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Simulating of Groundwater Flow in Sag El Naam Basin, North Darfur State, Sudan

[1] Anas Jafar, [2] Adil Elkrail, [3] Salah Abdel Razig
[1] Department of water resources, Faculty of Natural Resources, Al Fasher University, North Darfur, Sudan.
[2,3] Department of hydrogeology, Faculty of Petroleum & Minerals, Al Neelain University, Khartoum, Sudan.

[1] anas.gafaar@yahoo.com, [2] adilmagboul321@yahoo.com

ABSTRACT

The main objective of this study is to improve the understanding and evaluate the complex hydro geological situation and the groundwater flow regime in Sag El Naam Basin, based on visual MODFLOW computer Code. Arc GIS was used for conceptual model construction. A quietest software was used for calculating aquifers' hydraulic properties. The model was run and calibrated using trail-and error techniques. 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 Sag El Naam basin was realized through acceptable average (RMS) of 0.14 m, residual mean error of 0.09 m, average absolute mean error (AM) of 0.12 m, average standard error of the estimate (SEE) of 0.02 m and average normalized root mean square (NRMS) of 1.49 %.The contour map of the simulated heads visualized closer lines at the north-western and south-western sides assigning recharge from the Shagara basin and Shangli-Tobya sub-basin towards the southwest with steep hydraulic gradient and low permeability, whereas, the water heads decreasing towards the southwest and inside towards the center forming cone of depression which is considered to be due to over pumping. The model assigns the regional flow direction towards the north western, southwestern directions and from the peripheries of the basin towards the center. The main components of water budget were calculated for four years with total Inflow varying between 321.74 and 390.89 and total Outflow between 321.81 and 385.68 mcm. Generally this study successfully formulated a new method of groundwater modeling, confirmed that visual MODFLOW can be used as a comparative technique for evaluation of groundwater flow regime in Sag El Naam Basin.

Keywords: *Simulation, Trial – and – Error, zone budget, aquifer, calibration*

1. INTRODUCTION

Groundwater flow model is a valuable tool for better understanding groundwater flow in aquifers and helping to better manage groundwater resources [1]. It is of the few tools available that can consider a complex array of aquifer variables (hydraulic properties, recharge, pumping, rivers, structure, and heterogeneity) and allow these variables to interact with each other [2]. Exploring these interactions with a model can reveal how an aquifer behaves. Once a model is properly calibrated, it can be used for predictions to manage groundwater resources [3]. Regional groundwater flow models are either scientific or management models [4]. The goals of scientific models are to better understand ground water flow regime, water quality evaluation and hypothetical tests [5]. Management models are generally used for future predictions or test management scenarios [6]. In many cases, management models build upon previously done scientific models [7]. The groundwater flow modeling technique is introduced in this study to assess and evaluate aquifer system of Sag El Naam basin and predict the effect of increasing the extraction from aquifer for future development.

2. STUDY AREA

The area lies between latitudes 13º 3′ - 13º 32′ N and longitudes 25º 15′ - 25º 45′ E, covers an area of approximately 2250 km^2 (Fig.1). The climate of study area, it is a typical phase of the desert and semi-desert zones [8]. The average annual rainfall ranges from 150 mm to 286 mm, and the rainy season extends from July to September, with maximum rainfall in middle August to September. The average annual pan evaporation rate is 9.8 mm per day and relative humidity is 34% [9]. The average temperature is 20^0 C and it rises up to 36^0 C in the summer season [10]. From geological viewpoint the area is composed of Basement Complex, Nubian Sandstone and Superficial Deposits (Fig. 2). The basement rocks comprise metamorphosed group of banded gneiss, schist and low grade metasedimentary rocks and postmetamorphic group of igneous intrusions mainly granitic [11]. The sandstone is composed of coarse clastic succession mainly gritty sandstone with mudstone intercalation generally attributed to the Nubian sandstone formation [12]. The thickness of Nubian sandstone sediments reaches up to 1000 m at the northwestern of the basin and decreases to 400 m in the south eastern part [13]. Groundwater is the main water sources for domestic use in study area. The aquifer thickness varies from17m to 90m and effective average thickness of 50m [14]. The aquifer is characterized by good hydraulic properties when it is not intercalated by siltstone or/ and mudstone. From stratigraphic and litho logic point of view the Nubian aquifer in Sag El Naam basin is considered as one aquifers system [15] (Fig. 3).

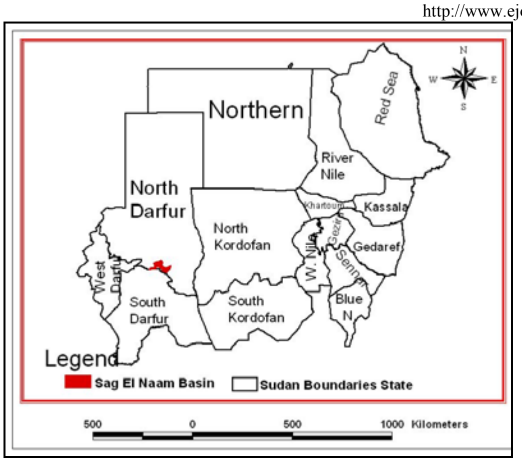

Fig 1: Location map

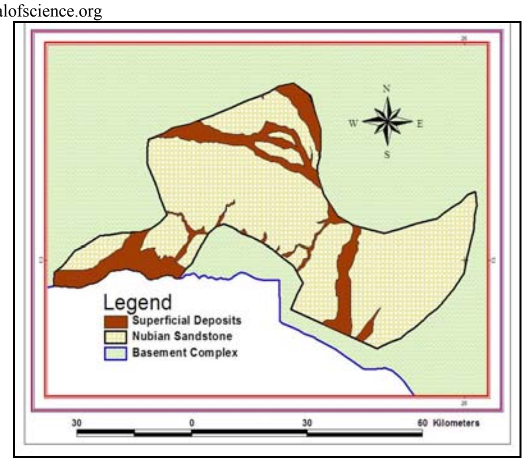

Fig 2: Geological map

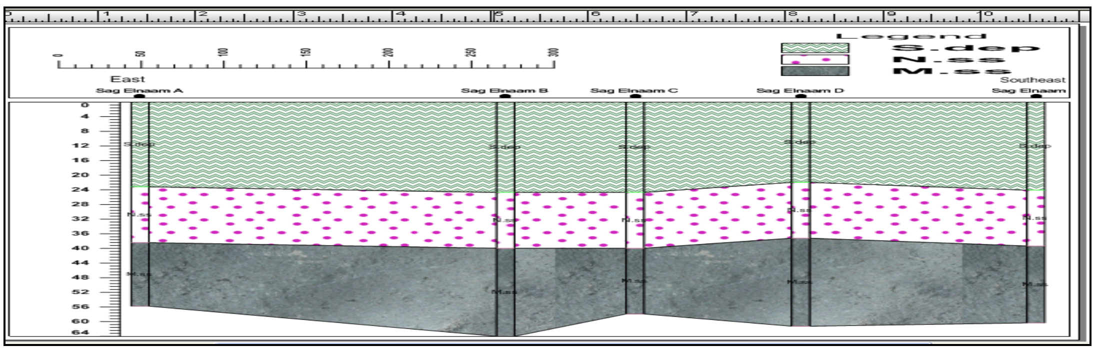

Fig 3: Sag El Naam basin cross section (S.dep: Superficial deposits (clay fine, grained, sandy, darkish gray in color). N.ss: Nubian sandstone (gravelly, fine and hard, white in color, Water zone) M.ss: Mudstone)

3. MATERIAL AND METHODS

Conceptual model of Sag El Naam basin was prepared from relevant geologic, hydrologic, hydro geological, climatologic data as well as domestic activity sites using ArcGIS software. The model considers two layers cover an area of 2250 km^2. Visual MODFLOW code was used for numerical model computation. Hydraulic properties were calculated from a number of boreholes using pumping test data manipulated through Aquitest software, considering confined condition of the Nubian Sandstone aquifer [16]. The model area is thus subdivided into 60 rows, 80 columns and 2 layers forming 4800 cells; covers an area of 2250km^2 with horizontal cell dimensions of 1691.1× 1597.4 m. The observed hydraulic heads measured during the year 2004 in the study area were used as initial heads to calibrate the model (Fig. 4). The simulation time interval was subdivided into 32 stress periods each discretized into ten time steps. Twenty seven boreholes were constructed in the area for groundwater abstraction. Twenty wells were used as observation wells (Fig. 5). The horizontal hydraulic conductivity (K) of the Nubian Sandstone aquifer in Sag El Naam basin was considered 19 m/d, where vertical hydraulic conductivities assigned as 10% of the horizontal hydraulic conductivity based on geological formations. The average storage coefficient value estimated to be 1.5×10^{-1} effective porosity 0.15 and total porosity ranging from 0.31 to 0.34 were considered in the model simulation as measured from grain size analyses. The bottom of the aquifer represents a horizontal barrier boundary. The upper surface of the aquifer represents a recharge boundary. Therefore, Dirichlet boundary was assigned for the model simulation [17]. 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, third and fourth 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.

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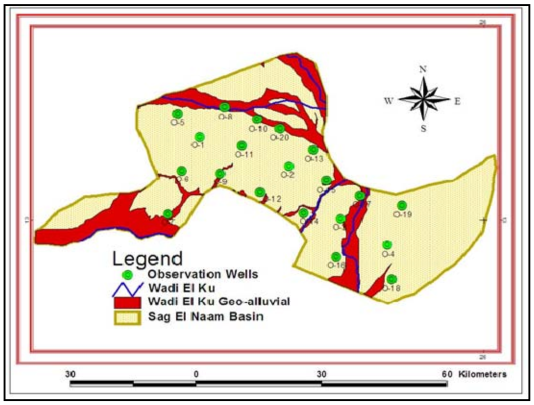

Fig 4: Observation Wells

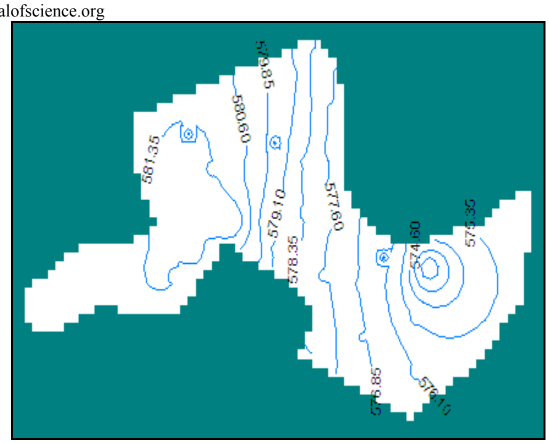

Fig 5: Initial head contour lines

4. 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. During model runs, Root Mean Square error (RMS), Residual Mean, and standard error of estimate were used as calibration criteria. However acceptable calibration was achieved with average (RMS) of 0.14 m, residual mean error of 0.09 m, average absolute mean error (AM) of 0.12 m, average standard error of the estimate (SEE) of 0.02 m and average normalized root mean square (RMS %) of 1.49 % (Fig. 6).

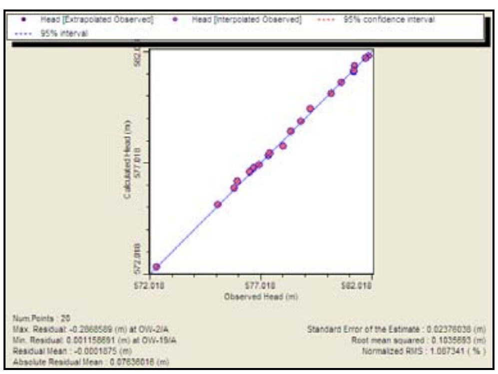

Fig 6a: Obs. vs cal. head at stress No.1

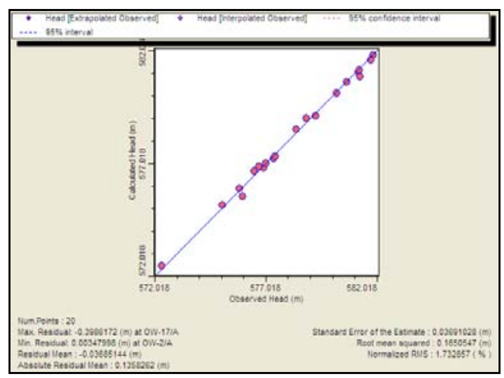

Fig 6b: Obs. vs cal. head at stress No.8

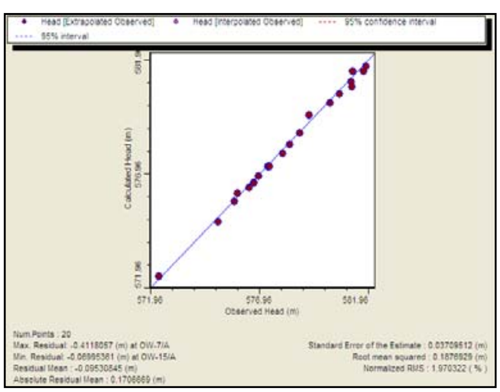

Fig 6c: Obs. vs cal. head stress No.16

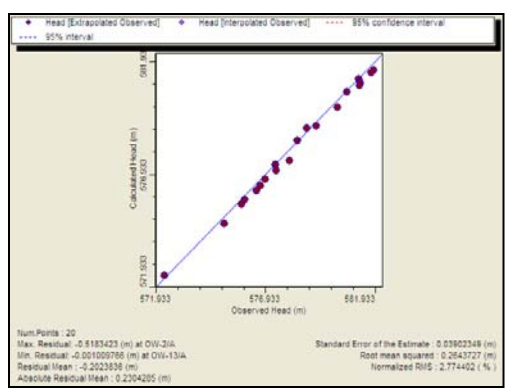

Fig 6d: Obs. vs cal. head stress No.24

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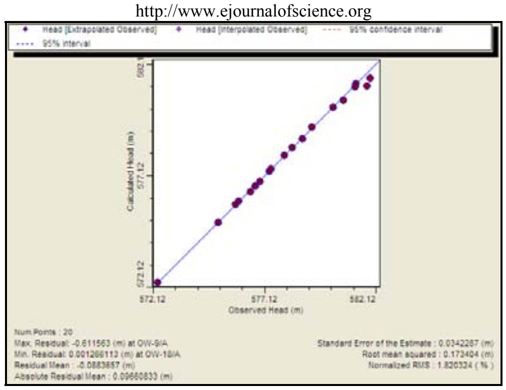

Fig 6e: Obs. vs cal. head stress No.32

The contour maps of the simulated heads were drawn (Fig.7), representing successive four stress periods (1 ~ 4). The contour lines were closer at the north-western and south-western sides showing recharge from the Shagara basin and Shangli-Tobya sub-basin towards the southwest with steep hydraulic gradient and low permeability, whereas, the water heads decreasing towards the southwest and inside towards the center forming cone of depression which is considered to be due to discharge stress. At the second, third and fourth stress periods (Fig.7), the contour line spaces becomes wider (gentle hydraulic gradient) showing minor effect of excessive pumping of groundwater denoting a productive target and high permeability zone.

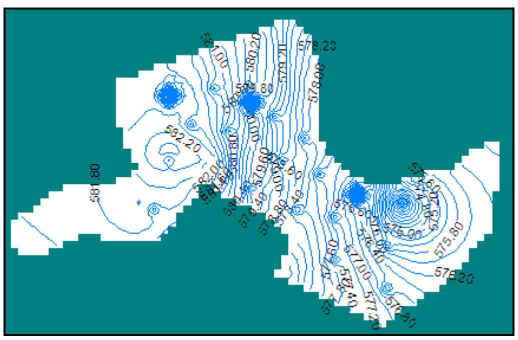
Fig 7a: Equipotential lines for the first year.

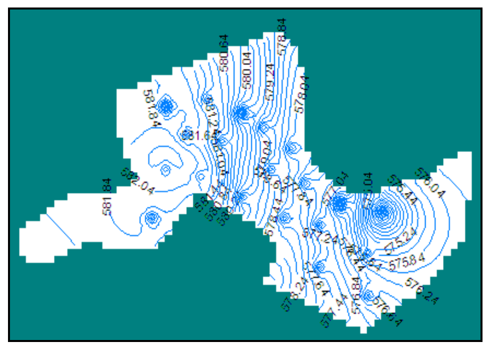
Fig 7b: Equipotential lines for the second year

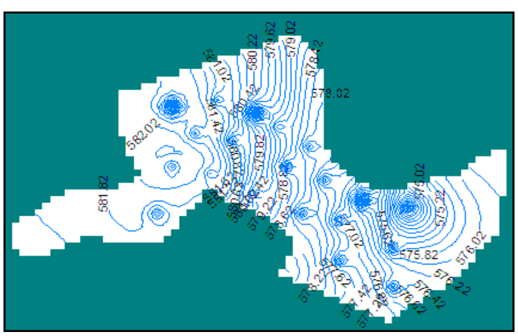
Fig 7c: Equipotential lines for the third year

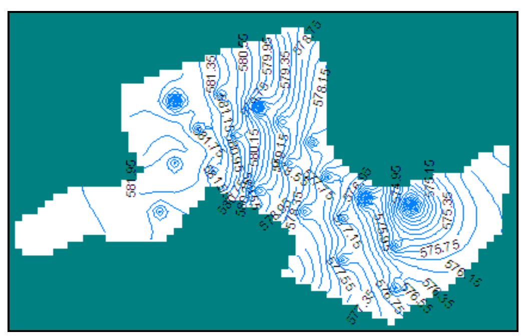
Fig 7d: Equipotential lines for the fourth year

Accordingly in Sag El Naam Basin the model assigned the regional flow direction towards the north western, south western directions and peripheries of the basin towards the center and then follows a south easterly direction (Fig.8).

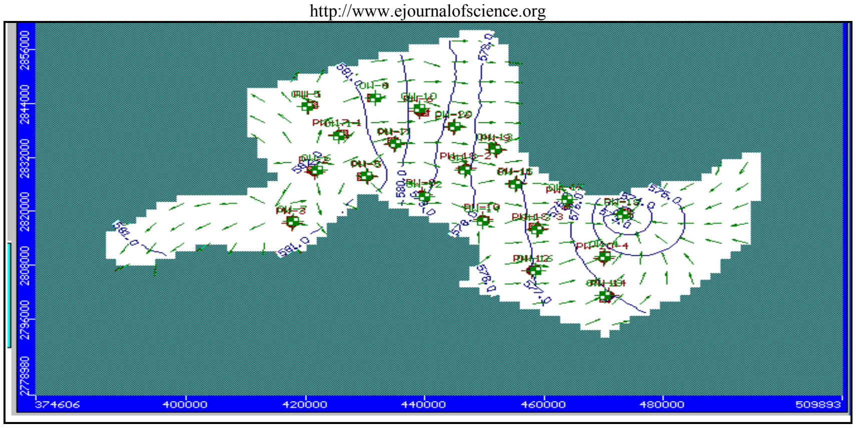

Fig 8: Equipotential lines with flow directions

Groundwater budget was calculated for the whole model area. The main effective calculated budget components of water balance include; storage, pump age and recharge. These components were calculated for the first, second, third and fourth stress periods respectively (Table.1). The cumulative volume of water in million cubic meters per year (mcm/y) and its percentage was calculated for each component. The total volume of the aquifer storage for the four stresses periods varies from 10.16 to 25.39 mcm/y with average value of 19 mcm/y and represent 5.22% from total inflow (Table. 1). Groundwater pumping volume in the entire area by twenty pumping wells varies from 17.34 to 26.77 mcm/y with average value of 22 mcm/y throughout the simulation period, which represents 6.07% of the total outflow from the aquifer (Table. 1). The recharge water volume was varies from 311.58 to 365.50 mcm/y with average value of 345.06 mcm/y and represent 94.78% of the total inflow (Table. 1). As a result, the three – dimensional transient groundwater flow model can sufficiently simulate the regional groundwater balance of the Nubian Sandstone aquifer of Sag El Naam Basin.

Table 1: Cumulative groundwater budget for the study area

Time	Component	Inflow (mcm)	Percentage %	Outflow (mcm)	Percentage %	Difference
1st year	Storage	10.16	3.16	304.47	94.61	
	Pump age	-	-	17.34	5.39	
	Recharge	311.58	96.84	-	-	
	Total	321.74	100	321.81	100	-0.07
2nd year	Storage	13.36	3.70	342.71	95.26	
	Pump age	-	-	17.05	4.74	
	Recharge	347.53	96.30	-	-	
	Total	360.89	100	359.76	100	1.13
3rd year	Storage	27.09	7.08	355.94	92.99	
	Pump age	-	-	26.84	7.01	
	Recharge	355.61	92.92	-	-	
	Total	382.70	100	382.78	100	-0.08
4th year	Storage	25.39	6.50	358.91	93.06	
	Pump age	-	-	26.77	6.94	
	Recharge	365.50	93.50	-	-	
	Total	390.89	100	385.68	100	5.21
Average	Storage	19.00	5.22	340.51	93.93	
	Pump age	-	-	22.00	6.07	
	Recharge	345.06	94.78	-	-	
	Total	364.06	100	362.51	100	1.55

5. CONCLUSION

The model calibration of Sag El Naam basin was acceptable within the average Root Mean Square error (RMS), Residual Mean, and standard error of estimate to be less than 0.14m, 0.09m and 1.49% respectively. The contour maps of the simulated heads show fair similarity with those generated from initial heads which confirm acceptable model calibration. The contour lines were closer at the north-western and south-western sides showing recharge from the Shagara basin and Shangli-Tobya sub-basin towards the southwest with steep hydraulic gradient and reflecting low aquifer permeability, whereas, the water heads decreasing towards the southwest and inside towards the center forming cone of depression which is considered to be due to pumping. The average values of storage, pump age and recharge of the aquifer during simulation time calculated to be 19, 22 and 345 mcm/y respectively (Table.1).

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