



Modeling Groundwater Flow for the Delineation of Wellhead Protection Area around a Water-well at Nachole of Bangladesh.

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Abstract

Delineation of wellhead protection area is an important component of groundwater contamination protection strategy to prevent probable environmental and health hazards. Modeling of ground water infiltration and movement in the wellhead area is a critical part of any effective wellhead protection program. Such models depend on an accurate description of the aquifer in the wellhead area for the reliable estimation of contaminant travel times and defining protection area. In this paper, a two-dimensional groundwater flow model is proposed for the estimation of contaminant travel time to water well and delineation of wellhead protection area. The model is applied for the demarcation of wellhead zone of a water-well situated at Nachol in Chapai Nawabganj District of Bangladesh. The parameters required for the modeling of groundwater flow and delineation of Wellhead protection area are obtained from borehole litholog and available literatures. The study shows that to ensure clean groundwater supply for a period of 10 years it is essential to impose restrictions on land use activities in an area of 1.91 km² around the water well.

Keywords: Groundwater Flow Modeling, Zone of Contribution, Zone of influence, Wellhead Protection Area.

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Introduction

Groundwater is the main source of drinking water to most of the people of Nachole Upazilla of Chapai Nawabganj District of Bangladesh. Contamination of groundwater resource is therefore, may cause sever environmental and health hazards. As the flow of groundwater is very slow and subject to little turbulence, contaminants in groundwater does not diluted easily. Consequently, if once the aquifers are contaminated they become very difficult to remedy and in most of the cases are abandoned. Protecting groundwater resources from pollution is therefore essential for its proper management and preventing probable hazards.

The method that is used widely for the protection of a single water well from probable pollution is known as Wellhead Protection Area (WHPA) method. In this approach a zone surrounding a public well or well-field through which water moves toward and reaches the well or well-field is defined and restricted to some land use activities (Baker et al. 1993). Though the approach is more complicated compared to other methods used for this purpose such as DRASTIC, SINTACS, etc., it is more realistic in sense of implementation and reliability.

The most critical part of an effective wellhead protection program is to model the movement of groundwater in the wellhead area. Effective modeling of groundwater flow is essential for reliable estimation of contaminant travel time (EPA, 1990). In this paper, a two-dimensional groundwater flow model is developed by using the uniform flow equations for the reliable estimation of contaminant travel time to water well and delineation of wellhead protection area.

Description of the Study Area

The study area Nachole (Lat. 24° 45' N, Long. 88° 25' E) under Chapai Nawabganj district is situated on the north-east part of Bangladesh. The location map of the study area is shown in Figure 1. Climatically, the area falls on Gangatic Bengal region with an annual average rainfall of 139 cm and temperature of 31° C. Geological map of the study area along with the elevation contour is shown in Figure 2. Topographically, the area is situated at an elevation of 30 m. The surface geology of the study area comprises of mainly alluvial sand, silt and clay of the active Ganges Flood Plain in the west. The eastern part of the area is covered by great Table Land which is a product of Pleistocene vertical upheaval. This uplifted Table Land is widely known as Barind Tract in this region (Alam et al. 1990, Khan 1991). The tract elongates like a low hillocks standing at a higher level than the surrounding Flood Plains in the area.

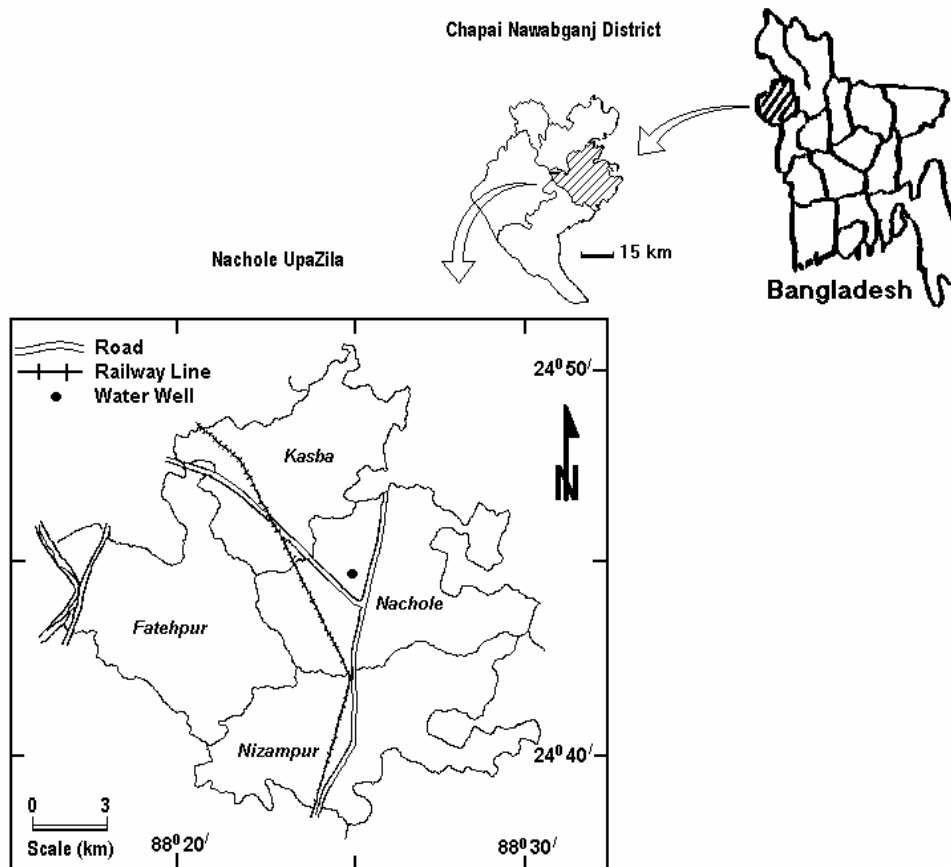


Figure 1: Location of the study area in Chapai Nawabganj District, Bangladesh.

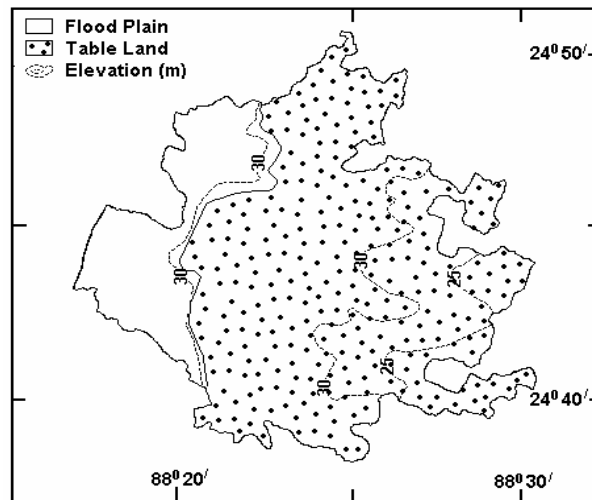


Figure 2: Surface geology of the study area with elevation contour in meter.

Aquifer Characteristics

A number of hydrogeological studies have been carried out in and around the study area (Alam et al. 1990, Ali 1993, Ahmed 1994, Ahmed and Burgess 1995, Begum et. al. 1997, Azad and Bashar 2000, Haque et al. 2000). The available literatures (BGS 2001) reports that the aquifers in the area occur in two broad horizon. The shallower one lies within 150 m from the surface and termed as the main aquifer (Shams 2002). Most of the people of the area meet their demands of irrigation and domestic water supply by tapping this shallow aquifers. Except some part of the Flood Plain area, the aquifers over most of the region are sandwiched between upper silt and clay aquitard and lower silt and clay aquitard (Shams 2002). The aquifer material is composed of a sequence of medium to coarse-grained sands with occasional gravels. The thickness of this layer ranges from 5 meters to more than 70 meters (Begum et al. 1997). Both confined and unconfined aquifers are found in the region. According to Ahmed (1994), groundwater in this shallow aquifer flows from north to south with localized outflow into the major rivers with a head gradient of 1:1000. The transmissivity of groundwater in the area (shown in Figure 3) varies very gently from 500 m²/day to 800 m²/day (Begum 1992).

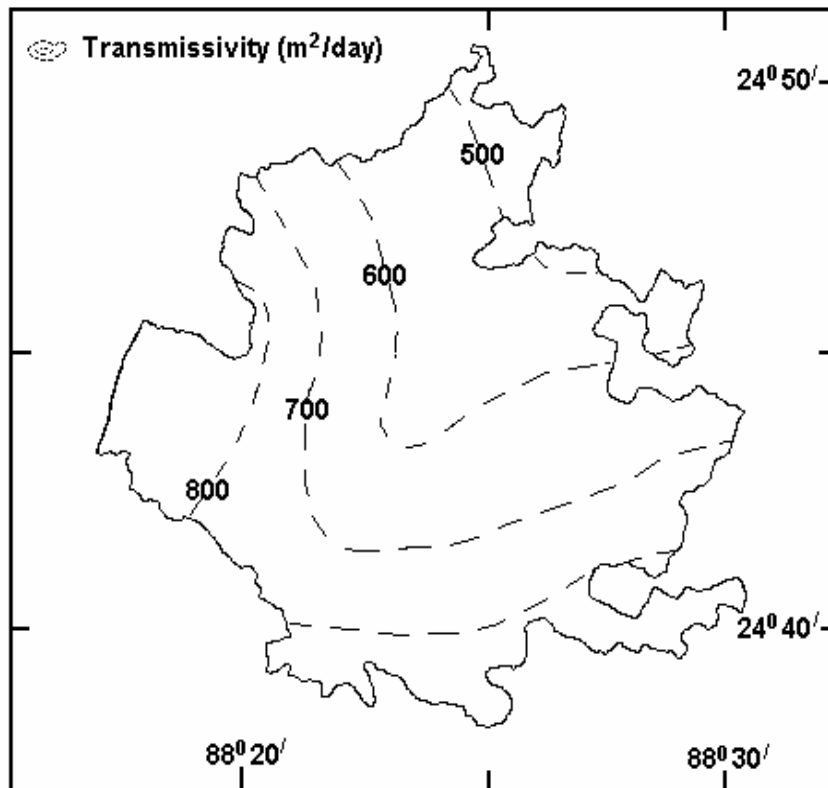


Figure 3: Transmissivity (m^2/day) contour of Nachole Upazilla.

Delineation of Well Head Protection Area

The areas to be included in the wellhead protection area are the zone of influence - the area affected by drawdown and the zone of contribution - the area that recharges or contributes water to the well (EPA 1987). There are several methods that have been used for the delineation of groundwater travel time boundary. Among the methods the numerical flow/transport modeling, is the most sophisticated one, yields reliable estimation of WHPA.

For demarcation of WHPA, it is essential to model the steady-state groundwater flow to the water well. For this purpose, a software is developed in this paper by using finite difference method. The total area is divided into a number of grids with a dimension of $100m \times 100m$ of each cell. As the groundwater in the area flows from north to south (Ahmed 1994), the upper and lower boundaries of the area are considered as constant head boundaries and the eastern and western boundaries are considered as no-flow boundaries. From the groundwater flow model the software computes wellhead protection area around the water-well in three main

steps, namely, (1) compute the zone of influence, (2) compute the zone of contribution for a user-defined time period, and (3) combine both zones to demarcate the wellhead protection area.

For the estimation of influence zone using analytical method, the following assumptions are made:

- (i) The aquifer is homogeneous, isotropic, and infinite in horizontal extent.
- (ii) Steady state conditions prevail.
- (iii) The aquifer has uniform transmissivity and no leakage.
- (iv) Vertical gradients are negligible.
- (v) The well is screened through the saturated thickness of the aquifer and pumps at a constant rate.

The edge of the capture zone for a confined aquifer in steady-state conditions is computed by using the following equation (Grubb 1993):

$$x = \frac{-y}{\tan(2\pi Kbiy/Q)} \quad (1)$$

where, Q = pumping rate [L^3/T]

K = hydraulic conductivity [L/T]

i = hydraulic gradient of the flow field in the absence of the pumping well (dx/dy).

b = thickness of the aquifer.

The distance from the pumping well downstream to the stagnation point that marks the end of the capture zone is given by:

$$x_0 = -Q/(2\pi Kbi) \quad (2)$$

The maximum width of the capture zone as the distance (x) upgradient from the pumping well approaches infinity is given by (Raghunath, 1987):

$$y_c = Q/Kbi \quad (3)$$

the zone of contribution around the water-well for a user-defined time period is calculated by using the following equation (EPA, 1990),

$$X_u = \frac{Tti}{b\theta} + \left(\frac{Qt}{\pi b\theta}\right)^{\frac{1}{2}}$$

(4)

where, T is the transmissivity of the aquifer

θ is the porosity of aquifer,

i is the hydraulic gradient,

b is the aquifer thickness, and

t is the user defined time period.

From the above equations, it is clear that WHPA depends on aquifer properties. For the delineation of WHPA of the proposed water-well, the aquifer parameters are obtained from borehole data and available literatures. The obtained parameters and their sources are summarized in Table 1. The well is screened in the saturated zone of the aquifer located between 10 m and 30.2 m below the ground surface. Head difference of 1 meter is considered for a distance of 1000m (Ahmed 1994). The pumping rate of the well is considered as 2400 m^3/day for the computation of WHPA.

Table 1: Aquifer parameters at the water-well field in Nachole.

<u>Aquifer's Parameters</u>	<u>Value</u>	<u>Source</u>
Thickness	20.2 m	Borehole Litholog
Head Gradient	0.001	after Ahmed (1994)
Transmissivity	601 m^2/day	after Begum (1992)
Hydraulic Conductivity	29.75 m/day	Computed from Transmissivity and Aquifer thickness
Porosity	0.29	analyzing borehole lithologs

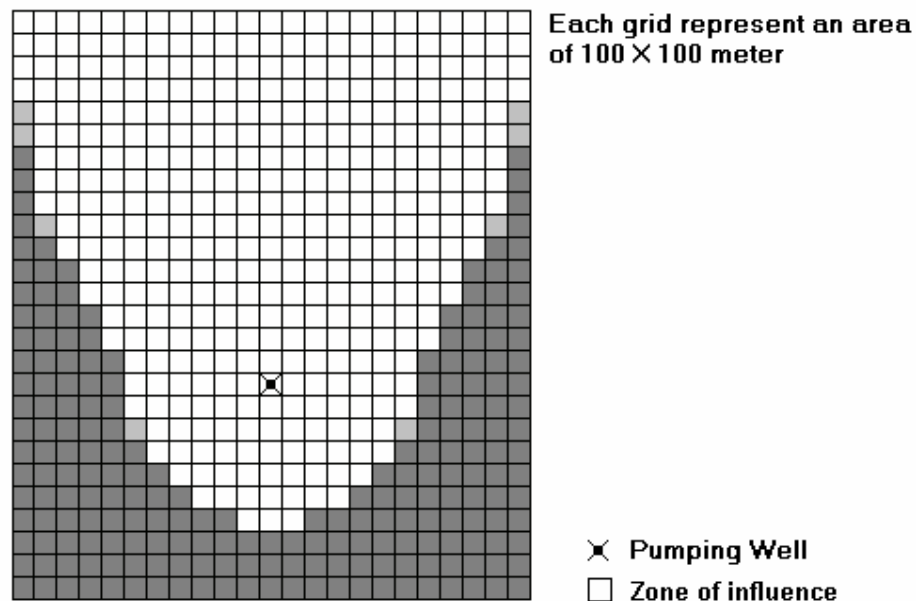


Figure 4: Zone of influence around the water-well.

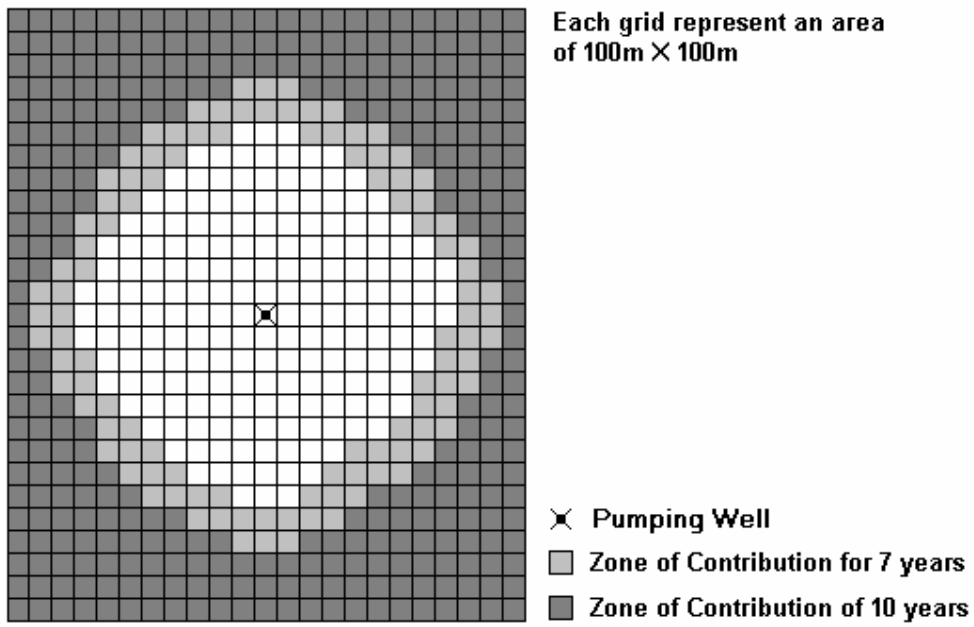


Figure 5: Zone of contribution for two user-defined time periods.

The zone of influence and the zone of contribution for different user-defined time periods computed by using the aquifer parameters are shown in Figures 4 and 5 respectively. In the last step, the area that is common to both the zones is mapped to demarcate the desired wellhead protection area of the well which is shown in Figure 6. Figure shows that an area of 1.49 km² is required to protect from contamination for a pollution free groundwater supply for 7 years. For 10 years supply of groundwater the protection area around the water well increases to 1.91 km².

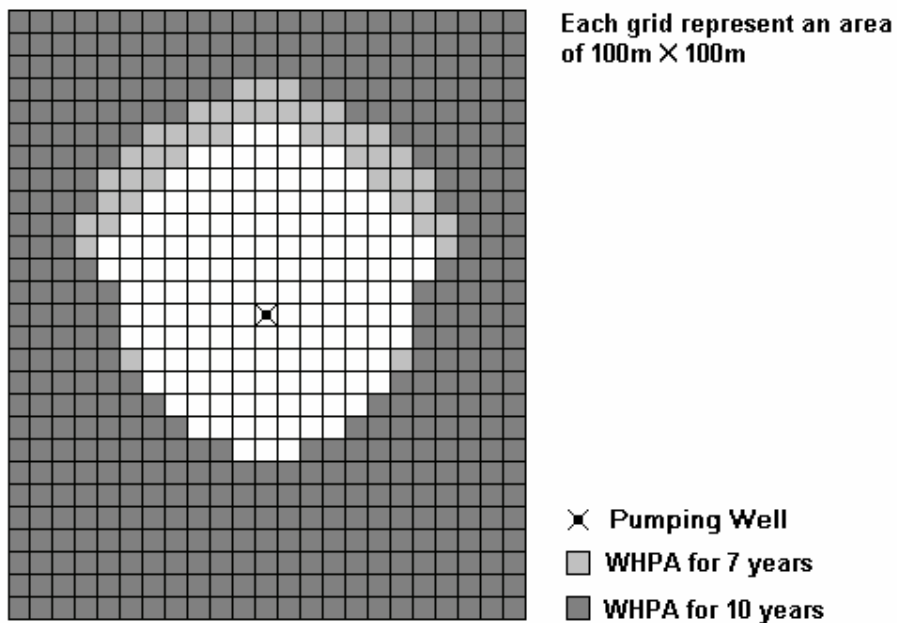


Figure 6: Delineated wellhead protection area around the well in Nachole for two user defined time periods.

Conclusions

Though there are many more sophisticated methods that can be used for the delineation of wellhead protection area, the analytical groundwater flow method is best if we consider both reliability and cost at the same time. In this paper, analytical groundwater flow model is used for the demarcation of Wellhead protection area around a water well situated at Nachole Upazilla of Chapai Nawabganj District of Bangladesh. For this purpose, a two-dimensional groundwater flow model is developed by using the uniform flow equations. The study shows that an area of 1.91 km² is required to restrict from harmful land use activities for a pollution free groundwater supply up to 10 years. The developed software could be used for the delineation of wellhead protection area of any small, medium or large -scale water supply well for different user defined time periods effectively.

References

- Ahmed, K.M., and Burgess, W.G. (1995) Bils and the Barind aquifer, Bangladesh. Chapter 8, In: Geomorphology and Groundwater, edited by A.G. Brown, pp. 143-155. New York: Wiley.
- Ahmed, K.M. (1994) The hydrogeology of the Dupi Tila sands aquifer of the Barind Tract, NW Bangladesh, Ph.D. Thesis, University College of London, London, 414p (Unpublished).
- Alam, M.K., Hasan, A.K.M.S., Khan, M.R. and Whitney, J.W. (1990) Geological map of Bangladesh, scale 1:1,000,000. Geological Survey of Bangladesh, Dhaka, Bangladesh.

- Ali, G.M.M. (1993) Geophysical study of subsurface structure in Nachole Thana of Greater Rajshahi District, M.Sc. Thesis, No. 247, Department of Applied Physics & Electronics, Rajshahi University, Bangladesh, 71p (Unpublished).
- Azad, M.A.S., and Bashar, K.(2000) Groundwater Zonation of Nawabganj Sadar Thana and its Relation to Groundwater Chemistry, *Bangladesh Journal of Geology*, 19, 57-71.
- Baker, C.P., Bradley, M.D., and Bobiak, S.M.K. (1993) Wellhead protection area delineation linking flow model with GIS, *Journal of Water Resources Planning and Management*, 119(2), 275-287.
- Begum, S.F. (1992) Evaluation of hydraulic properties of the aquifer from pumping test analysis of the Barind area, M.Sc. Thesis, Dhaka University, Dhaka, 148 p. (Unpublished).
- Begum, S.F., Bashar, K., and Hossain, M.S. (1997) An evaluation of hydraulic parameters of the aquifer and wells of the western part of the Barind area, Bangladesh, *Bangladesh Geoscience Journal*, 3, 49-64.
- BGS (2001) Groundwater studies for arsenic contamination in Bangladesh, In: British Geological Survey Report WC/00/19, edited by D.G. Kinniburgh and R.L. Snedley, London.
- EPA (1987) Guidelines for delineation of wellhead protection areas, In: Technical Report, Ground Water Protection Division, U.S. Environmental Protection Agency, Washington, D.C. USA.
- EPA (1990) Wellhead protection: computer delineation of well head protection area, In: Technical Report, Ground Water Protection Division, U.S. Environmental Protection Agency, Washington, D.C., USA.
- Grubb, S (1993) Analytical model for estimation of steady-state capture zones of pumping wells in confined and unconfined aquifers, *Ground Water*, 31(1), 27-32.
- Haque, M.N., Keramat, M., and Rahman, A.M.A. (2000) Delineation of groundwater potential zones in the western Barind Tract of Bangladesh, *Journal of the Bangladesh National Geographical Association*, 21-26(1-2), 13-20.
- Khan, F.H. (1991) *Geology of Bangladesh*, New Delhi: Wiley Eastern Limited.
- Raghunath, H.M. (1987) *Groundwater*, 2nd Edition, New Delhi: Willey Eastern Limited.
- Shams, S. (2002) Prototype GIS and Expert System for Arsenic Evaluation and Mitigation: A Case Study of Chapai Nawabganj District in Bangladesh, TRITA-LWR Master Thesis: 02-36, Royal Institute of Technology, ISSN 1651-064X.