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Investigation of Some Geochemical Characteristics and the Effect of Long-term Pumping on Groundwater Constituent Levels of Aquifers Underlie Communities of Eastern Area of the Blue Nile River of Sudan

Abdel-Monem M. Abdellah*, Hago M. Abdel-Magid and Nadia A.Yahia[1]

Dept. of Soil and Environment Sciences, Faculty of Agriculture, University of Khartoum, Sudan
[1]Dept. of Basic Sciences, Faculty of Dentistry, University of Khartoum, Sudan
✉ abdelmonemabdallah@hotmail.com

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Abstract: Previous data of 209 construction routine chemical analyses (CRCA) of boreholes were used to investigate the distribution of aquifer's static water levels (SWLs), productivity (P) and groundwater type (GWT), beside the effect of long-term pumping on groundwater constituent levels. A total of 32 of these boreholes were reanalyzed by the current study (CS) to investigate the effect of long-term pumping on groundwater constituents' levels. Result indicated that the low SWLs (0.0-25 m) were found in the southern part of the study area nearby the Blue Nile River (BNR). High SWLs (50-87 m) were found in central of the northern part of the study area while moderate SWLs (25-50 m) were found to dominate the rest of the study area. High P (50-115 m^3/h) was found in a small area at the southern part close to the BNR while low P (<25 m^3/h) was dominant in the northern part of the study area. Groundwater type has been dramatically shifted to HCO_3^- water-type while the other groundwater constituents levels were found to be fluctuated up-and-down, during pumping time, in a harmony type pattern governed by the so-called "natural physicochemical equilibrium in groundwater".

Key words: Groundwater, aquifer, productivity, Blue Nile, Sudan.

Introduction

Water is considered as the most important resource for sustainable living on the earth surface (Pelczar et al., 1977). Water can unite people that share a source of it or provoke conflicts among them as they compete for it (Musamba et al., 2011). Water quality influences many human activities and simultaneously, it is affected by these activities. Commonly, water quality is defined by its physical, chemical, biological and aesthetic (appearance and smell) characteristics. The suitability of groundwater resources is determined by both the quality of the water and by the available yield. The chemical quality of groundwater depends primarily on the chemical characteristics of TDS (Abdellah, 2011). The Blue Nile is considered the main source of recharge in aquifer of the study area. The presence of the impermeable clay beds, which are widespread in the study area, obstructed the percolation of precipitation to contribute to the recharge of the aquifer (Yasir, 2004). The recharge of the aquifer in Al-Butana region is from the west and south-west direction. The rise of water level in the Blue Nile during August-September months produces no effect on the regional configuration of the

*Corresponding Author

groundwater levels. However, along the riverbank a rise of 1-2 m in groundwater levels has been observed. Nearly at a distance of 5-8 km away from the river, the amount pinches out, i.e. flood stage has no effect on regional drawdown (Abdellah, 2011).

Productivity is greatly affected by linear fractures associated with geological structures of the aquifer such as fractures, faults, lithological boundaries and fold axis. However, quantification of how the structures are related with the flow and well productivity is not so simple, because it involves many factors of hydraulic properties and flow phenomena (Park et al., 2000). In some geologic environments, the thickness of the aquifer may not be sufficient to supply the required volume of water to a system of vertical wells, even though the aquifer is hydraulically connected to a nearby surface water body (Rash, 2001). It has been reported that crystalline rock aquifers seem to be related to large-scale groundwater flow field and well productivity (Park et al., 2000).

The hydro-chemical composition of ground water is related to differences in geological and hydrogeological settings (Alley, 1993). Generally, the type of ground water in the aquifer of the study area is calcium-bicarbonate water type and usually characterized by temporary hardness (Yasir, 2004). Therefore, this study is conducted to investigate the following objectives to: (1) locate areas where static water levels are low in order to avoid groundwater contaminants by bad practices, i.e. latrines and septic tanks, (2) locate areas where productivity is high in order to encourage population groups in the study area to reside in areas where ground water is of an adequate quantity, (3) follow the underground recharge-zone extension of the Blue Nile into the aquifers of the study area, and (4) study and to compare groundwater type between the previous CA and the recent CS in the study area.

Materials and Methods

Study Location

The study area was divided, administratively, into three regions as follows: (1) the whole area of East of Gezira locality, Gezira State. (2) The Western Administrative Units area of Umelghura locality, Gezira State. (3) The Eastern Administrative Units area of Shark-el-Neel locality, Khartoum State (Figure 1).

Samples and Data Collection

A total of 32 groundwater samples were collected from different boreholes of various communities using 250 ml plastic bottles. Samples were collected directly from the outlet points of the well, where and when possible. The hydro-meteorological data (climate elements) are available at Wed-Medani Meteorological Station. Hydro-geological information and the CA of boreholes were obtained from the Information Center archives of Groundwater Directorate and from the National Institute for Drilling at Wad-Medani and Water Corporation of East Gezira Locality, Rufaa' Town.

Mapping and Statistical Analyses of Data

The spatial data of SWL, D and TDS levels have been analyzed using geographic information system (GIS) software (Arc View). Basic statistics program (Microsoft Excel Spreadsheet) was used to calculate mean, range and standard deviation of the obtained data.

Results and Discussion

Table 1 revealed that a total of 102 boreholes out of 205 (about 50%) have SWLs below 30 m. In area where the SWLs reach 80 m only five boreholes (2.44%) were drilled. It has been reported that the depth to the piesometric surface in the aquifer west of Omdurman City is controlled regionally by the distance from the river (Farah et al., 1997). This is obviously observed at the southern part of the study area where the depth to ground water ranges between 0.0-25 m and gradually increases towards the north with gradual increase of distance from the BNR. The SWL GIS-map (Figure 2) indicates that the range between 25-50 m is dominated in the northern part of the study area even near the BNR while the range between 50-87 m is concentrated in the central region of the northern part of the study area. This condition may be attributed to the local impermeable geological formation that impedes the seepage of water-recharge from the BNR, or may be due to the aquifer underlying this area containing mudstone layers or solid rocks of a considerable relief buried into the sediment.

Abdel-Salam (1966) explained the problem of finding water (water shortage) in the Nubian Sandstone formation, even near the rivers, to the occurrence of impervious lenses of mudstone and the cut across of the Basement Complex rocks. To the extreme northeast of the study area an exception was observed; in spite of being away from the BNR this area showed low SWLs below 25 m. In this study, we attributed this exception to the local geographical conditions. This area overlies a shallow aquifer that takes water-recharge from direct rainfall and watercourses spreading throughout the area. Based on P values of 200 boreholes CRCA, 99 boreholes (49.5%) registered a moderate P (20-40 m^3/h) whereas

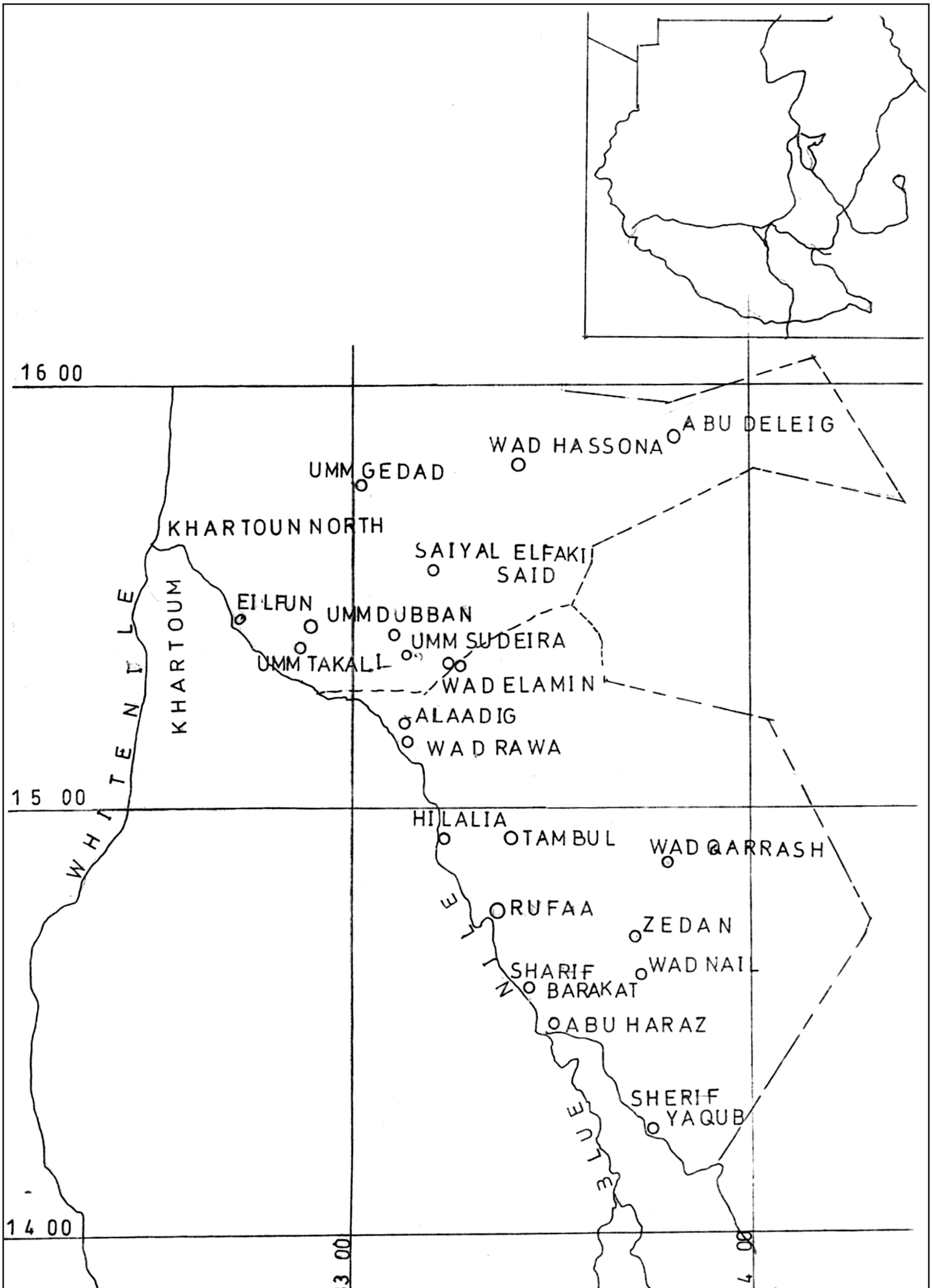

Figure 1: Map of the study area, Eastern Area of the Blue Nile River of Sudan.
Source: **Sudan National Survey Authority, prepared for the current study.**

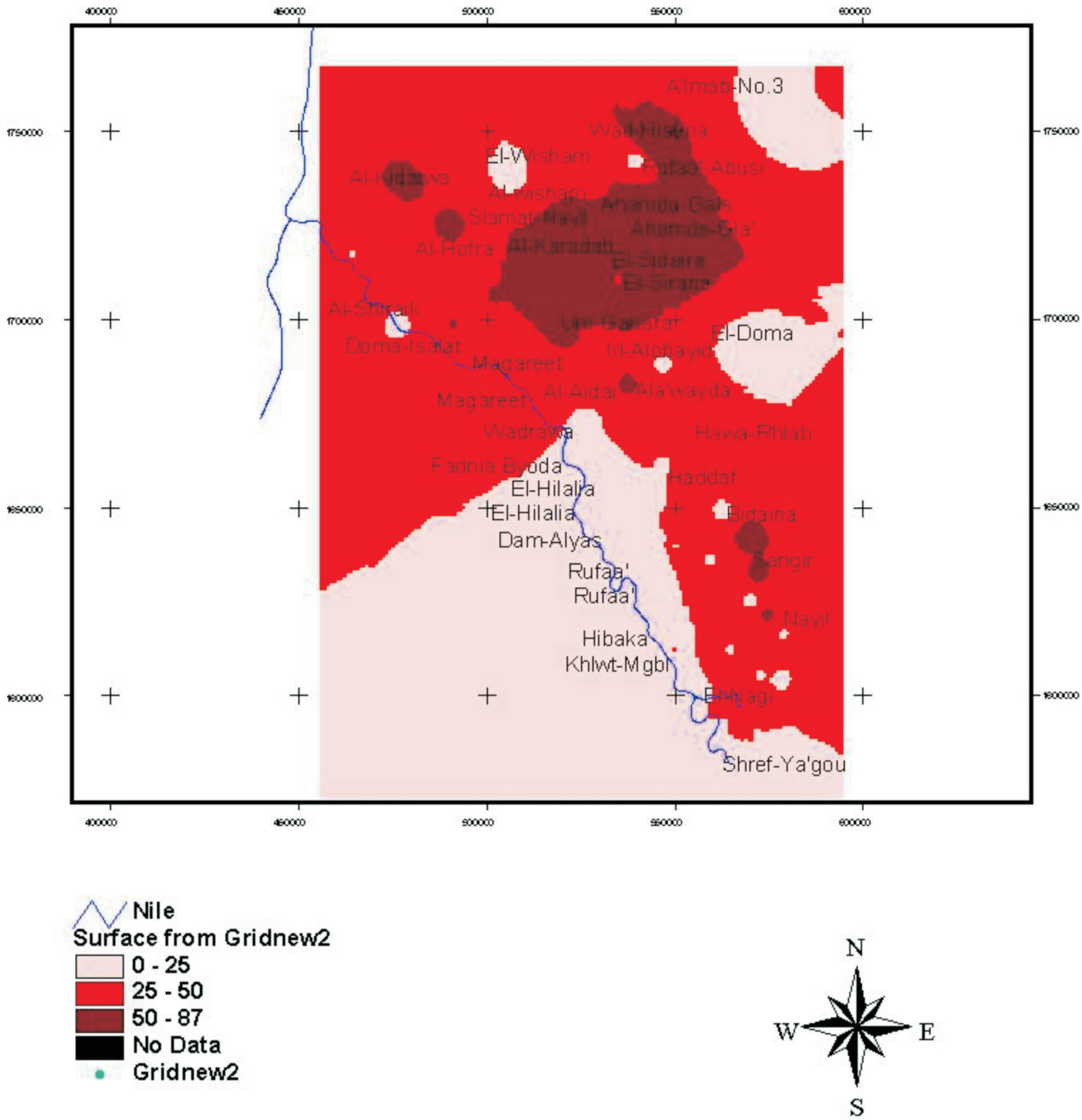

Figure 2: Distribution of SWL in the study area: Eastern Area of the Blue Nile River of Sudan.

78 boreholes (39%) registered low *P* values (<20 m^3/h). High *P* values (>50 m^3/h) were observed in only eight boreholes (4%) in the study area (Table 2). According to the GIS-map (Figure 3), high *P* values (>50 m^3/h) were observed in boreholes located at the extreme southern part of the study area.

In this part, the *P* is high in the proximity of the BNR and decreases gradually to the northern direction away from the Blue Nile associating with the increase of SWLs. Low *P* values were observed in the north and the central part of the study area. In spite of being at the BNR bank, wide area showed low *P* values (0-23 m^3/h). This may be attributed to the geological formations obstructing groundwater flow either from recharge or to discharge areas. Low *P* values, even with low SWLs, were observed in boreholes drilled in the northeastern part of the study area where aquifers with low depth sediment were underlaid by Basement Complex. The aquifer underlying the study area is situated inside the BNR-valley which supplies its main groundwater-recharge. This can be attributed to the influence of the recharge of the BNR on aquifer of the study area, which decreases progressively

Table 1: Distribution of the magnitude of the static water level (SWL) of some boreholes in the study area (Eastern Area of Blue Nile River of Sudan)

Static water level categories (m)	*Number of boreholes within category*	*% of total*
<20	45	21.95
20-30	57	27.81
30-40	54	26.34
40-50	14	6.83
50-60	13	6.34
60-70	8	3.9
70-80	9	4.39
>80	5	2.44
Total	205	100

Source: Groundwater Directorate, Kilo-a'shara, Suba, Khartoum, Sudan.

Table 2: Distribution of productivity values of some boreholes in the study area

Categories of productivity, m^3/h	*Number of boreholes within category*	*% of total within category*
<10	39	19.5
10-20	39	19.5
20-30	58	29.0
30-40	41	20.5
40-50	15	7.5
>50	8	4.0
Total	200	100

Source: Groundwater Directorate, Kilo-a'shara, Suba, Khartoum, Sudan.

in association with the SWL increase away from the BNR. The drastic slope of the BNR, from Ethiopian highlands through aquifers of the study area, has enough strengthened the current flow to seep into the highly porous and permeable Gezira and Nubian Sandstone formation and thus enabled the river to recharge more than 50 kilometres towards the south of the study area.

It is evident that the aquifer west of Omdurman City is recharged almost exclusively from the Nile Rivers (Farah et al., 1997). The aquifer underlying Abu-Deleig area is out of reach of the BNR recharge-zone. This aquifer, probably, takes water recharge annually from watercourses and direct rainfall during the rainy season. Abu-Deleig and the surrounding area (105 km distance northeast from the BNR) are situated among a watershed area (Whiteman, 1971). In some boreholes located at Abu-Deleig the SWLs are very low while some boreholes located at the northern boundaries of the BNR recharge zone have high SWLs. Apparently, this demonstrates that Abu-Deleig area is out of the BNR recharge zone. It has been reported (Mirghani, 2005) that in western Sudan (Darfur region) aquifer recharge is mainly from direct rainfall and from seepage of surface runoff originating from Jebel Marra.

Table 3 showed the comparison between HCO_3^- ion in boreholes drilled before and after the year 1990 in the CRCA and boreholes analyzed in the CS. In CRCA, 141 out of 144 (98%) of the boreholes drilled before 1990 were devoid of any HCO_3^- while only 3 (2%) showed negligible HCO_3^- presence. In contrast, 54 out of 65 (83%) of boreholes drilled after 1990 showed appreciable HCO_3^- whereas only 11 (17%) of the investigated boreholes were devoid of any HCO_3^- ions. All of the investigated boreholes in the CS showed appreciable HCO_3^- dominance. Therefore, the type of ground water has dramatically shifted to HCO_3^- water-type. The level of HCO_3^- of ground water in the study area is governed by the *natural physico-chemical equilibrium* (NPCE) during pumping. However, the ground water in the study area is mainly alkaline as previously reported by Yasir (2004).

Tables 4 and 5 summarize the changes in the levels of the cations and the anions that continuously occur in the study area during pumping time, respectively. A low level of the groundwater constituent in the CRCA was, apparently, increased in the CS and at the same time a high level in the CRCA was apparently decreased in the CS even in the same borehole. For example, in the borehole located at Magareet-1 (Table 4), Ca^{2+} and Mg^{2+} increased from 15 mg/l and 5 mg/l (CRCA) to 32 mg/l and 17 mg/l (CS) and at the same time, Na^+ and K^+ decreased from 40 mg/l and 10 mg/l (CRCA) to 30 mg/l and 3 mg/l in the CS, respectively. In general, appreciable changes were observed in the mean value of Na^+, which was decreased from 57 mg/l (CRCA) to 34 mg/l in the CS (Table 4). In Table 5, the mean values of HCO_3^- and Cl^- increased from 60 mg/l (CRCA) to 281 mg/l (CS) and from 50 mg/l (CRCA) to 101 mg/l (CS), respectively.

It may be inferred from this study that when ground water was stagnant in the aquifers underlying the study area, before deep tube-wells were introduced, the connate ground water is dominated by HCO_3^--free water type. Long-term pumping has excited the connate groundwater surrounding well screen and CO_3^{-2} bubbled through groundwater withdrawal and finally $Ca(HCO_3)_2$ precipitated, thus, HCO_3^- level has begun to increase

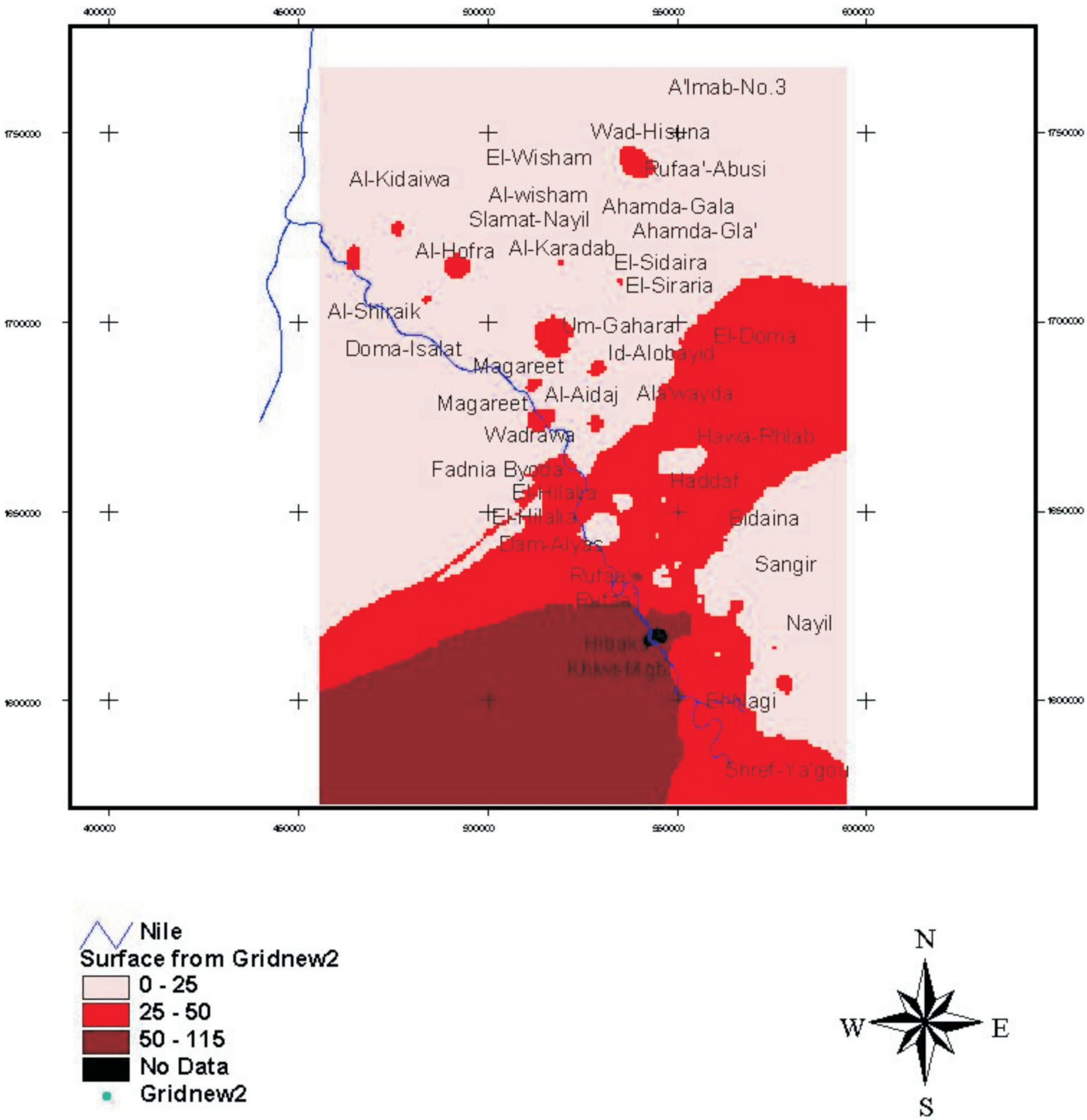

Figure 3: Distribution of productivity in the study area: Eastern Area of the Blue Nile River of Sudan.

gradually and the type of ground water shifted towards HCO_3^- water-type. This dramatic change of HCO_3^- levels in ground water during long-term pumping in the study area is not unique, but actually has occurred in concomitance with the other changes in groundwater chemical constituents. The harmony of the NPCE of ground water towards a certain level of a certain groundwater constituent increases when the level of this constituent is in its minimum concentration. At a certain saturation level, reached by the constituent, the pH changes; as a result, the constituent level begins to decrease while another constituent starts increasing in a similar way, and so on. Noteworthy that both of F^- and NO_3^- is not affected by the NPCE rule.

Conclusions and Recommendations

Based on the results of the present investigation, the following conclusions may be drawn: (1) Low SWLs (0.0-25 m) dominates the southern part of the study area. Most of the boreholes (29%) were drilled in communities with SWL ranging between 20-30 m. (2)

Table 3: Comparison between HCO_3^- dominance in boreholes drilled before and after 1990 (CRCA) and boreholes analyzed in the current study (CS)

Analysis	*Date of analysis*	*Number of boreholes with HCO_3^-*	*% of total*	*Number of boreholes devoid of HCO_3^-*	*% of total*
CRCA (*n* = 209)	Before 1990 (*n* = 144)	3	2	141	98
	After 1990 (*n* = 65)	54	83	11	17
CS (*n* = 121)	2008	121	100	0.0	0.0

CRCA = Construction routine chemical analysis, CS = Current study analysis.

Table 4: The fluctuation of pH and cations caused by the "natural physico-chemical equilibrium rule" of ground water during continuous pumping in selected boreholes located in the study area (*n* = 32)

Name of village	*Date of drilling (date of CRCA)*	*pH CRCA*	*pH CS*	*Cations concentration, mg/l*								*Duration in years between CRCA and CS*
				Ca^{+2} CRCA	*Ca^{+2} CS*	*Mg^{+2} CRCA*	*Mg^{+2} CS*	*Na^{+} CRCA*	*Na^{+} CS*	*K^{+} CRCA*	*K^{+} CS*	
Magareet-1	29,5,1972	7.8	7.5	15	32	5	17	40	30	10	3	36
Magareet-2	23,10,1984	7.5	7.6	60	28	20	14	25	30	2	9	24
Altikailat	25,6,1985	8.4	7.4	5	20	5	22	140	76	15	13	23
Aidaj	12,1,1978	8.5	7.6	20	20	10	10	155	50	15	5	30
Wadrawa	20,10,1984	7.2	7.8	15	20	25	10	14	63	10	0.4	24
Sayal-Thwra	1,8,1990	8.9	8.1	16	12	15	7	142	93	3	7	18
Fadnia-bioda	16,1,2001	7.6	7.9	36	22	21	20	3	70	0	3	7
Tayba-Mahs	27,10,1998	7.3	7.8	44	32	23	22	65	82	3	8	10
Damgadkrem	25,4,1972	8.0	7.9	30	28	25	26	10	31	5	3	36
Almetamma	26,4,1972	8.0	8.0	30	28	20	26	5	24	5	4	36
Alnabti	12,5,1975	7.5	6.7	32	16	19	17	60	36	50	26	33
Alhilalia	5,6,1983	8.6	7.8	25	32	15	19	15	60	5	3	25
Hillat-idrees	3,1,2001	7.2	7.9	34	32	15	12	9	25	0	2	7
Mahas-rgaba	23,5,1988	6.8	7.6	18	17	32	30	0	9	0	78	20
Rufaa-1	3,10,1986	8.0	7.3	59	70	19	24	15	2	0	1.4	22
Rufaa-2	8,10,1986	8.3	7.5	48	70	18	25	17	2	0	2	22
Rufaa-3	9,10,1986	7.9	7.5	40	73	11	27	10	4	0	1.8	22
Wadelnour	8,7,1971	7.2	8.0	30	64	20	26	30	39	5	1	37
Kidaiwa	5,6,1971	8.0	7.6	10	40	30	31	100	18	5	2	37
Wadelfadul	14,7,1986	7.9	8.1	60	52	10	34	75	73	5	5	22
Ahamda-Gal	14,11,1999	7.5	7.9	28	70	23	24	236	3	10	2	9
Dallawat	5,12,1971	8.0	8.0	50	28	10	26	15	24	5	4	37
Alteragma	9,10,1971	8.0	7.7	40	32	30	17	400	23	50	3	37
Abugalfa	9,2,1978	8.0	7.5	25	52	15	17	50	21	5	1	30
Sharafa-bkt	4,4,1987	7.9	7.5	35	48	15	2	0	1	0	2	21
Tamboul	27,10,1983	7.4	7.5	25	36	10	22	10	20	15	1	25
Wadrawa	20,10,1984	7.2	7.8	15	20	25	10	14	64	10	0.4	24
Iddelhaj	27,5,1971	8.0	7.7	40	28	20	19	25	18	15	1	37
Alhufra	3,2,2001	7.5	8.1	19	16	14	7	31	40	0	10	7
Aldoma-islat	20,11,2001	7.6	7.5	16	36	9	17	78	44	0	20	7
Awaida-mhb	10,12,1981	7.8	7.2	30	36	5	7	0	15	0	2	27
Awaida-msl	8,7,1987	8.0	7.2	34	36	12	14	32	11	0	2	21
Mean	1984	7.8	7.7	32	36	17	19	57	34	8	7	25
Range	1971-2001	6.8-8.9	6.7-8.1	5-60	12-70	5-32	7-34	0-400	1-93	0-50	0.4-78	7-37
SD	11	0.5	0.3	15	17	7.4	7.8	58	26	12	14	10

SD = Standard deviation.
Duration in years between CRCA and CS means age of the borehole.

Table 5: The bicarbonate and chloride fluctuation during long pumping in selected boreholes located in the study area (n = 29)

Name of village	*Date of drilling time*	*Anions concentration, mg/l*				*Duration in years between CRCA and CS*
		HCO_3^- level (CRCA)	*HCO_3^- level (CS)*	*Cl^- level (CRCA)*	*Cl^- level (CS)*	
Alfadnia	22,8,1998	427	207	333	163	10
Magareet-2	23,10,1984	0.00	232	10	71	24
Altikailat	25,6,1985	0.00	354	130	71	23
Aidaj	12,1,1978	0.00	256	10	53	30
Wadrawa	20,10,1984	0.00	281	105	110	24
Sayal-Thwra	1,8,1990	244	256	51	85	18
Fadnia-biod	16,1,2001	171	244	15	75	7
Siraria	25,2,1999	293	390	227	334	9
Almetamma	26,4,1972	0.00	244	15	78	36
Alnabti	12,5,1975	0.00	256	10	78	33
Alhilalia	5,6,1983	0.00	281	20	85	25
Hillat-idrees	3,1,2001	195	244	13	78	7
Mahas-rgaba	23,5,1988	0.00	329	30	78	20
Rufaa-1	3,10,1986	0.00	427	6	89	22
Rufaa-2	8,10,1986	0.00	443	10	43	22
Rufaa-3	9,10,1986	0.00	438	0.0	78	22
Wadelnour	8,7,1971	0.00	293	20	277	37
Kidaiwa	5,6,1971	0.00	244	150	124	37
Dallawat-bh	5,12,1971	0.00	244	10	78	37
Alteragma	9,10,1971	0.00	293	30	71	37
Abugalfa	9,2,1978	0.00	293	20	89	30
Sharafa-bkt	4,4,1987	0.00	244	30	89	21
Tamboul	27,10,1983	0.00	195	10	64	25
Wadrawa	20,10,1984	0.00	281	105	110	24
Banet	30,1,1978	0.00	244	20	82	30
Alhufra	3,2,2001	183	183	18	71	7
Aldoma-islat	20,11,2001	220	329	29	103	7
Awaida-mhb	10,12,1981	0.00	146	25	75	27
Awaida-msl	8,7,1987	0.00	275	0.0	124	21
Mean	1985	60	281	50	101	23
Range	1971-2001	0-427	146-443	0-333	43-334	7-37
SD	9.6	114	70	75	51	9

SD = Standard deviation.
Duration between CRCA and CS means age of the borehole.

High productivity values were observed in the southern part of the study area. (3) Concentrations of groundwater constituents in aquifers of the study area are fluctuating up-and-down in a harmony type pattern governed by the so-called "natural physicochemical equilibrium in groundwater" with a noticeable decrease in TDS levels during pumping time. (4) The study recommends that the respective authorities should encourage population groups in the study area to reside in areas where ground water is of an acceptable quality and adequate quantity. (5) The study strongly recommended the governments to establish new agricultural schemes in aquifers of high productivity. (6) Enforcement of and compliance with the NO_3^- level guidelines is of paramount importance, especially in large communities in the study area, where NO_3^- levels exceeded the permissible and recommended levels.

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