Mohammed Ginaya, Adil Elkrail, Abdalla Farwa / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 3, May-Jun 2013, pp.217-222

Numerical Modeling of the Groundwater Flow in Ennahud Basin, Northern Kordofan state - Sudan.

Mohammed Ginaya1, Adil Elkrail 2 and Abdalla Farwa3

1Al Salam university-El Muglad – South Kordofan state –Sudan
2Department of hydrogeology, Faculty of Petroleum &Minerals, Al Neelain University, Khartoum – Sudan
3Khartoum University, Faculty of Science, Dept. of Geology

Abstract

The groundwater model techniques were used to improve the understanding and evaluate the complex hydrogeological situation of the study area. Visual MODFLOW code was selected to run the model scenarios. The aquifer hydraulic conductivity, storativity, recharge, and constant head boundary (CHB) were adjusted during calibration to obtain acceptable match between calculated and observed heads and fluxes. The calibration of three-dimensional finite difference flow model of Ennuhud sedimentary aquifer was realized through the calibration which is acceptable within the average Root Mean Square error (RMS) of 1.482m, Residual Mean of 0.526m, and standard error of estimate to be 0.22 where the contour maps of the simulated heads produced by visual MODFLOW show fair similarity with those drawn using initial heads which confirm acceptable model calibration. The calculated zone budget reflects that volume of aquifer storage for the three years varies from 3.57 to 8.3 million cubic meters (mcm). The annual average pumpage was estimated through the model run to be 6.73 mcm, whereas, the annual historical pumpage was 6.2 mcm. The annual recharge was estimated to be; 143.8, 579.9 and 867.5 mcm during the three successive years (2005-2007) respectively, whereas the annual average recharge was 530.4 mcm. The model assigns the regional groundwater flow direction towards the center where some water flow diverges to localized cones of depression ascribed to heavy pumping. The contour maps of the simulated heads show fair similarity with those generated from initial heads which confirm acceptable model calibration. The predictive simulation for 10 years starting from 2005 shows that the continued pumping will create relatively high changes in head distribution in the model area, and gives a maximum drawdown of 5m at 2015.

Key words: simulation, Trial- and- Error, zonebudget, aquifer, calibration

I. Introduction

Groundwater exploration and management comprises application of different techniques; geological, hydro-geological, geophysical and hydrochemical well as modeling techniques. Temporal and spatial changes of the hydrological cycle as results of climatic changes have a significant associated impact on water resources (Stoll et al. 2011). In semi-arid and arid environments, recharge is often heterogeneous (Wood and Sanford 1995; Harrington et al.2002; Scanlon et al. 2006). The greater the aridity of the climate, the smaller and potentially more variable in space and time is the recharge flux (Sibanda et al. 2009). Jyrkama and Sykes (2007) investigated the future spatial variation of the groundwater recharge. The results show increasing groundwater recharge in the future due to reduced extent of ground frost in tropical climate and increasing intensity of rainfall in arid and semiarid climate. Different modeling approaches have been used for the assessment of groundwater resources. Building of theoretical model for the optimal extraction of groundwater by spatially distributed users reflected that some aquifers may be more akin to private property rather than open access and may be subject to significant lagged effects from pumping (Brozovic et al. 2006, 2010). The groundwater modeling is a relatively modern technique for the assessment and evaluation of groundwater resources,(Elkrail, 2004,). The groundwater problems related to water supply are normally described by partial differential equation, in terms of hydraulic head. The resulting model providing a solution for this equation is related to groundwater flow model. Groundwater flow models have been extensively used for such problems of regional aquifer studies, groundwater basin analysis and near-well performance. Numerical models allow analysis of flow if the complexity of the mathematical model prevents an analytical analysis (Anderson and Woessner 1992). In groundwater flow modeling, the simplest numerical model considers the groundwater system as a single control volume. Changes in groundwater heads are expressed as averages over the groundwater system and are calculated by a global mass balance,(Keidser et al,1990). The groundwater flow modeling technique is introduced in this study to assess and evaluate aquifer system of Ennahud basin and predict the effect of increasing the extraction from aquifer for future development. Special attention is directed to delineate the geometry of Ennahud basin.

II. The study area:

The area lies between latitudes 12º 20´ - 13º 20N and longitudes 28º 00 - 30º 00E, covers an area of approximately 24311 km¬¬2(Fig.1).

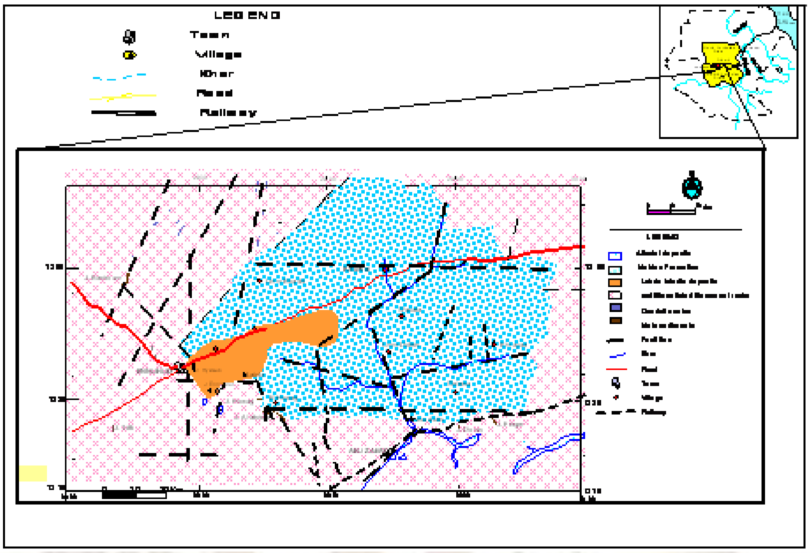

Fig.(1) Location and Geological map of the study area

On geological viewpoint the area is composed of Quaternary deposits, Mesozoic-Cretaceous sedimentary formations and Precambrian – Cambrian Basement in descending order (Fig. 2).

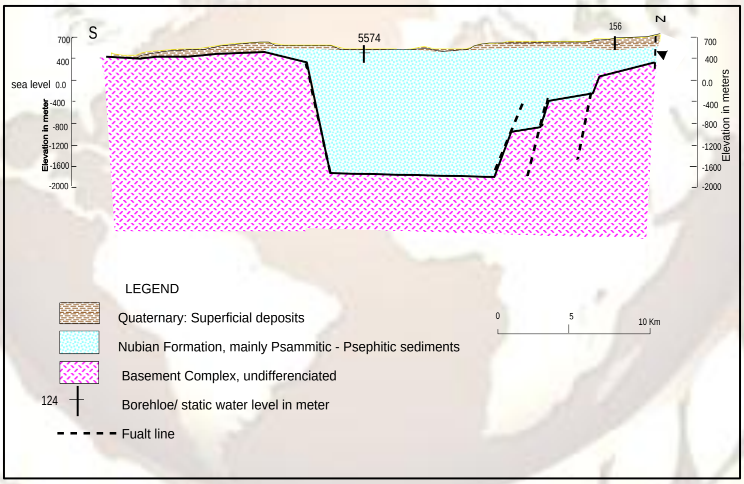

Fig.2 Schematic geological cross-section through the Model Domain

The basement rocks comprise ortho- and Para-gneisses, hornblende gneisses and amphibolites which were recorded at J. Mondra and at the boundary of the area. Graphitic schist, granite and synite are found at Rahad Essopagh area. Cretaceous Sedimentary rocks comprise the principal water- bearing formation in the area. They consist of sandstone and conglomerates. The thickness of these layers in the study area varies from 10 m to over 400m (Ginaya, 2001). Groundwater is the main water sources for domestic use for Ennahud and Abu Zabad towns. The elevations of the top of the Basement rocks, detected from borehole drilling, were used to define the bottom of the aquifer (one aquifer system) based on the lithological description and aquifer thickness. The aquifer effective thickness varies from30m to 70m. The aquifer is characterized by good hydraulic properties when it is not intercalated by siltstone or/ and mudstone. From stratigraphic and lithologic point of view the Nubian aquifer in Ennahud basin is considered as one aquifer system, with some slight variations in lithological characteristics.

III. Material and Methods:

Visual MODFLOW code was used for numerical model computation in the study area. A conceptual model for Ennahud basin was constructed, considering unconfined condition of the Cretaceous sedimentary aquifer (Ginaya, 2001).The grid network, used to cover the study area, has constant spacing of 4195.4m by 1582.25m. The model area is thus subdivided into 40 rows, 80 columns and 1 layer forming 3200 cells; covers an area of 21236.7km2.The observed hydraulic heads measured during June 2005 in the study area were used as initial heads to calibrate the model. The simulation time interval was divided into 22 stress periods each discretized into ten time steps. One hundred thirty boreholes were constructed in the area for groundwater abstraction. Forty wells were used as observation wells Fig. (2). Aquifer hydraulic parameters were calculated through pumping test using appropriate methods. The horizontal hydraulic conductivity (K) of the sedimentary aquifer in Ennahud basin was considered isotropic and ranged between 0.66m /d and 25m/d, where vertical hydraulic conductivities assigned as 10% of the horizontal hydraulic conductivity in the model domain. The bottom of the aquifer represents a horizontal barrier boundary. The upper surface of the aquifer represents a recharge boundary. For this situation, Dirichlet boundary condition is the most suitable boundary to be assigned for the model simulation. The hydraulic properties, initial conditions and boundary condition were assigned and can be adjusted during calibration. Constant head and No-flow boundary were assigned for boundary conditions. The main calibration targets are heads and mass balances. Groundwater budget was prepared to estimate the amount of groundwater inflow, outflow, and change in storage. The zone budgets for first, second and third year respectively, for the whole area were calculated (Table 1). The calibration of the three – dimensional finite difference flow model of the basin was performed using the Root Mean Square error (RMS), Residual Mean, standard error of estimate and mass balance percent discrepancy. The parameters determined by the model calibration were used for model prediction. For the future response of the system on the calibrated model, a time period of10years and the calculated heads of year 2005 were used. The prediction is done by changing the simulation period from 1092 days to 3466 days, (year 2015) Fig.(18). Keeping all other hydrogeologic and aquifer parameters as prevailing during simulation period, the change in the water levels through the time up to year 2015 was obtained.

IV. Results and Discussions:

Groundwater model is an effective tool for water evaluation. The groundwater discharge, recharge, water budgets, fluctuations, aquifer hydraulic properties and boundary condition can precisely determine through model applications. Accordingly, the historic total groundwater discharge from pumping wells was calculated to be 6.2 million cubic meter per year(mcm/y) whereas the average annual recharge to the sedimentary aquifer was estimated to be 288 mcm. Therefore, the recharge from precipitation is assumed to be spatially uniform over the basin.

The model calbration criteria, using Root Mean Square error (RMS), Residual Mean, and standard error of estimate to be less than 1.482m, 0.526m and 0.22 respectively (Fig. 3 A&B). Since the precipitation, pumpage, and the lateral flow witnin the study area varies from season to another, there is a minor variation in the equipotential contours in different stress periods within simulation time. In the most central part of the basin, the wide spaced equipotential lines indicate high permeability zone (Fig.5). The hydraulic conductivity values obtained from model calibration ranges from 1.5 to 25m/d which confirm the values derived from pumping test data. The specified boudary conditions prove as appropriate chioce for model simulation. As a result, the three – dimensional transient groundwater flow model can sufficiently simulate the regional groundwater flow of the Cretaceous sedimentary aquifer of Ennahud basin. It is obvious that the general groundwater flow converges towards the center of the area, while some local groundwater flows reflect cone of depressions at specified areas of high abstraction (Fig. 4B).

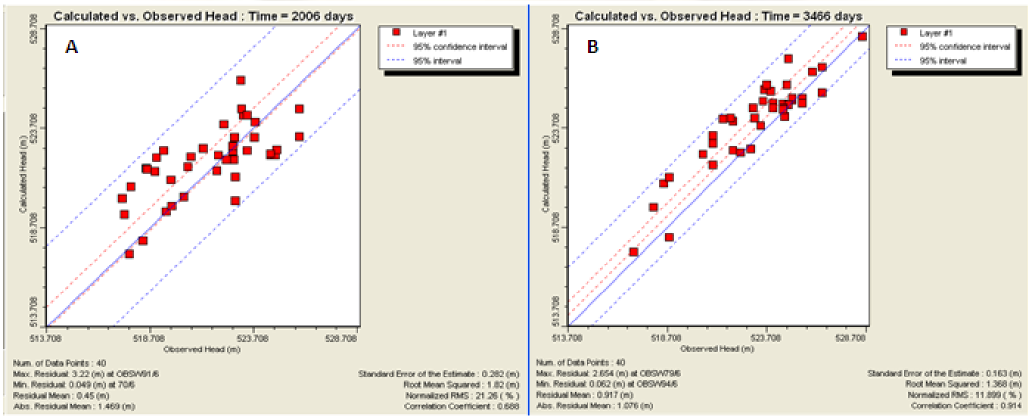

Fig. 3. Observed versus calculated heads After 2006 days(A) and 3466 days (B)

The calculated zone budget components include pumpage, recharge, storage and constant head boundary for the whole area. The volume change of storage of the aquifer during simulation time varies from 3.57 to 8.3 mcm. The groundwater pumpage volume in the whole area calculated by the model varies from 2.7 to 9.9 with average of 6.73 mcm, through the simulation time (Table1). The annual historical pumping is 6.2 mcm, which is almost similar to the computed value. The annual recharge during the three successive years (2005 to 2007) are; 143.8, 579.9 and 867.5 mcm, respectively(Table1), with annual average value of 530.4 mcm.

Table 1. Cumulative groundwater budget for the study area

Time	Component	Inflow Mm3	%	Outflow Mm3	%
Ist year (2005)	storage	3.57	1.7	206	98.7
	Constant head	61.4	29.4	0.038	0.0
	pumpage	0.0	0.0	2.7	1.3
	Recharge	143.8	68.9	0.0	0.0
	total	208.7	100	208.7	100
2nd year (2006)	storage	7.4	0.94	774.5	98.99
	Constant head	195	24.9	1.5	0.19
	pumpage	0.0	0.0	7.6	0.97
	recharge	579.9	74.11	0.0	0.0
	total	782.4	100	782.4	100
3rd year (2007)	storage	8.3	0.73	1121.29	99.08
	Constant head	255.97	22.62	0.49	0.0
	pumpage	0.0	0.0	9.9	0.87
	recharge	867.5	76.65	0.0	0.0
	total	1131.77	100	1131.77	100
Average	storage	6.4	0.90	700.6	98.95
	Constant head	170.79	24.14	0.676	0.10
	pumpage	0.0	0.00	6.73	0.95
	recharge	530.4	74.96	0.0	0.00
	total	707.59	100	708.0	100

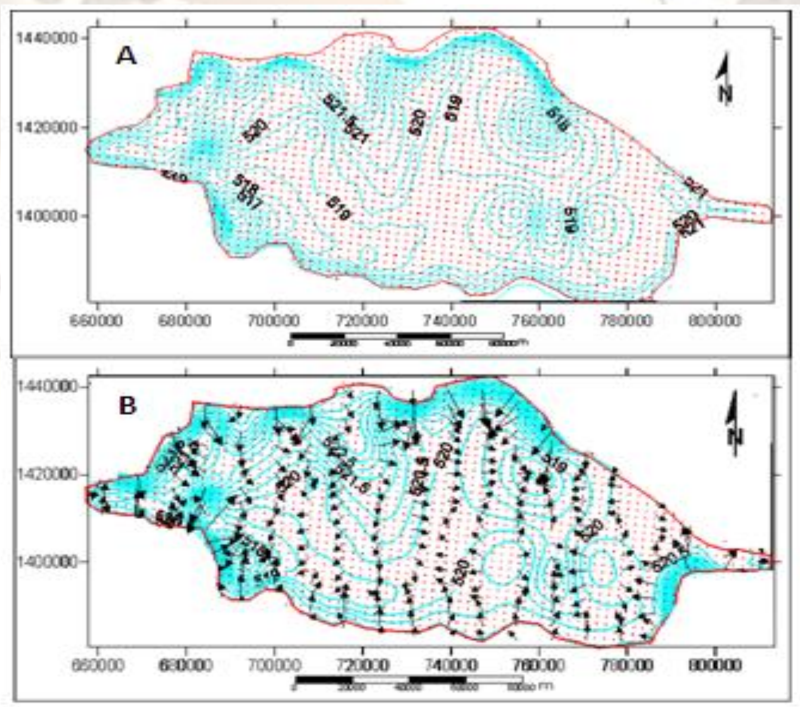

Fig. 4. Distribution of initial head (A) and simulated head with flow direction (B).

The predictive simulation for the years, 2010 and 2015 using the calculated heads of year 2005, shows that the continued pumping will create relatively high changes in head distribution in the model area, and gives a maximum drawdown of 4m at year 2010 and 5m at 2015. The hydraulic processing in the system show rise and fall in water table with respect to the head of year 2005, (Table 2). The average magnitude of water level fluctuation is around 3m, which is comparable with the observed value. There is a large predictive volume of recharge to the aquifer compared to the predictive volume of pumpage in year 2015 which encourage future groundwater resources improvement for decision makers for development planning.

Table (2) Predicted cumulative groundwater budget for the study area

Time	Component	Inflow Mm3	%	Outflow Mm3	%
year (2010)	storage	14.13	0.72	1974.85	98.52720
	Constant hea Constant head	396.9	19.79	3.40	0.16967
	pumpage	0.0	0.0	26.117	0.13030
	Recharge	1593.6	79.49	0.0	0.0
	total	2004.6	100	2004.37	98.82
year (2015)	Storage	14.27	0.42	3321.15	99.08
	Constant head	484	14.25	29.18	0.0
	pumpage	0.0	0.0	45.97	0.87
	recharge	2897.24	85.33	0.0	0.0
	total	3395.56	100	3400.60	99.95

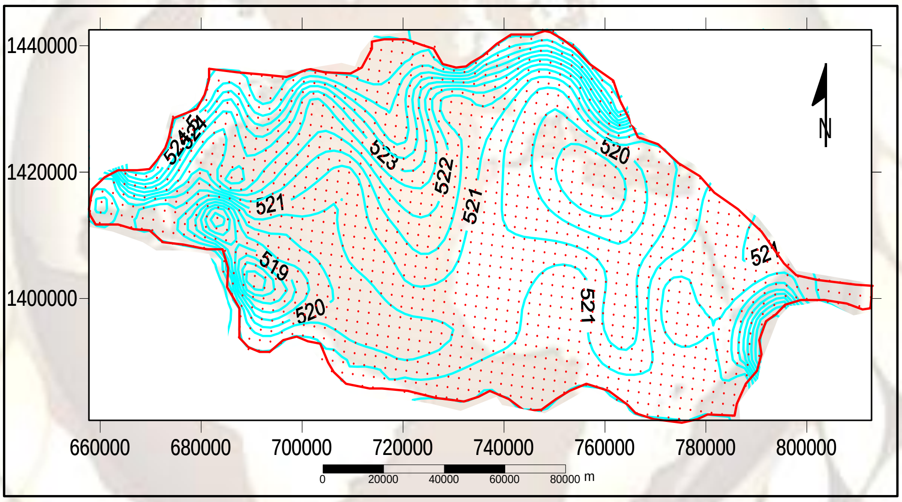

Fig.5 Predicted water level contour for year 2015

V. Conclusion

The model calibration of Ennahud Cretaceous sedimentary aquifer was acceptable within the average Root Mean Square error (RMS), Residual Mean, and standard error of estimate to be less than 1.482m, 0.526m and 0.22 respectively. The contour maps of the simulated heads show fair similarity with those generated from initial heads which confirm acceptable model calibration. The regional groundwater flow direction is towards the center with localized cones of depression ascribed to heavy pumping. The average change of storage, pumpage and recharge of the aquifer during simulation time calculated to be 5.62, 6.73 and 530.4 mcm respectively. The predictive simulation for ten years using the calculated heads of year 2005 shows that the continued pumping will create relatively high changes in head distribution in the model area, and gives a maximum drawdown of 5 m at 2015. The average magnitude of water level fluctuation is around 3m, which is comparable with the observed value.

References

[1] Anderson, MP, and Woessner, WW, 1992. Applied groundwater modelling, Simulation of Flow and Advective Transport, pp.1-27.

[2] Brozovic N, Sunding DL, Zilberman, D, 2006. Optimal management of groundwater over space and time. In: Goetz RU, Berga D (eds) Frontiers in water resource economics. Springer, New York

[3] Brozovic N, Sunding DL, Zilberman D, 2010. On the spatial nature of the

groundwater pumpin externality. Resour Energy Econ 32:154–164

[4] ElKrail AB, 2004, Numerical simulation of Subsurface Flow and Groundwater Vulnerability Assessment in Songhuajiang River Valley, Dissertation of Doctor of Engineering Hohai UniversityP.R.of China.

[5] Ginaya MA, 2001. Hydro- geophysical investigation of En Nuhud basin, Western Kordofan, MSc.Thesis Dep. of Geology and Mining Univ. of Joba. Sudan,

[6] Harrington GA, Cook PG, Herczeg AL.,2002. Spatial and temporal variability of groundwater recharge in central Australia: a tracer approach. Ground Water 40(5):518–528

[7] Hsu KC, Wang CH, Chen KC, Chen CT, Ma KW., 2007. Climateinduced hydrological impacts on the groundwater system of the Pingtung Plain, Taiwan. Hydrogeol J 15(5):903–913

[8] Jyrkama MI, Sykes JF, 2007. The impact of climate change on spatially varying groundwater recharge in the Grand River Watershed (Ontario). J Hydrol 338(3–4):237–250

[9] Keidser, AD, Rosbjerg, K, Hogh Jensen, and Bilsch K, 1990. A joint Kriging and zonation approach to inverse groundwater modeling, In Calibration and Reliability in Groundwater Modeling (K. Kovar, ed.), IAHS Publ. 195, pp. 171-184.

[10] Scanlon BR, Keese KE, Flint AL, Flint LE, Gaye CB, EdmundsWM, Simmers I, 2006.Global synthesis of groundwater recharge in semiarid and arid regions. Hydrol Proc 20:3335–3370

[11] Sibanda T, Nonner JC, Uhlenbrook S, 2009. Comparison of groundwater recharge estimation methods for the semi-arid Nyamandhlovu area, Zimbabwe. Hydrogeol J 17:1427–1441

[12] Stoll S, Hendricks Franssen HJ, Butts M, Kinzelbach W, 2011. Analysis of the impact of climate change on groundwater related hydrological fluxes: a multi-model approach including different downscaling methods. Hydrol Earth Syst Sci 15:21–38

[13] Wood WW, Sanford WE, ,1995. Chemical and isotopic methods for quantifying ground water recharge in a regional, semiarid environment. Ground Water 33(3):458–468