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Groundwater Modelling of Dhaka City and Surrounding Areas and Evaluation of the Effect of Artificial Recharge to Aquifers

Shireen Akhter, Md. Sarwar Hossain

Abstract — **Dhaka city lies on the Madhupur Clay overlying the Plio-Pliestocene Dupi Tila Formation which forms the principal aquifer. Massive withdrawal of water from this aquifer caused fall of water table at an alarming rate which might provoke subsidence, ecological and environmental hazards [1]. It has been found that the aquifer system of the study area can be divided in to four aquifers and four aquitards up to a depth of 400m. The long term hydrographs for the observation wells within the Dhaka City shows a sharp decline of water level with little or even no fluctuation which indicates over exploitation of aquifers [2]. The water table contour maps of wet and dry season show a pointed cone of depression in the central part of the study area. The research work has been carried out to predict the future response of groundwater level after 20 years for increasing abstraction and assessment of the usability of the artificial recharge of aquifers of the Dhaka City using groundwater modelling technique. An eight layer transient groundwater flow model was set up with time steps of a month using MODFLOW. Two model scenarios were considered for model prediction. For the first scenario it has been found that after 20 years the elevation of groundwater level will decline to about -120m in the central part of the Dhaka City, and the mega cone of depression will spread over an area of about 1962 km2. For the second scenario substantial water is injected into the aquifer for recharging the aquifer artificially. The quantity of artificially recharged water was equal to the abstraction of water in Dhaka City. The model predicted that the elevation of the groundwater level after 20 years of pumping will not decline anymore and will be fixed at 70m which is the present minimum groundwater level. The area of the mega cone of depression around Dhaka city will reduce by 945km2 for the next 20 years. As a consequence of artificial recharge predicted environmental degradation in and around Dhaka City can be prevented.**

Index Terms— **Artificial Recharge, Dhaka city, Groundwater declination, Mega cone of depression.**

I. Introduction

Dhaka is located in the center of Bangladesh between longitude 90°20'E and 90°30'E and latitude 23°40'N and 23°55'N.The area of the present city is 256km2 bounded by the Buriganga river in the south, the Demra in the east, the Tongi Khal in the north and The Turag river in the west. The Metropolitan city is bounded by Gazipur in the north, Manikganj in the west, Rupganj in the east, Narayanganj in the southeast and Keraniganj in the south. The greater Dhaka region including part of Manikganj, Gazipur, Narayonganj, and Munshiganj is taken for modeling purposes. (Figure-1.1).

The study area is entirely an alluvial deltaic plain [3]. The elevation of greater Dhaka is between 2 to 13m above main sea level but is generally around 6.5m.The central part of greater Dhaka district is occupied by the southern half of the Madhupur Tract. The rest of the region is covered by the floodplain of the Jamuna-Padma-Meghna Rivers. The geo-tectonics and its structural arrangement in the area control the geology-stratigraphy and hydrogeology of the area [4]. An extensive network of rivers flows through the study area. Aquifer gets waters as a result of natural recharge from precipitation, rivers, lakes, irrigation, stream flow and seepage from the channel.

From the analysis of the individual log and cross section sections, the aquifer system of the study area can be divided in to four aquifers and four aquitards (fig-1.2). The Lower Dupi Tila Aquifer-1 and Aquitard-4 is not encountered in all the boreholes. From all the cross sections it is clear that the Aquitard-1 is present in the whole region and within the city the layer is not so thick. The Upper Dupi Tila Aquifer-1 is overlain by the Aquitard-1 in the maximum places. In the whole region the thickness of this layer ranges from about 5m to 143m.

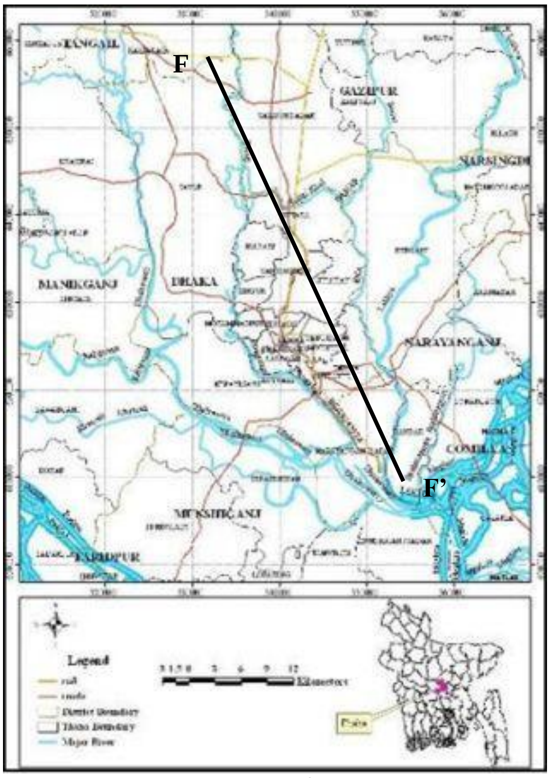

Fig 1.1: Location map of the study area.

Shireen Akhter, Deputy Manager (Geology), Bangladesh Petroleum Exploration and Production Company Ltd (BAPEX) Dhaka, Bangladesh,
Md Sarwar Hossain, Lead Specialist (Network Infrastructure), Banglalink Digital Communication Ltd and Independent Consultant, Dhaka, Bangladesh

From the data the range of maximum elevation of groundwater level (fig-1.4) in the Dhaka City, is -13 to -61mPWD. The range of minimum elevation of groundwater level (fig-1.3) in Dhaka City is -17 to -62mPWD. Minimum fluctuation occurs mainly in the central and northern part of the study area. The fluctuation of groundwater elevation varies from 0 to 2 mPWD in the Dhaka City. Fluctuation indicating poor recharge in this area. Long term hydrographs (fig-1.6) within the city shows the present condition of the Dhaka metropolitan area. The cross plot (fig-1.5) of rainfall, groundwater level and river stage graph indicates that the rainfall is not directly involved with rainfall and river stage. The current study from the long term aquifer test on lower Dupi Tila aquifer that the average transmissivity is 1805.61m2/day, the storage coefficient is 0.00239 and the hydraulic conductivity is 27.09 m/day [5].

Dhaka, the capital city of Bangladesh, having higher growth rate than the other developing countries. Large abstraction by water wells has been causing a sharp drop in groundwater level and dewatering of the aquifer. The rate of abstraction increased drastically which reflects the increased population, rapid expansion of the city and uncontrolled drilling of wells [6]. The natural recharge is very negligible in Dhaka city, compare to the abstraction. Overexploitation of groundwater beneath many large cities in the world has resulted environmental hazards including water quality problems.

If the groundwater level declination continues at the present rate, this will create pressure on water storage and may invite subsidence; ecological and environmental hazards in Dhaka City and its surroundings. So to prevent these problems and meet up the increasing demand of groundwater in the near future, immediate steps should be taken.

From this point of view, the thesis work is carried out to predict the future response of groundwater level after 20 years abstraction with the gradual increase of new tube wells and assessment of the usability of the artificial recharge of aquifers of the Dhaka city by using groundwater modeling technique. A quantitative evaluation of the resource is complex and time consuming without the help of a computer. With the advent of computer the scope of quantification of groundwater and its future response to abstraction have widen significantly. Computer modeling predicts the future response of water resource system under a variety of hydro geological and hydrological scenarios.

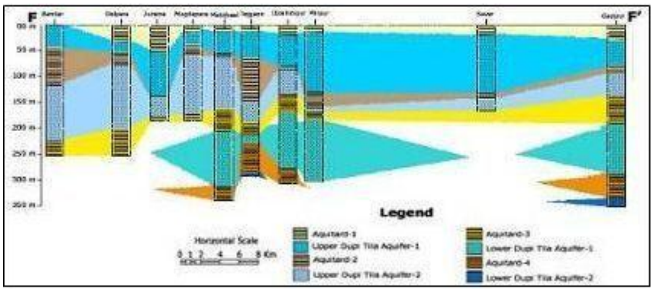

Fig 1.2: Cross section along FF'.

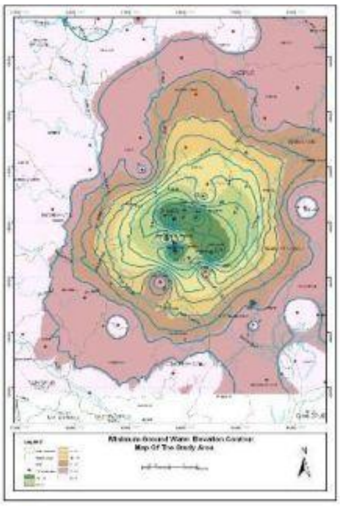

Fig 1.3: Contour map of minimum groundwater elevation (mPWD) in 2008 in the study area.

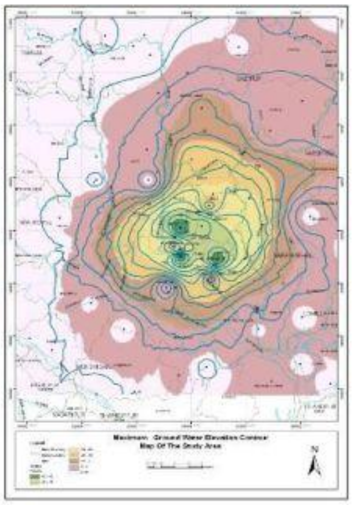

Fig 1.4: Contour map of maximum groundwater elevation (mPWD) in 2008 in the study area.

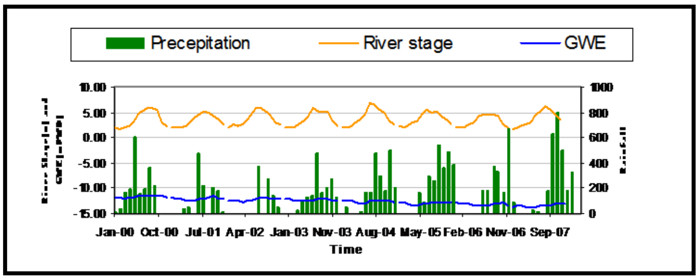

Fig 1.5: Cross plot of river stage data of Buriganga River (Station no-SW42), groundwater level of the well GT2688021 and rainfall data of the study area.

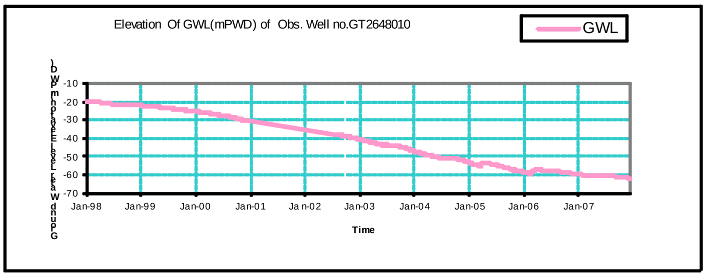

Fig 1.6: Hydrograph showing the groundwater elevation of observation wellno.GT2648010 (Mirpur).

Modelling is a technique that can predict the change in groundwater level. After the simulation of the model, it represents approximately the present situation. The model may be used to predict the effects of proposed groundwater change. In this research work modeling is used as a tool to predict the response of groundwater level after 20 years if the aquifer of Dhaka city is artificially recharged.

II. Methods and Methodology

The present research work deals with the augmentation of groundwater in Dhaka City by artificial method, called artificial recharge method. Methodology adapted for this research work can be divided into-

a) Geological and
b) Hydro geological

For the development and management of water resource of the study area from artificial recharge perspective, a detail study on climate, hydrology and hydrogeology have been considered.

A. Methods

The research work deals is broadly divided into four main categories-

- Data collection and review of the existing data, reports, map and images from the different organizations & institutions.
- Field Experiment of Artificial Recharge
- Desktop study, data processing and map preparation by GIS and modeling.
- Result, interpretation and recommendation.

First of all collecting literature, hydro geological and climatic data, studied and checked thoroughly whether the data are reliable or not. Data are collected from Bangladesh Water Development Board (BWDB), Institute of Water Modeling (IWM), and Bangladesh Meteorological Department.

Field test mainly concentrated for the measurement of volume of water that can be recharged at a definite time. The collected data and field test data are analyzed and processed both manually and by computers using different softwares. The following softwares have been used for the analysis and interpretation of all the data and maps-

1. Arc view3.2 and Arc GIS9.2 used for the preparation of different location maps. (Study area map, Borehole location map, Observation well location map, Model area map)
2. Arc GIS9.2 used for the preparation of physiographic, flood and drainage distribution map
3. 3D analyst tool (Arc GIS9.2) has been used for the preparation of isopach map.
4. Spatial analyst tool (Arc GIS9.2) has been used for the preparation of contour maps
5. Rockworks 2004 used to prepare the hydrostratigraphic 3D model and panel diagram.
6. Hydrographs and cross plot of river stage; rainfall and groundwater level are plotted by Excel.
7. Visual MODFLOW 3.1 is used for modeling and pumping test data analyzed by Infinite Extent software.

B. Selection of Model

For ground water flow and recharge modelling, Visual MODFLOW has been selected as the software. It is an environmental simulation's version of the popular USGS groundwater flow model for Microsoft Windows basis. A model is constructed by using MODFLOW with the most intuitive and powerful graphical interface available. The simulation methods used in the model is based on the Integrated Finite Difference Method (IFDM). The mathematical approach to model simulation is conceptually simple and involves the conversion of different equations which describes the groundwater flow into water balance equations for the element of the model grid network. Time domain is also subdivided into time steps.

C. Model Preparation

The model requires an extensive database. Most of the model parameters need to be defined for each of the model grid. In construction of the model, the first stage was to define the modeled area and boundary condition with natural physical features and limits. The model covered an entire area defined by BTM coordinated of 20000 to 131500 east and 20000 to101500 north. All kinds of data related to hydro- geological parameters and aquifer geometry are used to build the model grid network. The model covers the whole area of Dhaka District, Narayonganj, Gazipur, Manikganj, Munshiganj and Narayonganj and Norsigdi.It extended to the river Jamuna in the west, Padma in the southwest, Meghna in the east and Old Brahmaputra in the north. The whole study area is represented in grid reference. Data needed to import in the model is prepared according to grid reference (fig-1.9). Number of grid and grid spacing is selected to incorporate the whole study area. Grid spacing can be selected to get better resolution. It is based on the repeated subdivision of a regular square mesh. The area of a single square mesh is 4km2. But the central part of the study area, where the Dhaka City is situated is represented by finer grid spacing and the area of a single square mesh is1km2.

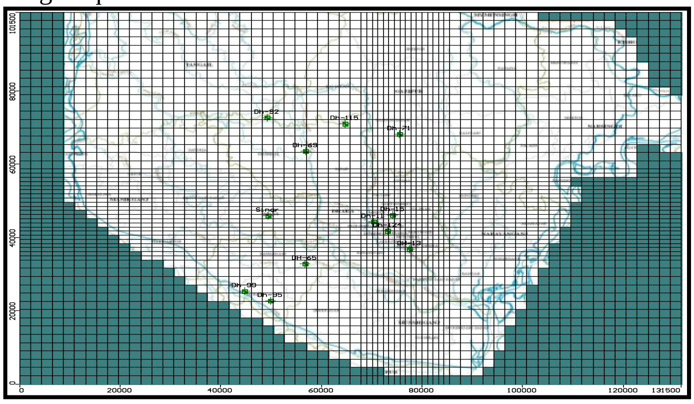

Fig 1.9: Model Grid of Dhaka City and surrounding areas

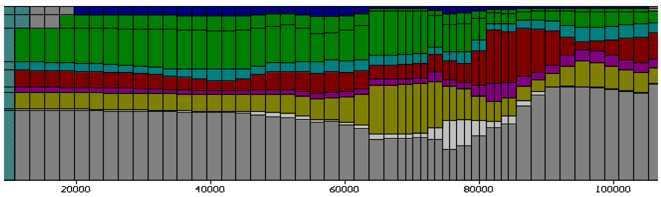

Fig (a) Cross section (Row).

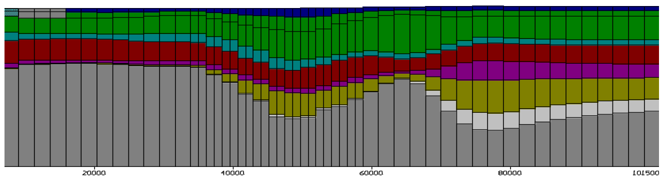

Fig (b) Cross section (Column).

Fig 1.10: Modeled area along with cross section.

For the purpose of any groundwater model, complex geological conditions must be approximated by simplified hydraulic equivalents. Eight layers are included in the. Layer 1, 3, 5 and 7 represent aquitard layers and layer 2, 4, 6 and 8 comprise sand aquifers. Different hydro geological parameters are assigned for each of the modelled layer (Table 1.1).In figure-1.10; the aquifer geometry of the modelled area is shown. Boundary conditions may be a head (piezometric level) controlled, gradient controlled (Hydraulic gradient due to topographic variation) or flow (water flux) controlled. The Padma in the south east, Jamuna in the west, Meghna in the east and The Old Brahmaputra River in the north are considered as external boundaries for modelling purposes.

Table 1.1: Hydro geological parameters setting for the model.

Hydrostratigraphy	**Kx (m/s)**	**Ky (m/s)**	**Kz (m/s)**	**Ss (1/m)**	**Sy**	**Total porosity**
Aquitard-1	2E-08	2E-08	3E-8	.0001	.035	.5
Aquifer-1	.0002	.0002	4E-5	.0012	.15	.2
Aquitard-2	5.8E-07	5.8E-07	5.8E-7	.00015	.05	.48
Aquifer-2	.0003	.0003	4E-5	.00107	.21	.3
Aquitard-3	1.2E-7	1.2E-7	1.2E-7	.0002	.08	..40
Aquifer-3	.00043	.00043	4.3E-5	.00109	.23	.33
Aquitard-4	1.2E-8	1.2E-8	1.2E-8	.0002	.084	.41
Aquifer-5	.00043	.00043	.000043	.002	.233	.48

Indicators: Kx, Ky, Kz = Conductivity, Ss =Specific storage, Sy= specific yield

Different hydro geological parameters are assigned for each of the modeled layer. Parameters that have been incorporated to the model are mean horizontal and vertical permeability of each layer, storage co-efficient, specific yield and porosity of each layer. Type of aquifer (e.g. confined, unconfined or semi confined) also declared before the model calibration. Recharge and evapotranspiration estimates have been derived directly from the MPO (1990) [7] and UNICEF (1998) Upazila base estimation respectively. These data are imported to the model as MODFLOW package file for the top layer only. River has a distinct influence on the water balance of an area. Width, length and depth of the channel are given to the model. River stage data and permeability of the river bottom was also incorporated to the model

For flow modelling (MODFLOW) dynamic equilibrium conditions are adopted using monthly time steps. The average quantity of recharge; evapotranspiration and abstraction are incorporated in the model for each time steps. These parameters vary seasonally for changes in weather conditions. It is assumed that the rainfall, river water level and other climatic factors would not change in the next 20 years.

Groundwater abstraction for both irrigation and water supply can be specified for individual modelled layers and grid cells. Gross abstraction is simulated in the model with part of irrigation abstraction allowed to re-infiltration in the uppermost layer. In the study area, the rate of abstraction from tube wells for urban and irrigation use are specified for individual cells. According to BADC, 1992 report deep tube wells generally operates 12 hours per day for about 100 days per annum. It has been calculated that a tube well abstract about 2447m3 of water per day in the dry season. Annually each tube well operates from January to mid April. The average discharge rate of shallow tube wells is 0.5cusec. They operate about 12 hours a day and 100 days per year. Therefore the abstraction of tube wells is 612m3 per day of dry season. In the Dhaka city the scenery is different. The total number of deep wells is approximately 500 and average abstraction is 4000m3/d.

Table 10.4: Projected demand and supply up to 2025 in the Dhaka City

Year	population(million)	Demand(mld)	Abstraction(mld)
2005	10.06	1999	1460
2010	12.27	2485	1814.05
2015	14.93	3050	2226.5
2020	18.04	3686	2690.78
2025	21.63	4419	3225.87

Table10.4 shows the projected demand and supply of Dhaka City. To consider this projection the number of deep tube wells is predicted for modelling

Year	Num. Of DTW
2008	500
2011	560
2014	620
2017	680
2020	740
2023	800
2026	860

D. Model Calibration

The traditional method of model calibration is to run the model frequently in trial and error method. The close understanding of the modeller with the real aquifer may result in better approximation of the real system to the model system. In order to identify any possible problems due to the chosen discrimination, it is always better to proceed from the simple to the complex during the calibration stage

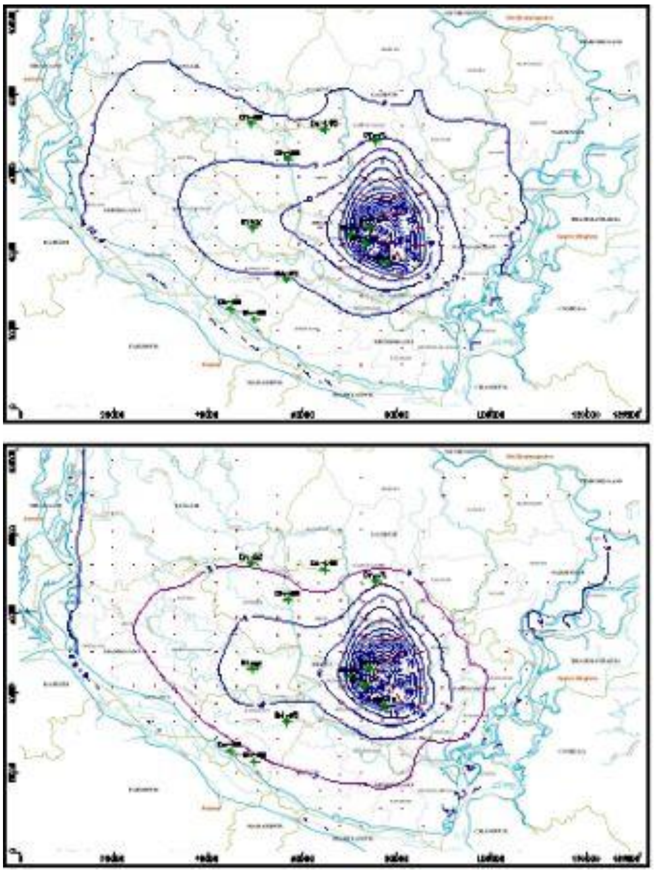

Fig 1.11: Model simulated present water table contour map for (a) wet season (b) dry season.

III. RESULTS

After calibration, the model may be used to predict the effects of proposed groundwater change. It involves the operation of the model after specification of the future abstraction (municipal or agricultural) or recharge pattern. The choice of the simulated period and the time steps can be specified depending on the objectives of the modelling. Model prediction can be represented as piezometric maps.

The reliability of prediction simply depends on the authenticity of database. The confidence, limits of the database should be expressed because the future climatic condition and consequently the recharge cannot forecast accurately. Even a model with best database and most rigorous calibration cannot predict the exact water level that will occur on a specific date in the future.

After the simulation of the model, it represents approximately the present situation (fig-1.11).Then the model can be used to test the future response of the groundwater level with increasing tube wells and abstraction. Again it can be used to predict the response of groundwater level by adding recharge wells through which the aquifers can be recharged.

Figure 1.11(a) and (b) represents the present situation of the water table after calibration for wet and dry season. The worst situation in both dry and wet season prevails in the central part of the study area that means in the Dhaka city, which exhibited by the sharp declination of piezometric heads and mega cone of depression with the water table elevation of about -65m in the wet season and -70m in the dry season. The area of mega cone of depression is about 1017km2. For the purpose of the prediction, two model scenarios are considered.

A. Scenario-1

The study area is urbanized very rapidly. As the Dhaka city expands towards north, many industries are shifted in the study area and number of peoples in the study area also increased. Their demand of water also increased. As a result the number of deep tube wells, municipal well also increased. As a result greater amount of abstraction will be needed surrounding the growth centers.

If we consider that pumping wells are increased with time, then from the first scenario it has been found that after 20 years the elevation of groundwater level will decline to about -120m in the central part of the Dhaka City. Figure shows a great declination of groundwater table in the central part of the Dhaka city, especially in the Tejgaon, Gulshan, Banani, and Lalbagh area. This huge declination of groundwater level will increase the area of mega cone of depression. The mega cone of depression will attain an area of about 1962km2. So, after 20 years the area of mega cone of depression will increase by 945km2 which are more or less double than the present value. As a result a huge number of wells located in the city or outside the city with pump setting levels at 25m below ground surface will be affected. So the abstraction cost will be higher to extract water from the deeper aquifer. On the other hand this huge declination can also produce subsidence or other environmental degradation in or around Dhaka City. Figure-1.12 also shows that, in the western part of the study area, the situation remains more or less good.

B. Scenario-2

In the second scenario injection wells for artificial recharge were included in the model in addition to the new pumping wells. From the second scenario it has been found that if we inject the amount of water that is equal to the abstraction of water in the Dhaka City, the model predict that the ground water level will not decline from the present situation. Figure-1.13 shows that the ground water elevation is -70m after 20 years. That means after artificial recharge there is no change in groundwater level. So from the scenario -2 we can predict that groundwater level will be fixed at -70m and the area of mega cone of depression will be reduced by 945km2 after 20 years due to artificial recharge. As a result any future loss of natural resource or environmental degradation can be prevented.

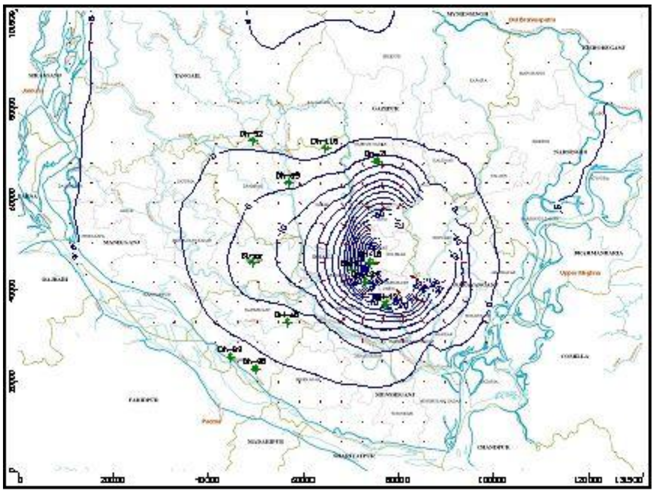

Fig 1.12: Predicted groundwater level after 20 years with no recharge.

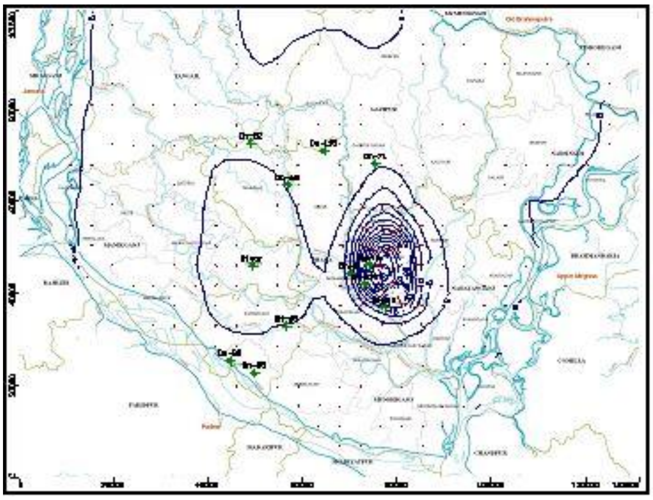

Fig 1.13: Predicted groundwater level after 20 years with artificial recharge.

IV. CONCLUSION

Modelling is a technique that can predict the change in groundwater level. After the simulation of the model, it represents approximately the present situation. The model may be used to predict the effects of proposed groundwater change. It involves the operation of the model after specification of the future abstraction (municipal or agricultural) or recharge pattern. The main purpose of groundwater modelling of the study area is the assessment of the present groundwater conditions, future scenery of the groundwater and finally evaluating the suitability of the artificial recharge in the Dhaka city. The simulated situation shows the worst condition is in the central portion of the Dhaka city and more or less good condition found in the western portion. Urbanization of the study area along with increased abstraction is also simulated in different scenarios to predict the impact of over abstraction. In the study area, lowering of water table will occur, if no alternative source of water for human consumption is introduced. But the alternative source is not available. So we have to think about artificial recharge. The model predicts that groundwater level will decline to about -120m in the central part of the Dhaka City after 20 years if the abstraction increases with increasing number of wells with time and if we inject significant amount of water into the aquifer for recharging the aquifer artificially the elevation of the groundwater level after 20 years will be fixed at -70m and the area of the mega cone of depression around Dhaka city will be reduced by 945km2 for the next 20 years.

If the lowering of groundwater level continues at an alarming rate, in the near future, a devastating situation can be created in the mega City Dhaka. To avoid any future loss of natural resource, deterioration of water quality, environmental hazard, like land subsidence and to meet up the future demand of groundwater it is highly recommended that action plan and pilot project is needed for artificial recharge of aquifers of Dhaka city as early as possible. So, artificial recharge of aquifer of Dhaka City is an unavoidable need and relevant government authorities should consider taking immediate steps to avoid any future environmental degradation of Dhaka City and its surroundings.

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First Author:

Ms. Shireen Akhter is a post-graduate in Geological Sciences from the reputed public university of Bangladesh known as Jahangirnagar University. She has outstanding records in academic and innovative research in the specialized and advanced areas of geology. She has been in service for 10 years in place she spent eight years in Bangladesh Petroleum Exploration and Production Company Ltd (BAPEX) within senior managerial capacity.

Ms. Akhter is excellent in Field Supervision of Wire line, Logging Operation including Perforation, Quick Look Log Interpretation, Log Analysis (Manual interpretation & Software interpretation using Schlumberger TechLog), Reserve Estimation, Geo-Environmental Research, Geographical Information System, Basin Analysis (using Schlumberger Petrel and PetroMod), Seismic Interpretation and map preparation, Mudlogging (Anax System, procured from Weatherford), Gas Seepage spot investigation and Laboratory data analysis.

Ms. Akhter is a brilliant researcher already marked her footprints in international R&D arena of geological sciences and petroleum exploration. Numbers of trainings, seminars, conferences, presentations, projects have been accomplished under her supervision in such short span of her service. Key publications of Ms AKhter are:

- Reserve Estimation of Saldanadi Gas Field Bangladesh. International Journal of Innovation and Applied Studies. ISSN 2028-9324, Vol. 16 No. 1, May 2016, pp. 166-172
- Soil Geomorphic Evaluation of Sitalakhya, Dhaleshwari Interfluves. Bangladesh Geo science journal, volume-17, 2011.
- Clay Mineral Identification of Sitalakhya, Dhaleshwari interfluves. Bangladesh Journal of Geology, volume 29-30, p 88-99, 2011.

Ms. Akhter always thinks 'out of the box'. Alongside professional life, she decided to utilize her credentials in making business. Nurturing different dreams she recently has started entrepreneurship in graphic designing. She also takes interest in doing counseling of mostly unattended human behaviors like stress releasing, overcoming frustrations etc.

In personal life, Ms. Shireen Akhter is a simple, friendly and persuasive woman. She is married with Chief Repoter of News Bangladesh (a prominent online news portal), lives in Dhaka, Bangladesh. She wishes to make remarkable contribution in advancement of geological sciences in Bangladesh; and likes to embrace people at her door for any kind of support.

Second Author:

Md Sarwar Hossain is a registered 'Surveyor' of Bangladesh, has acquired two post-graduations first in Geography & Environment from a public university of Bangladesh known as Jahangirnagar University and secondly, in Disaster Manager from another public university named Dhaka University; and completed two graduations in Geography & Environment from Jahangirnagar University and Bachelor of Laws (LLB) in Law and Justice in Bangladesh University of Business and

Technology. He has 12 years of professional experience in GIS system, network infrastructure, site survey and acquisition, liaison with high officials of Government and effective communication. Vast work experiences in national and international platform with government, private sector and development partners have led Mr. Hossain to become a successful 'Consultant' in project management, law and justice, network infrastructure, environment and other technical and development issues of Bangladesh.

Mr. Hossain is also familiar in diverse surroundings by owning memberships of Bangladesh Association for Advancement of Science (BAAS), Bangladesh Geographical Society (BGS), Bangladesh National Geographical Association (BNGA), Bangladesh Society of Environmental Scientist (BSES), Bangladesh, Member of Earth Forum of Stamford University, GIS forum of Department of Geography and Environment, Jahangirnagar University and Jahangirnagar University Geographic Association.

He has publications in reputed journals on expanded areas of development of Bangladesh. One paper titled 'International and National Discourse of Business and Children's Right: Bangladesh Perspective (ISBN: 9783668317260)' notes a crucial issue of Bangladesh connecting child rights affected by different activities of non-formal businesses. And another review article titled "Natural Fibre Composite (NFC): New Gateway for Jute, Kenaf and Allied Fibres in Automobiles and Infrastructure Sector" shows how natural fibres can play a significant role in infrastructure and automobiles sectors, most importantly in green economy of the world.

Md Sarwar Hossain is happily married for 8 years lives in Dhaka, Bangladesh. Her wife is a government service holder designated as 'Joint District Judge' of Bangladesh and he has bestowed with two beautiful young daughters. He finds his interest in undertaking research, achieving set goals in work and family and last but not the least, leading a peaceful life.