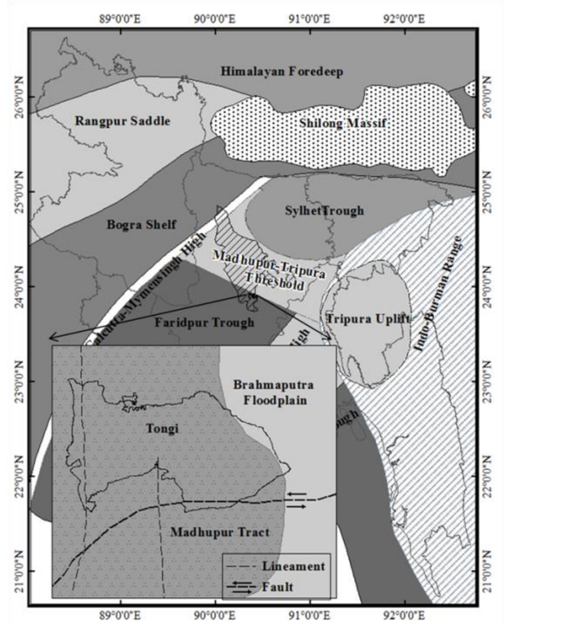

Figure 2: Tectonic map of Bangladesh showing emphasis on the study area (inset)

Karim and Haider 1994, Karim 2003 and Karim et al. 2003, Rahman and Karim 2005 identified three distinct geomorphic units of the study area (Fig. 3):

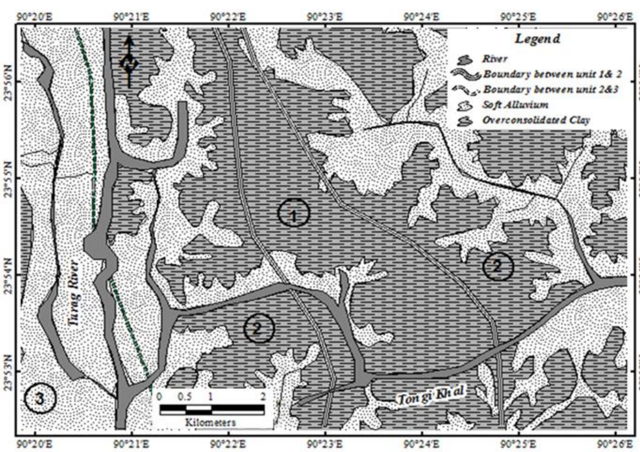

Figure 3: Map showing three geomorphic units of the study area: central high area (1), complex of high and low areas (2), complex of low areas (3)

Zone 1: Central High Area

This zone forms the axial zone and represents an elevated and north-south elongated table surface above the flood plain level (~7m from MSL). The Madhupur Clay Formation (red soil) is well exposed throughout the zone and is covered by indigenous surface soil in places.

Zone 2: Complex of High and Low Areas

This zone is characterized by saddles of Madhupur Clay alternating with gully type depressions. Elevation varies from 2-5m above MSL. The nodes of the Madhupur Clay Formation are exposed at lower elevation or buried under thin cover of young alluvium or fill materials.

Zone 3: Complex of Low Areas

This zone is a flat, low lying alluvial plains (<2m above MSL) formed of flood plain silt-sand and very soft clay-silt and is located in the western periphery of Tongi Pourasava.

The older sediment sequence of the study area consists of sandstone of the Dupi Tila Formation which is unconformably underlain by the Madhupur Formation. The Madhupur Formation is overlain by Recent Alluvium (Tab. 1 & Fig. 4).

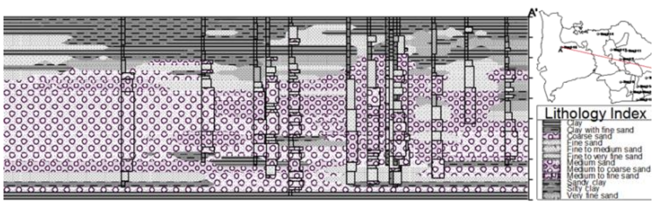

Figure 4: Stratigraphic profile of Tongi area along line AA'

Table 1: Stratigraphic Succession in and around Dhaka-Tongi Area (after Alam, 1988)

Age	Formation	Lithology	Thickness (m)
Holocene	Alluvium	***Lowland:*** *River bed deposit:* Grey sand and silty sand, medium to fine grained.	0-9
		Natural levee and interstream deposit: Sandy silt, silt and loam, grey and friable.	1.21-4.7
		Backswamp and depression deposits: Clay and silty clay, grey, bluish grey to dark grey.	0.61-1.5
		Highland: Silt and clay above the present flood level.	0-3.5
Pleistocene	Madhupur Clay	***Red clay:*** Light brown to brick red and massive, pisolitic with fossil wood, ferruginous and calcareous nodules and surficial deposits of slag. ***Mottled clay:*** Earthy grey with patches of orange, brown colour, massive and containing calcareous sand ferruginous nodules.	31
Pliocene	Dupi Tila	***Sandstone:*** Yellow to yellowish grey, massive, cross bedded, mostly fine to medium grained containing scattered gravel lenses, moderately consolidated.	90+

The main aquifer of Tongi area is confined to semi-confined Pliocene Upper Dupi Tila aquifer with three distinct subunits – an upper, middle and lower aquifer (Ahmed et al. 2002). A thick clay sequence/aquiclude (Pleistocene Madhupur clay) overlies the whole aquifer system. There are some local perched aquifers which supply water for hand tubewells (Tab. 2 & Fig. 5).

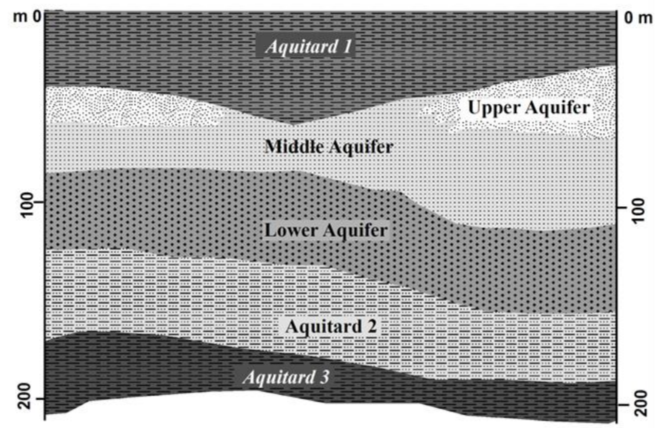

Figure 5: Aquifer system of the study area

Table 2: Aquifer system of the study area

Aquifer System	Hydrostratigraphic Unit	Average Thickness (m)	Average Bottom Depth (m)	Lithology
	Aquitard-1	40	40	
Upper Aquifer	Aquifer-1	25	65	Very fine to fine sand
Middle Aquifer	Aquifer-2	45	110	Medium sand
Lower Aquifer	Aquifer-3	35	145	Medium to coarse sand
	Aquitard-2	40	185	
	Aquitard-3	25	210	

Materials and Methods

DRASTIC model is used for vulnerability assessment of the study area. Data for creation of the DRASTIC parameters have been collected from different sources (Tab. 3). Each DRASTIC parameter was assigned a relative weight between 1 to 5 where 5 is considered most significant in regard to contamination potential and 1 being considered least significant (Tab. 4). In turn, each of the variables was subdivided into numerical ranges (depth to water table) or media types which impact pollution potential. Finally the ratings are used to quantify the ranges/ media with regard to likelihood of groundwater pollution. The final vulnerability map based on the DRASTIC index (Di) which is computed as the weighted sum overlay of the layers using equation (1).

Table 3: Type and source of data used for the construction of DRASTIC layers

Parameters	**Description**	**Data type**	**Data source**	**Output layer**
Depth to water	Represents the depth from ground surface to water table, deeper water table implies lesser chance for pollutants to contaminate groundwater	Water level	Bangladesh Water Development Board (BWDB)	D
Net **R**echarge	Represents the amount of water penetrating through the ground surface to water table. Recharge water represents the medium for transporting pollutants	Rainfall, Landuse map	Bangladesh Meteorological Department (BMD), SMEP-GD Project	R
Aquifer media	Refers to the saturated zone material properties that controls the pollutant attenuation process	Borehole log	Department of Public Health Engineering (DPHE), BWDB,BADC	A
Soil media	Represents the uppermost weathered zone of the unsaturated zone that controls the amount of recharge infiltrating downward	Soil map of Bangladesh	Banglapedia	S
Topography	Refers to the slope of land surface, it dictates whether the runoff will remain on the surface to allow the contaminant percolation to the saturated zone	Engineering Geomorphological map of Dhaka-Tongi area	Atlas of Urban Geology, vol14; ESCAP	T
Impact of vadose zone	Represents the unsaturated zone material that controls the passage and attenuation of the pollutants to the saturated zone	Borehole log	DPHE, BWDB,BADC (Bangladesh Agricultural Development Corporation)	I
Hydraulic **C**onductivity	Indicates the ability of aquifer to transmit water, hence determines the rate of flow of contaminant material within the groundwater system	Aufifer Test data	(Dhaka Water & Sewage Supply Authority) DWASA, BWDB	C

Once the DRASTIC index was computed, it was possible to identify the area which was most likely to be susceptible to groundwater contamination relative to others (Tab. 5).The higher the DRASTIC index, the greater the groundwater pollution potential. The methodology flow chart is depicted in Fig. 6.

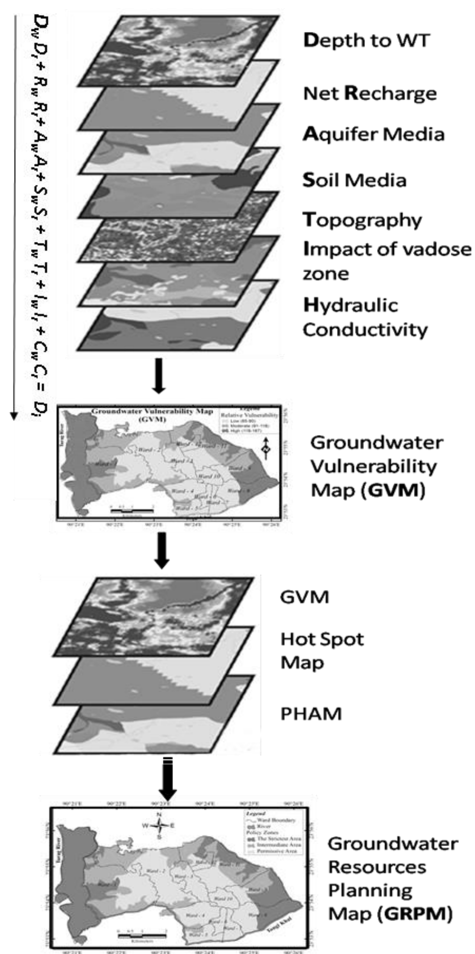

Figure 6: Methodology Flow chart for vulnerability assessment using DRASTIC model in GIS

Results and Discussions

Parametric maps

Fig. 7 & 8 present all of the associate parameter maps used to determine DRASTIC Index for vulnerability assessment in Tongi industrial area:

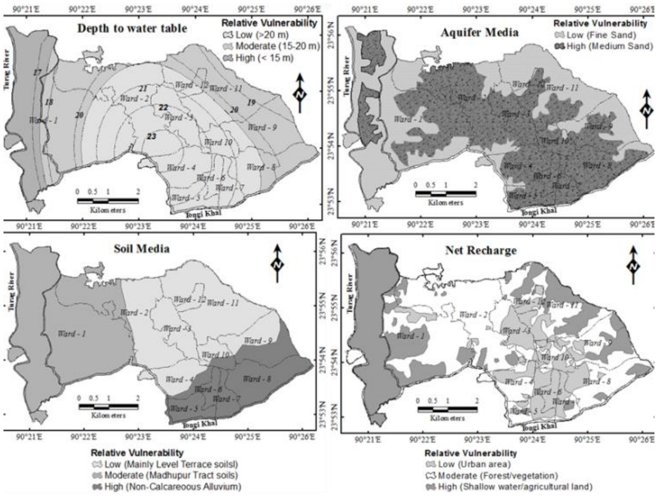

Figure 7: DRASTIC Parametric maps: Depth to groundwater table (upper left) with water table contours, Aquifer media (upper right), Soil media (lower left) and Net recharge (lower right)

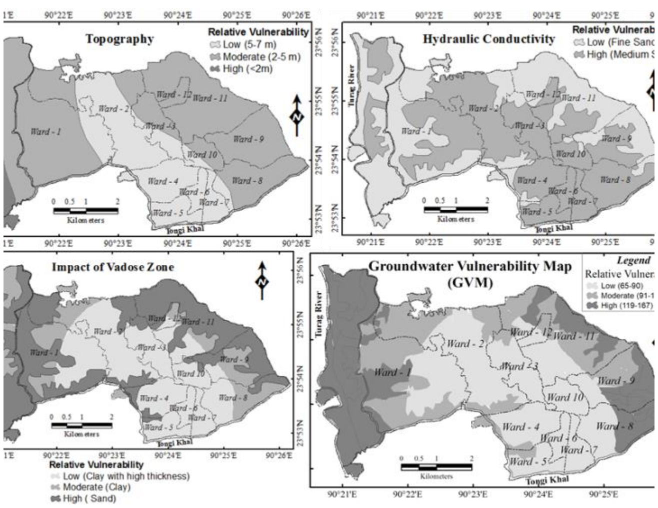

Figure 8: DRASTIC Parametric maps: Topography (upper left), Hydraulic conductivity (upper right), Impact of vadose zone (lower left) and Groundwater vulnerability map (GVM) of the study area

Depth to water table

Groundwater depth of the study area was calculated by subtracting groundwater level from elevation. Data of water level from 5 representative observation wells in and around the study area of last 31 years (1975-2006) have been analyzed. Depth of groundwater table ranges from 15m to 24m with an average depth of 20 m. Water table depth is the highest in the central part and the lowest in the western part indicating the western part is more susceptible to contamination and thus is assigned to the highest score according to DRASTIC assumptions (Tab. 4 and Fig. 7).

Net Recharge

Net recharge is the amount of water per unit area of land penetrating through the ground surface to the water table. The main source of recharge is rainfall, canal seepage and irrigation seepage. Although the study area is characterized by a high annual rainfall (~2000 mm/year), the net recharge to the groundwater aquifer is mainly controlled by the type of land use/cover on the surface. Net Recharge map is produced from Land use map of the study area (February 2003) (Source: SMEP-GD Project 2008).The lowest recharge rate was associated with the urban land use because roofs and pavements prevent the penetration of rainwater downward. The highest recharge rate is associated with shallow water area and agricultural land (Tab. 4 and Fig. 7).

Table 4: Assigned weights, ranges, ratings and index for DRASTIC parameters

DRASTIC Parameters	Assigned weights(w)	Ranges	Ratings(r)	Index
Depth to water table	5	Low (>20 m)	1	5
		Moderate (15-20 m)	5	25
		High (<15 m)	10	50
Net Recharge	4	Low (urban area)	1	4
		Moderate (Forest/vegetation)	5	20
		High (Shallow water/agricultural land)	10	40
Aquifer Media	3	Low (Fine sand)	2	6
		High (Medium to coarse sand)	7	21
Soil Media	2	Low (Mainly level Terrace soils)	1	2
		Moderate (Madhupur Tract soils)	4	8
		High (Non-Calcareous Alluvium)	8	16
Topography	1	Low (5-7 m)	1	1
		Moderate (2-5 m)	5	5
		High (<2 m)	10	10
Impact of Vadose zone	5	Low	2	10
		Moderate	4	20
		High	10	50
Hydraulic Conductivity	3	Low	2	6
		High	6	18

Aquifer Media

Aquifer media refers to the consolidated or unconsolidated rock constituting the aquifer. The larger the grain size and more fractures or opening within the aquifer, the higher the permeability and thus the vulnerability of the aquifer. The aquifer media thus affects the flow within the aquifer. This flow path controls the rate of contaminants contact within the aquifer (Aller et al 1987).The aquifer media of the study area was characterized from the borelog data and stratigraphic cross section of the area. The main aquifer mostly constitutes of medium to coarse grained sand was assigned a high rating score and the uppermost aquifer, mostly composed of fine sand was assigned a low rating score (Tab. 4 and Fig. 7).

Soil Media

Soil media represents a significant factor for influencing groundwater pollution potential. The most significant biological activities occur in the uppermost portion of vadose zone that is the upper weathered zone (6 feet on average) of the earth's surface. The makeup of soil media on groundwater vulnerability directly impacts the recharge and the ability of contaminants to infiltrate the vadose zone. Therefore, soil permeability and contaminant migration are directly linked to soil type, shrink and swell potential and grain size of the soil (Aller et al 1987). The soil media of the study area is rated into three classes according to Soil Map of Bangladesh (Tab. 4). The northeastern part of the area is composed of Mainly High Level Terrace soils (classified as Ferric Luvisols and Alisols) which are brown and red-mottled, strong to extremely acidic, friable clay loam to clay soils and are moderately to imperfectly drained. The western part of the area is composed of Madhupur Tract soils (mainly Ferric Alisols) and they are well to moderately well drained, reddish brown to yellow-brown, strongly to extremely acidic, friable clay soils. The southeastern part of the area is composed of Non-Calcareous Alluvium which is sandy or silty, grey or olive, neutral to slightly alkaline. Most of these soils have been included as Eutric Fluvisols. The different soil types were assigned corresponding rates according to their permeability (depending on the texture and structure) (Tab. 4 and Fig. 7).

Topography

Topography is an important controlling factor for pollutant runoff or infiltration. At 0-2% slope (gentle slope), there tends to be less pollutant runoff, thus more retention of pollutants and the greatest potential for pollutant infiltration. But at 18+% slope (steep slope), existence of pollutant potential is little as there is more pollutant runoff and less infiltration. Moreover, areas of gentle slope tend to retain water for a longer period of time than the areas of high slope thus more likely to vulnerable to contamination. Thus topography will give an indication on whether a pollutant will run off or remain on the surface long enough to infiltrate into the groundwater (Lynch et al. 1994). However, contamination to surface water increases along with a greater probability of erosion (Aller et al. 1987). The topography of the study area is classified into three ranges as low, moderate and high areas which are assigned to their relative ratings (Tab. 4 and Fig. 8).

Impact of vadose zone

The vadose zone is the zone below the soil layer up to the water table or the saturated zone of the aquifer. This zone is unsaturated or discontinuously saturated. Vadose zone is important in terms of pollution because this zone can absorb or attenuate contaminants as they pass through it by biodegradation, neutralization, mechanical filtration, chemical reaction, volatilization and dispersion (Aller et al 1987); thus determines the attenuation characteristics of the pollutants. In the impact of vadose zone layer, the fine sand rich alluvial deposits were assigned a high rating value (10). Vertical permeability of the overlying aquiclude varies from 6.5x10-4 to 1.5 x 10-2 m/d with an average value of about 4.6 x 10-3 m/d (WASA 1991) and its specific yield ranges between 0.02 and 0.27 with an average value of 0.084 (Barker et al. 1989), thus was assigned the low score (Tabl.e 4 and Fig. 8).

Hydraulic Conductivity

Hydraulic conductivity, or the coefficient of permeability is the ability of aquifer to transmit water, which largely controls the rate at which groundwater or any contaminants will flow under a given hydraulic gradient. Hydraulic conductivity is dependent upon the sedimentary characteristics of the aquifer media. Therefore, it is the function of the grain size, shape, sorting and packing of the aquifer materials and properties of the fluid passing through the aquifer.

Aquifer test data indicate that the main (lower) aquifer is good to excellent, with permeability values between 11 and 18 m/d (WASA 1991), and storativity of 0.02 to 0.05 (BWDB 1998). The transmissivity of the aquifer varies from 131 to 3352 m2/d with an average value of 1600 m2/d (WASA 1991), which indicates the high degree of water transmitting capacity of the aquifer. Therefore, the lower aquifer was assigned to a high rating score. No separate aquifer tests have been conducted on the upper and middle aquifers. But, the upper aquifer sediments are highly weathered due to the oxidized mafic minerals originally present during post-depositional periods of weathering. These formed red-brown ferric oxide cements and secondary clays and reduced intergranular porosity and permeability (Davies 1994). So, the upper aquifer was assigned to a low rating value (Tab. 4 Fig. 8).

Groundwater Vulnerability Map (GVM)

The DRASTIC Index (Di) was computed according to Eq. (1) and from the result three major zones were identified as 'Low', 'Moderate' and 'High' vulnerable zone (Tab. 5). The resultant Groundwater Vulnerability Map (GVM) represents High vulnerability zone (dark grey) in the eastern and the western part of Tongi area while the central part is characterized by low vulnerability (light grey) zone (Fig. 8). This pattern is mainly dictated by the variation in depth to aquifer and the vadose zone characteristics. The central part of the study area displays low aquifer vulnerability which is due to the combination of deep water table, less recharge rate, less-porous soil type and vadose zone and high slope. The western and the eastern part of the study area are under higher risk of contamination associated with low water table depth, high recharge rate, gentle slope and highly porous vadose zone.

Table 5: DRASTIC Index used for vulnerability mapping of the study area

Index	Vulnerability classification
65-90	Low
91-118	Moderate
119-167	High

Potential Hazardous Activity Map (PHAM)

Potential Hazardous Activity Map (PHAM) assessing groundwater vulnerability requires an appraisal of the sensitivity of the groundwater system being adversely affected by an imposed contaminant load. There have been many attempts to produce comprehensive lists of activities that are potential sources of groundwater pollution and to classify these by type. One such classification system is given in Tab. 6.

Table 6: Classification of potentially polluting industry types based on activity code

Type of Industry	Activity Code
Administration/retail	0∗
Iron and Steel	1
Metal Processing	2
Mechanical engineering	3
Non-ferrous metals	4
Non-metallic minerals	5
Petrol and gas refineries	6
Plastic products	7
Rubber products	8
Organic chemicals	9
Inorganic chemicals	10
Pharmaceuticals	11
Woodwork	12
Pulp and paper	13
Soap and detergents	14
Textile mills	15
Leather tanning/processing	16
Food and Beverage	17
Pesticides / herbicides	18
Fertilizers	19
Sugar and alcohol	20
Electric power	21
Electric and electronic	22
Fuel filling stations	23
Other∗∗	24

∗ Include all service/tertiary activities not likely to generate a significant pollution load

∗ Other includes any activity that may be potentially polluting not covered by the other 23 codes

There are 210 different types of industries in Tongi (Tab. 7) which are small and large industrial units such as textiles, lead batteries, ceramic, paper and pulp mills, pharmaceuticals, rubber, paints, detergents, iron and steel etc (Fig. 9). Major industries are located in Tongi BSCIC area, Tongi Industrial area, Cherag Ali, Ershadnagar and Gazipura. According to Tongi Pourashova, the number of industries is 480. Most of these industries are discharging their untreated wastes and effluent containing toxic chemicals, salt, alkali, sulfuric acid, dyes, oil, formic acid, various heavy metals directly on the low land or into open water courses that poses a serious threat to public life by creating incidents of water borne and skin diseases.

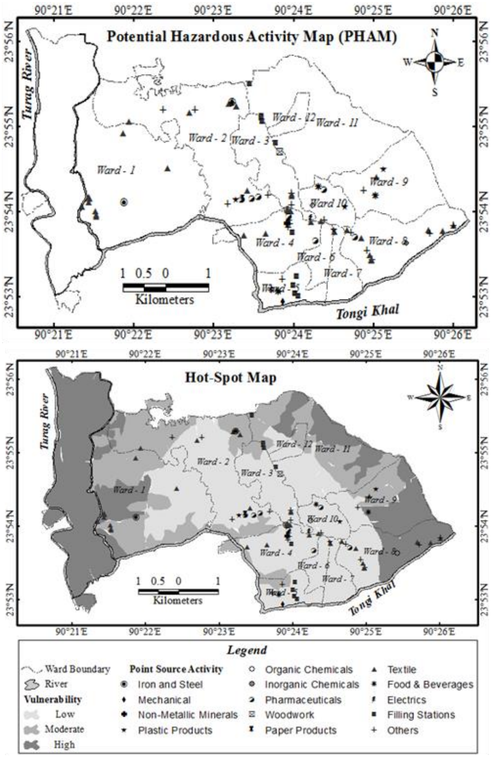

Figure 9: Potential Hazardous Activity Map (PHAM) showing industry locations and Hot-Spot map displaying low, moderate and highly vulnerable areas of Tongi pourashava

Table 7: Types and numbers of industries in Tongi area (SMEP-GD Project, 2008)

Category of industry	Number
Dyeing, Washing, Garments, Composite, Spinning	19
Sweater, Textile, Knitting	86
Accessories	6
Chemical	9
Cosmetics	1
Electrical, Electronics	5
Engineering	10
Food	5
Glass	2
Manufacturing	3
Pharmaceuticals	9
Plastics	6
Re-Rolling	4
Shoe	2
Others	40
No Data	3
Total	210

Hot-Spot map

The specific vulnerability can be obtained by overlying a representation of the actual pollution sources on the intrinsic vulnerability map. Hot-Spot Map is the result of risk assessment mapping in the study area and is produced by the superposition of the GVM and PHAM. It is the precursor of the Groundwater Resource Planning Map and shows where deleterious activities are taking place, providing a present contamination hazard or where unplanned expansion could prejudice the resource in future. The Hot-Spot map of the study area shows one iron and steel industry and some textile and food industries in high vulnerable areas (Fig. 9) which must be immediately removed for the protection of groundwater of the Tongi industrial area.

Groundwater Resources Planning Map (GRPM)

Groundwater Resources Planning Map (GRPM) considers the features of the aquifer vulnerability and potentially hazardous activities component of the study area. This map can be used as a tool for assessing the degree of groundwater vulnerability to pollution. It can also help the city planners and administrators by prioritization of areas for monitoring, for selecting industrial or waste disposal sites.

GRPM of the study area exhibits three zones as ‘High Risk Zone’, ‘Low Risk Zone’ and ‘Permissive Zone’. (Fig. 10). The High Risk Zone is low-lying area near riverbanks that are very much restricted for future development of effluent producing industry, commercial and residential use.

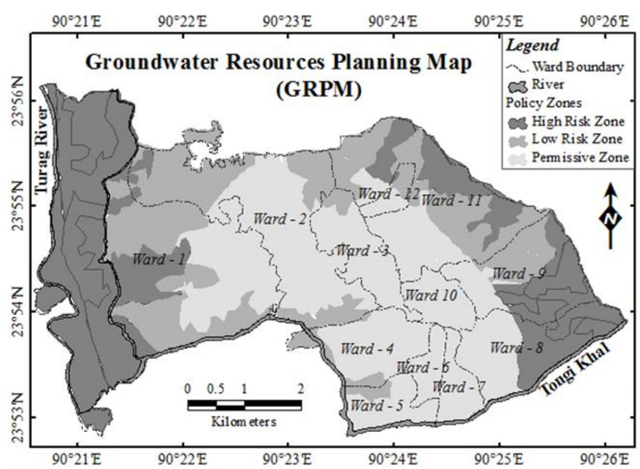

Figure 10: Groundwater Resources Planning Map (GRPM) of the study area

Conclusions and Recommendations

In this paper, an attempt has been made to assess the aquifer vulnerability of Tongi Industrial Area employing the empirical DRASTIC model of the USEPA. The DRASTIC groundwater vulnerability map (GVM) indicates that the western and the eastern part of the study area are dominated by 'High' vulnerability class while the central part was characterized by 'Low' vulnerability class. The Potential Hazardous Activity Map (PHAM) and resultant Hot-Spot Map exhibits the point sources of pollution (industries). Groundwater Resources Planning Map (GRPM) indicates the low lying areas near riverbanks that are highly vulnerable to pollution and therefore prohibited to industrial or commercial uses.

It is therefore recommended that in order to check the pollution trend, Tongi Pourashava or the Government of Bangladesh should establish efficient waste treatment and disposal system. Also, the Government of Bangladesh should take initiatives to implement existing rules to minimize pollution. However, additional researches should be devoted to a more comprehensive assessment of the anthropogenic pollution load in the study area.

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