ESTIMATION OF CLIMATE CHANGE INDUCED GROUND WATER LEVELS AND RECHARGE OF GROUND WATER BY PROPOSING RECHARGE WELLS AT NARAI KHWAR HAYATABAD PESHAWAR.

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Abstract

Climate change is variation in patterns of weather that lasts from decades to centuries. The increasing levels greenhouse gases are playing key role in producing global warming and it has decisive impact on hydrological cycle of earth. The resulting temporal and spatial availability of water makes it imperative to exercise innovative way of water conservation strategy. In this study ground water rehabilitation strategy is proposed for groundwater recharge using excess storm water to be injected in recharge wells at Narai Khuwar. The current groundwater levels of tube wells and well logs of Hayatabad were obtained from Peshawar Development Authority for over 70 tube wells. The hydrological study has been performed using rainfall-runoff model WIN TR 20 by using rainfall data of last 40 years and other hydrological and hydro-geological parameters. The UHG of different time intervals (2 to 200 years) were obtained to determine the availability of water. The subsurface geology was determined by conducting resistivity test. Extensive numerical modeling was performed for current and future water levels in these wells.
using MODFLOW. The calibrated model was then used in simulation mode and an estimate of water levels in the study area was made for 30 years (2019 - 2049) with and without application of proposed recharge strategy. The study indicates that mitigation measures are required to arrest the rapid water decline in Hayatabad.

**Keywords:** Climate change, Groundwater recharge, Numerical modeling, Rehabilitation strategy, UHG (Unit Hydrograph), Resistivity Test, Rainfall runoff model WIN TR2

I. Introduction

Climate change is variation in patterns of weather that lasts from decades to millions of years. It is a well-known element and its effect on all the sectors including water, health, agriculture and forests are visible around the globe [III]. Due to lack of information and availability of resources developing and under developed countries suffer consequences of climate change far more than the developed countries especially if we scale down this fact to community level. After massive and uncontrolled growth of industries and increasing emission of carbon dioxide, carbon monoxide and other Green House Gases (GHGs) in the atmosphere enhanced rapidly from industry and vehicular burning fossil fuel. These emitting gases disturb the eco system of the world and cause the overall increase in global temperature. During 20th century the global temperature was recorded 0.76 degree centigrade but after first decade in this century an increase of 0.6 degree centigrade has been noticed [II]. Even a minor enhancement in earth temperature which takes place due to climate change may have worst effects which includes rising sea level due to melting of polar ice caps which ultimately cause damages due to storms. Increasing ocean temperature brings strong and periodic storms, increase in precipitation events which ultimately lead toward flash flooding and cause damage to the urban areas.

Pakistan a developing country of south East Asia is feared to face worst consequences of climate change because of its location and reliance on glacial fed water. The country has an enlarged latitudinal range extending from south (Arabian Sea) to the north (Himalayan Mountains). There are almost five thousand glaciers in Pakistan region having a huge quantity of water stored in solid form which withstand our supply of water through rivers by their melting process [III]. The snowfall in winters tends to sustain the ice mass in ice caps and glaciers but the balance is affected due to increase of heat due to change in the climatic conditions. Most of the residents are directly affected from climate change as most of them live in low river deltas or coastal areas where level of sea rise and floods are possible consequences of increase in temperature due to the phenomena of climate change.

Khyber-Pakhtunkhwa is located in northwest region of the country in which major portion of population lives in rural area and their living is dependent upon farming. Just like other parts of the country Khyber-Pakhtunkhuwa is also affected by climatic change as many glaciers (Chitral, Kamalpaya and Soriawi Glaciers etc.) And river systems (River Kabul,River Jundi,River Kunhar etc.) lie in this region.
During last decades, constant interruption of mankind resulting in increased emission of greenhouse gases and urbanization has affected quality of water as well as the Groundwater depth has increased which has become a threatening problem for both developed and developing countries. This has not only become a threat for quality life but has also put burden on the economy of the states. Likewise, other affected countries, Pakistan face the same issue which needs proper consideration to cope with it. Groundwater depth in Hayatabad a major township in Peshawar, KP, has declined very rapidly in recent years as per record of Peshawar Development Authority (PDA) [XIII]. The water table depletion patterns of two random tube wells of Hayatabad are shown in Figure 1. The main reasons are the same mentioned before (i.e. Urbanization, increase in pumping rate, and decrease in recharge rate).

![Water level depletion pattern in Sector E-3 and Sector J-3 of Hayatabad](image)

**Fig 1: Water level depletion pattern in Sector E-3 and Sector J-3 of Hayatabad [XIII]**

In this study a groundwater rehabilitation strategy is proposed by suggesting recharge wells for injection of excessive surface runoff water for aquifer recharge. Extensive numerical modeling for groundwater has been done using MODFLOW. Four different scenarios have been modeled for the study area and simulations were conducted.
made in order to determine their impact on ground water level for future predictions of groundwater level for 30 years (2019-2049). Using some detailed information’s of study area the present paper has inspected the effect of about 15 pumping wells and three recharge wells proposed to be located at Narai Khuwar (Natural Drain of Hayatabad). Hydrographs were obtained in order to check the availability of water in Narai Khuwar to know the run off potential of the area for various return periods for checking the reliability practical implementation of the project. The hydrographs for 2, 10, 100 and 200 years were obtained from Win TR-20 model. The Narai Drain Hydrograph was derived at Board bridge (i.e. outlet R1) using Win TR-20 model after considering the information on land use, topography and history of rainfall for the Peshawar City for the last 40 years (i.e. source Pakistan Metrological Department) [XI]. The stratograph has been determined by performing Resistivity Survey at the study area. The instrument, used to measure electrical resistivity measurements in research area, was DC Terrameter SAS 4000 ABEM. Schlumberger electrode configuration was used as it suited the area and less laborious as compared to other electrode configuration techniques [XIV]. The input data was used in Strator 3 Golden software by which stratographs were determined. The main aim of the resistivity survey was to determine the depth of sand and gravel layer having high hydraulic conductivity to improve recharge efficiency. The quality of water was also determined by performing grab sampling of both storm and ground water of the study area at the interval of 30 minutes. The collected sample was tested in laboratory of University of Engineering and Technology Peshawar and several tests (Turbidity, Hardness, Alkalinity, PH, Sulphide Content, Chloride Content, DO, BOD, COD) were performed both on storm water and ground water samples in order to determine whether the storm water is going to contaminate the ground water or not.

The objective is to quantify the benefit of this proposed recharge system to the groundwater level in Hayatabad.

II. Baseline Studies

The rapid drawdown of water table in Hayatabad has not stirred the concerned authorities yet, if proper rehabilitation measures are not adopted, boring of new tube wells will be required which might include rock cutting. This will be a huge burden on economy and the water obtained from such depth may be saline. Therefore, a comprehensive study needs to be undertaken to enhance Groundwater recharge using storm water runoff, since there is no other intermittent water source in the vicinity. Ghumman et al. (2013) estimated the impact of artificial recharge wells on groundwater. The study carried out for Buryadah, Qassim Saudi Arabia. The modeling has been done by using MODFLOW. Recharging capacity of six recharge wells were determined and their impact on aquifer and recharge of 34 pumping wells of the study area was simulated [V]. Similarly the effects of artificial recharge was also analyzed by M.C. Sashi kumar et al (2017) in which the a suitable site was identified to augment the groundwater source and its performance was accessed through GIS (Geographic Information System) and numerical groundwater modeling techniques using MODFLOW, [IX]. S. Selvam et al (2016) adopted integrated
approach to study the delineate groundwater recharge potential zones using ArcGIS 9.3 Software. An attempt was made to propose the suggestions for maintaining equilibrium between groundwater quantity and its exploitation. B.El Monsuri et al (2015) conducted a study to improve the potential of groundwater resources by exploring the feasibility of artificial groundwater recharge. The quality of water for use in artificial recharge is critical and can be minimized in infiltration basins by selecting graded sand/gravel packs to keep clogging close to the surface of the infiltration interface Data processing using a GIS tool allowed us to identify favorable areas for artificial recharge [XIV]. Hashimet. al. (2012) Estimated change in groundwater recharge by introducing artificial recharge system and form an ephemeral river channel by MODFLOW- 2000 to simulate recharge for both steady- and unsteady-state conditions. The model was standardized and certified on the basis of observed hydraulic head in observation wells, model accuracy, uncertainty, and model sensitivity. The recharged water from the surface runoff was estimated through an inverse groundwater modeling approach. Groundwater model was used to estimate aquifer hydraulic parameters from 1993 to 2007 [XIV].

III. Study Area and Details

Hayatabad is a modern suburb of Peshawar, KP and is one of the largest township of Peshawar. It is located between latitude 33.968060 and 33.969753 and between longitude 71.412002 and 71.451299. The weather of Hayatabad, Peshawar used to be generally dry. The rainfall pattern is changing and is getting comparatively more rain. The strata of Hayatabad consist of clayey nature, which resist infiltration of water. The surface layer mostly comprised of sand, clay, and sand stone. Based upon the catchment characteristics, slope, and land use, geological composition of the study area, rainfall data of last 40 year (1973 – 2013), time of concentration, stream cross section and other hydraulic parameters were considered to develop a rainfall run off model for quantification of available water in the stream. WINTR-20 model has been used to determine the Unit Hydrograph (UHG) of different time interval (2 to 200 years).

![Unit Hydrographs of 2, 10, 100, 200 Years](image)

Figure2: Hydrograph for 2,10,100,200 years return period to reach R-1 at downstream respectively

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Figure 2 showing the hydrograph of 2,10,100 and 200 years respectively, At the outfall near Board Bridge over the Narai Drain which generates a runoff rate of 13.6 m$^3$/s during storm duration of 25 hours where as the one for 10 years generates a runoff rate of 83 m$^3$/s during storm duration of 22.81 hours, the hydrograph for storm of 100 years return period, at the outfall near Board Bridge over the Narai Drain which generates a runoff rate of 348 m$^3$/s during 20.22 hours storm duration while hydrograph of storm of 200 years return period generates a runoff rate of 488.3 m$^3$/s in storm duration of 20.22 hours.

To determine the appropriate depth of recharge wells resistivity survey data of the study area was used as an input for the software Strater 3 by which stratification of Narai Drain was obtained. The depth of layer of sand and gravel was determined in order to estimate the depth of recharge wells (i.e. Figure 4a and Figure 4b).

Figure 3 (a, b): Stratograph of Narai Drain at suggested location for various depths

Figure 3(a) indicates the stratograph of Narai Khuwar, where construction of recharge wells is suggested. It shows that the surface crust contain sand and clay layer of 2.5 m thickness with the second layer of sand stone of 6 m thickness. The third permeable layer is sand and clay with a thickness of 2 m. The dominant layer of the zone is lateritic soil of 53 m thickness. The last layer identified is sand and gravel with a thickness of 5 m which is of maximum permeability. It is suggested to dig the recharge wells up to a depth where the hydraulic conductivity is optimum in order to achieve the maximum utilization of storm water for recharging of groundwater. Figure 3 (b) indicates the surface materials of sand and clay having 9 m thickness underlined by a thin layer of sand stone of 3 m thickness. The third layer is soil media of boulder and clay with 3 m thickness while the dominant strata estimated is sand stone with mixed silt and clay having a 35 m thickness while The last strata is sand and gravel which is a permeable layer of more than 10 m thickness. The proposed depth of recharge well will be 55 meter according to the obtained results.
Table 1: Water quality of storm water at Narai Khuwar

| S. No. | Test                      | Sample | Standards (i.e. WHO/ NEQS) |
|--------|---------------------------|--------|----------------------------|
| 1      | Turbidity                 | 166    | 147                        | 151 | 5 NTU |
| 2      | PH                        | 8.00   | 8.00                       | 8.00 | 6.5-8.5|
| 3      | Alkalinity                | 189    | 200                        | 241 | 250 mg/l |
| 4      | Hardness (EDTA)           | 266    | 271                        | 260 | 500 mg/l |
| 5      | Sulphide Content          | 14     | 16                         | 18  | 400 mg/l |
| 6      | Chloride Content          | 31     | 33                         | 29  | 250 mg/l |
| 7      | Dissolved Oxygen          | 1.1    | 1.2                        | 1.1 | Variable|
| 8      | BOD (i.e. 5 days)         | 142    | 131                        | 120 | 80 mg/l |
| 9      | COD                       | 288    | 301                        | 257 | 250 mg/l |

For the purpose of determining quality of water grab sampling was done in study area at different locations and time. Three samples were collected with the frequency interval of 30 minutes. The results of storm water are shown (i.e. Table 1).

Quality parameters of storm water (Alkalinity, hardness, sulphide content, chloride content) are within the acceptable limits according to World Health Organization (WHO) and National Environmental Quality Standard (NEQS). PH value indicates that the storm water is alkaline and can be used for drinking after natural filtration.

The grid in Figure 4 is representing the model area, red dots are representing the location of tube wells and black dots are representing the position of suggested recharge wells.
Figure 4: Grid representing model area of Hayatabad.

The details of pumping rate of sixteen (16) pumping wells in the study area are as under.

Table 1: Pumping rate of Tube wells [XIII]

| S.No. | Well ID               | Pumping Rate (m³/sec) |
|-------|-----------------------|-----------------------|
| 1     | Hayatabad Sector H-3  | 0.052                 |
| 2     | Hayatabad Sector J3   | 0.052                 |
| 3     | Hayatabad Sector J4   | 0.052                 |
| 4     | Hayatabad Sector J3   | 0.052                 |
| 5     | Hayatabad Sector H1   | 0.041                 |
| 6     | Hayatabad Sector G1   | 0.043                 |
| 7     | Hayatabad Sector G1   | 0.052                 |
| 8     | Hayatabad Sector G3   | 0.041                 |
| 9     | Hayatabad Sector G4   | 0.052                 |
| 10    | Hayatabad Sector J2   | 0.052                 |
IV. Working with MODFLOW versions

MODFLOW-2000 is significantly enhance new version of the USGS modular finite-difference ground-water flow model. MODFLOW-2000 will also include SEN sensitivity process and PES parameter estimation process [XV]. MODFLOW-2005 simulates flow in a flow system in which aquifer layer are confined or unconfined. Flow from external stresses, such as flow to well, flow to drains, flow to river bed, areal recharge and evapotranspiration can be simulated. MODFLOW-USG was initially released in 2013, which is designed to adapt a wide range of grid variation using unstructured grid.

The specific aspects of a groundwater-flow system are simulated by these codes by use of independent modular-programming component called “package,” such as the well package, river package, recharge package, drain package, drain return package, unsaturated zone flow package.

The general equation solved by MODFLOW is:

\[
\frac{\partial}{\partial x} \left( K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_{zz} \frac{\partial h}{\partial z} \right) + W = \frac{S_s \partial h}{\partial t} \tag{1.1}
\]

Where;

- \( K_x, K_y, K_z \) are hydraulic conductivity, with principal directional oriented along a coordinate axis
- \( W \) is volumetric source/sink, unit of 1/t (i.e., volumetric flux per unit volume of aquifer). Areal source/sink are converted to these unit. \( S_s \) is the specific storage 1/L, \( T \) is the time.

V. Groundwater Modeling of Study Area

Processing MODFLOW 8.04 [XV] have been used in the recent study for groundwater modeling of the study area. The area under study is represented by 40 rows and 40 columns which cover 8000 X 8000 feet of the study area majorly covering the tube wells of Phase 2 and Phase 3 of Hayatabad.
between two natural drains. A denser mesh was created at the locations of the wells to model as accurately as possible. It is worth mentioning that grid used in the Figure 2 showing the approximate location of the tube wells and suggested recharge wells in the study area (Hayatabad). However, the normal grid used in the MODFLOW is 40 x 40 which was made further denser near the wells. As the thickness of aquifer is 440 feet two layers have been chosen for modeling.

Upper layer represents the impermeable cover to the 440 feet thick aquifer. The aquifer is divided in two layers 230 feet and 410 feet from the natural surface level. Recharge from the surface of the aquifer is negligible as the surface is clayey in nature so the recharge from three wells were taken into the account which are placed in the natural drain (Narai Khuwar). Water contours were drawn from the observation data and initial and prescribed heads were selected. The discharge and location of tube wells with respect to row and columns of the finite difference grid were also used as an input data. The deep Groundwater outflow is negligible and was not considered in the model. The location and pumping rate of wells of the study area are given in table 2. The location of the recharge wells and tube wells were defined by their coordinates within the active cell region (Figure 2) for analysis of pattern flow from recharge wells post impound. The cells between two Natural drains at study area were considered as active cell regions and the rest of the area covered by grid was considered as non-active region. As the recharge from recharge wells is dependent upon the storm water in the natural drain which is mostly present in the period of May to August that’s why two stress periods were considered for the analysis. The Calibration and Validation of model is as under.

Calibration and Validation of Model

Calibration and Validation of model is important before simulation [I]. For the purpose of calibration, the known historic data of water levels are compared with the model results making necessary adjustments in aquifer and boundary conditions. Aquifer parameters were adjusted in stress period 1 only and the same were used in the remaining stress periods, however boundary groundwater potential heads change in all stress periods from one to ten. In this study boundary condition was majorly adjusted for model calibration. Data of water levels for the year 2011 were used as initial water levels. The observed water in 2014 were used to calibrate the model and in 2019 for validation of model for transient flow conditions. There are few methods for testing the model accuracy. In this study model accuracy is checked by Root mean square error which is given below

\[
RMS = \sqrt{\frac{\sum_{i=1}^{n}((Y_m)_i-(Y_s)_i)^2}{n}}
\]  

(1.2)

Where “Ym” is observed water level and “Ys” for simulated water level and “n” is number of observation wells and RMS is root mean square error.
Figure 5 and 6 show the simulated and observed hydraulic head for 2014 and 2019 for calibration and validation of model. The root mean square error was 0.45 for calibration and 0.52 for validation which are well in range as compared to the results of Ghazaw, Y.M et al (2014) [V].

The following three recharge wells and sixteen pumping wells have been evaluated and simulations have been made for future 30 years (2019 – 2049). Option-I simulates the drawdown with constant pumping rate without recharge wells. Option-II simulates the drawdown with increased pumping (1 % per annum) without recharge wells. Option-III simulates the drawdown of constant pumping with recharge wells. Option-IV simulates the drawdown of increased pumping (1 % per annum) with recharge well.

**Option – I: Impact of Constant Pumping Discharge Without any Recharge Well**

This option deals with a precaution to be adopted for future in order to enhance the life of aquifer. In this option the pumping rate is assumed constant for the coming 30 years (2019 – 2049) and the impact on drawdown of water has been simulated which shows the change in hydraulic head (drawdown) of 58 feet’s in 30 years as shown in Figure 9. The concentration of tube wells is high center of study.
area. Although a water conservation strategy is adopted in this option by keeping the rate of discharge constant throughout for 30 years still such a large draw down may result low pressure in aquifer allowing the contaminated water to seep into aquifer, Therefore a serious disaster may occur, more over construction or boring of new tube wells will be required of large depths in order to fulfill water supply demand which will be ultimately a huge burden on economy.

The hydraulic head of water for predicted 30 years is shown in Figure 8.

![Figure 8: Predicted groundwater level in aquifer in year 2049 in case of constant pumping without any recharge well](image)

Option-II Impact of Increased Pumping Discharge without any Recharge Well

The trend of groundwater consumption is enhancing day by day because of rapid growth of population and change in the trends of living standard of people. In this option an increase of 1% per year in present pumping rate is considered from 2019 to 2049. The simulation of drawdown has been done with the help of the model. The groundwater level in case of increased pumping rate without provision of any rehabilitation or groundwater recharge strategy is predicted to be 95 feet’s as shown in Figure 9.
Fig 9: Predicted groundwater level in aquifer in year 2049 in case of increased pumping without any recharge well

Option-III Impact of Constant Pumping rate With Recharge Well

This option is dealing with two precautionary strategies. First of all, the discharging rate of pumping wells is kept constant and secondly the storm water is utilized for groundwater recharge. The result of this option shown in Figure 10. It is observed that the drawdown of 27 feet’s have been observed in 30 years. The water contours show the recharge in Groundwater near recharging wells. The recharging wells will be only operational in storm season (May – September) that’s why the simulations have been made using two stress periods per year.

Fig 10: Predicted groundwater level in aquifer in year 2049 in case of constant pumping with recharge wells

Option-IV: Impact of Increased Pumping with Recharge Well.

This option deals with increase in extraction rate with the provision of recharge wells in NaraiKhuwar. The increase in abstraction rate is considered 1% per

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annum in year 2019 to 2049. Figure 11 shows the simulated groundwater level for the year 2049.

Fig 11: Predicted groundwater level in aquifer in year 2049 in case of increased pumping with recharge well

The highest drawdown is observed in the center of study area where the concentration of recharge well is high. It has been observed that the water level drops by 43 feet in 30 years at the end of 2049.

VI. Conclusion

The modeling results show that groundwater recharge by using recharge well is necessary to prolong the life of aquifer. The simulations indicate that the rate of depletion will be minimized if pumping rate is made constant along with the provision of recharge wells for aquifer recharge. Four options for extraction rate with and without provision of recharge wells have been studied. The drawdown in case of constant pumping with recharge well is 27 feet in 30 years which is approximately 28% less than the existing situation. It is recommended to determine the exact depth of recharge wells (by using resistivity survey) which may vary for site to site condition with respect to subsurface lithology. Moreover, the price of water is not defined in Hayatabad that’s why people do not care about the excessive waste of water. An enhancement in price of water and public awareness campaigns about water conservation for future should be adopted in order to reduce the consumption of water. The present source of water will be depleted after some years that’s why small dams for storing storm water should be constructed along with recharge wells in order to recharge the aquifer and to utilize surface runoff after storm events.

A research work for future is also necessary to utilize the waste water from mosques and kitchens after required treatments.
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