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Modeling of Climate Changes Impact on Groundwater Resources of Berrechid Aquifer

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ABSTRACT: Morocco is a semi- arid to arid ecosystem which is vulnerable to water stress. This phenomenon is closely linked to climate changes that interact with socio- economic and environmental conditions of water systems. Moreover, the man acts directly on ecosystem and water resources sometimes irrational and notefficient planning. Several studies have shown the impact of climate change on water resources in Morocco both in qualitative and quantitative issues. Furthermore, the demand for water has increased significantly over the past three decades to meet different needs, including water supply, industry and irrigation of agricultural land.

At the river watershed Bouregreg, the quantity and quality of groundwater have fallen sharply in recent decades, especially at the aquifer Berrechid, where the head decreases up to 20 m in some places. It is therefore important in the context of climate change and water demand increase, to simulate the hydrodynamic behavior of the aquifer to better understand the issue of the management and decision making of this groundwater system.

Thus, a numerical model of hydrodynamics simulation of the aquifer is proposed. It is based on MODFLOW model, using the GMS interface. The analysis of the impact of climate change on groundwater resources mobilized is based on the IPPC (Intergovernmental Panel on Climate Change) approach in terms of scenarios.

The simulations in the numerical model were based on three scenarios of the IPCC, including changes in groundwater recharge. The results show the continuing trend of declining groundwater heads with a variation between 1 and 25 m.

KEYWORDS: Numerical model, Berrechid aquifer, Modflow, GMS, Climate change, groundwater, Water planning, Scenarios, IPPC.

I. INTRODUCTION

According to GIEC classification [1], Morocco is an arid to semi-arid country withvulnerability to hydraulic stress. This phenomenon is strongly related to the climate changes, which interact with the socio-economic and environmental conditions of any hydraulic system [1].

The variations in the temperature, the irregularities of precipitations and the increase in the sea level are inevitable. The fourth report of the international program of the climate changes [2], show that these changes have a negative impact on both the quantity and the quality of the water resources. These climate changes combined with the anthropic process and the proofing of the grounds present fatal consequences on the water supply of the surface or deep aquifers.

The demand for water increases considerably to meet various water requirements, particularly for the drinking water supply or the irrigation of the agricultural land. The latter is the activity which consumes the greatest part of the water resources exceeding in many cases 70%. However, the water resources are increasingly rare because of hydraulic stress and of the climate changes.

Berrechid aquifer's one of Moroccans systems which is vulnerable to climate changes. Several studies [3], [4] showed the huge decrease of the groundwater reserves under the effect of the drought and the big increase of water demand, under the effect of the urban, agricultural and industrial development.



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Thus it is important to study and analyze the influence of the climate changes in the future, by using some scenarios for better apprehending the problems related to management, planning and decision making of groundwater resources of Berrechid aquifer.

The constraints imposed on the numerical model were based on several IPCC scenarios (2007) [2], including the variations of the aquifer's recharge. The numerical simulations show a clear reduction of renewable groundwater resources, particularly in some places where the water taking out are important.

II. MATERIALS AND METHOD

The methodology is based on combining the aquifer dynamics modeling, the hydro geologic system mapping and predictive scenarios representing the climate change impact on the groundwater system. The tools used in this study are MODFLOW/GMS to simulate the groundwater hydrodynamics in both steady and unsteady regimes. The GIS analysis is based on ArcGis to develop different maps representing the groundwater system. Different data (hydrologic, hydrogeologic, geologic, climatic, piezometry, well pumping, etc.) are used to understand the groundwater system behavior. The aquifer recharge is used to link the aquifer dynamics with the climate change impact

III. DATA ANALYSIS

The data used are of several issues: geology, geomorphology, hydrogeology, hydrology and climatology. They are presented in the form of charts or of data cards. The whole information collected is treated and gathered in a database, then organized in a geographical information system (SIG), which makes possible putting thematic charts.

III.1. CLIMATOLOGY

The climatic data are based on the actualization of monthly and annual precipitations related to stations El Mers, Sidi Ahmed Ben Ali and Tamdrost. The data used are spread out over 50 year's period (from 1965 to 2014). Average annual rainfall on the stations selected varies between 100 and 700 mm, according to whether the situation is in dry year or wet year (Fig.2). The annual average of precipitations of Berrechid plain varies between 280 and 310 mm/an. The temperature presents wide variations between the winter and the summer, with 24, 9°C as an average of the maxima and 9,6°C as an average of the minima (ABHBC).



Fig. 2. Evolution of annual rains at stations El Mers, Sidi Ahmed Ben ali et Tamdrost



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III.2. GEOLOGY

The geological map (Fig.1) was reproduced with more details starting from the geological of Berrechid aquifer data. Those are extracted from the existing documents, of the geological map (1/500000), the analysis of image ETM+ of Land sat 7 [5] and of drillings of recognition.

The plain rests on a series of old geological grounds of the Primary age to Quaternary (Fig.1). It is presented in the form of a basin subsidize of Meseta, limited to the South and South-east by limestone of the Cretaceous and elsewhere by Primaries' formations made up by schist and quartzite. The filling is formed by marine and dune likings of Pliocene. It constitutes the interesting level of Berrechid aquifer.



Fig.1. Situation and Geology of Berrechid aquifer extracted and analyzed from images ETM+ from Landsat and from geological map (scale 1/500000)

The morphology of Berrechid plain is regular. Level curves are directed NE-SW on the major part of the plain. Altitudes vary from 350 m in extreme cases related to Settat's plateau and140m North of the plain related to the transition zone towards Chaouia. The topographic slope is lower than 0.2% in the center and can reach 0.8% in Southeast, by the limit of the South and near Settat's plate.

III.3. HYDROLOGY

The hydrographic network is endoergic. It crosses the plain in its Southern part and South-eastern by rivers downstream which go down from the plate, crossing the plain on less than 20km and disappear in the center of the plain. The most important ones are from South-west to North East: Tamdrost, Ahmeur, Aidaand Asseïla(Fig.1). Their interest lies in the



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fact that they contribute to groundwater alimentation byflood resources. This tendency is confirmed by the fast increase observed in several piezometers heads and which appear after floods periods.

III.4. PIEZOMETRY

We considered the data related to 40 piezometers (21 well and 19 forging mills) of which 29 have measure until 2008 (Fig.3). The analysis of the whole piezometric information is carried out by characterizing the evolution of the piezometers as well on interannual scale or seasonalscale ElAssaoui and al[3].



Fig. 3. Piezometric network; recharge zone and boundary limits

A seasonal variation is observed on all the piezometers (Fig.4). It increases for the rainy period, and continue to fall until the end of the summer. It shows groundwater aquifer sensibility to the natural recharge which constitutes the main source of water resources.

We observe a generalized tendency of declining with variable importance depending to the area considered. This decline is important in the South of Berrechid in Lahssasna perimeter where irrigation is by pivots and in Sidi EL Aïdi corresponding to water supply pumping.

In general all over the zone we observe a succession of decrease and increase of rains. The period of increase is short in response to episodes of recharge by raining especially due to floods with short periods. While the decrease periods are carried over long periods.



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Fig.4. Continuing declining of piezometry with seasonal fluctuations

The sequences of increase on the majority of piezometers corresponding to the years 1970/1971, 1978/1979, 1995/1996, 2003/2004 (Fig. 5) and most important is that of September 2008 and August 2009 having allowed a recharge of 1m at Berrechid aquifer.

Since 1980, the declining of water level due to the decreasing of aquifer's resources, exceeds 5m in some places, and can reach 20m on the piezometer 154 which is dry. The 2881/20 piezometer's level increase by 3.6m at 1968/1971 (Fig.5). From 1968 to 1979 piezometry is rather stable around 7m, with attenuation of periods of increase and decline with equal amplitudes. From 1979 to 2008 we observe a general declining of piezometry level, with a total decrease of 14m. The seasonal amplitude fluctuation is 2m between 1968 to 1979, and lowers than 2m since 1979 except for the year 2003which is equal to 2m.



Fig.5. Declining of piezometric water levelwithseasonal fluctuations

We established a piezometric chart representing the actual position of the piezometric surface for the year 2008(Figure 6b), while based on the investigating data in situ relating to the water taking away and also to the inspection network. The latter compared with piezometric chart for the 1980 year of reference was used to clarify the piezometric surface evolution and to calibrate the unsteady hydrodynamic model (El Assaoui and al[4]).

The figures (Fig.6a and 6b) show that the general structure of the flow remains the same. The flow direction is SW in SW zone of the plain, and SE-NW in SE zone, while inthe North of Berrechid the flow direction has a tendency to curve and to take the SN direction. The direction is similar to the general tendency of topography Thegroundwater head varies regularly from South-East tothe North-West. They are about 30 to 40 m at the bottom of Settat plate and morein downstream. They are about 5 m to 10 m nearMediouna.



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The aquifer water alimentation is done by direct infiltration of rainfall, by streaming water and from the phosphates plate on large zone (Fig.3).



Fig.6. (a)piezometric chart 1980 (b) piezometricchart 2008

IV. NUMERICAL MODEL DEVELOPMENT: RESULTS AND DISCUSSIONS

The numerical model developed aims to help decision makers to wellmanage groundwater resources in the future. The approach is based on long term simulations of aquifer head variation. Different scenarios related to climate changes are used for this purpose. Its implementation was first based on hydrodynamics simulation of the aquifer groundwater, using MODFLOW-GMS model. The results were compared to those obtained by watershed Agency works (ABHBC) [3].

In the second step, the model calibrated was stressed using threeIPCC scenarios and including recharge variation. The main objective is to better understand the impact of these climate changes on the behavior of the aquifer.

IV.1NATURE, WALL AND ROOF OF THE AQUIFER

Two surfaces are necessary to define the geometry of the aquifer for the mathematical model development: the roof and the substratum.

The geometrical reconstitution of the topographic model of the aquifer was based on a database of 980 drillings with geological description. 320 drillings selected have data including the thicknesses of main geological formations, the nature of crossed zones and the piezometricheads of the aquifer crossed [4].

The plio-quaternairesdeposits constitute the mainreservoir of the aquifer of Berrechidplain. Most lithological characterization of drillings indicates a sandy limestone facies, with the existence of basic conglomerates. These depots areas an elliptic sedimentary prism where the main axis is directed SW-NE. The thickness varies out of the zones East and West to 40 m in the basin center. The aquifer also coversmarno-limestones of Cenomanien, trials and primary formations.

The substratum geology configuration depends on zones:marno-limestonecenomaniennes, red clays, infra cénomaniennes, of Triassic basalts in a zone limited of 110 km^2 North of El Gara and schistous in the SE and in the N-W.

The aquifer'sroof is generally consisted on formations of argillaceous silts red, with a thickness varying between 20 and 40 m in the middle of the plain and decreases gradually towards the West and basin East.

The Fig. 7 represents the annual variation of effective precipitations. We can observe that low values of the effective precipitation are those calculated in Tamdrost and in Nouacer where the averages are respectively 11.8 and 14.4, whereas the highest median values are of 32 and 37 calculated respectivelyin El Gara and Benahmed



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Fig.7.Annual variation of effective precipitations (mm)

VI.2 NUMERICAL MODELING OF THE AQUIFER HYDRODYNAMICS

The mathematical modeling of the aquifer groundwater is based on MODFLOW, developed by the USGS (United States Geological Survey) [9]. The 3D numerical modeling is based on finite differences approach using the GMS interface "Groundwater Modeling System" [6].

The field of study representing the aquifer is composed on one layer representing the whole thickness of the aquifer. Simulations considerboth steady and unsteady regimes. The zone of study has an area of 1509 km². The grid of calculation is composed on 24329 square active meshes with a width of 250meter. This grid is selected for well representing the geometry of the geological formations of the zone of study.

After generating themodel griddata stored were transferred to graphic layers related to the conceptual model for each mesh of the grid. The files containing altimetrylevels of both roof and substratum of the aquifer were imported from the geographical information system (SIG). They are interpolated under GMS and transferred to the MOFLOWgrid. The figures 8 and 9 shows respectively the bottomisohypses Curves and the top isohypses Curves.





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The model calibration for steady flow wasbasedon data collected in1980. For unsteady flow simulation, data corresponding to the periodbetween 1980 and 2003 was used. The step of calculation is annual. The aquifer's recharge was calculated for each year, and pumpingwas estimated for the same period taking in account values estimated by the ABHBC [3].

THE BOUNDARY LIMITS

We introduce piezometricheads on upstream limits(A and B) (Fig. 3). For the downstream Limits (Chaouia outlet and the Mellah river of the basin we used Dirichlet Condition [7]. This kind of condition allows an exchange of flow (input or output) in the model. The input flow calculated by the model is compared with that estimated by the ABHBC. The limits North (sections AB and CD), East (section EF) and South-east (section GH) model correspond to topographic or impermeable limits (Neumann Condition) [7], with no flow.

The piezometry measured in 1980 (fig. 6a) was considered for the steady flow calibration and as initial condition for the unsteady flow simulation.

AQUIFER'S HYDRODYNAMIC SIMULATION

The calibration of the steady model was improved by comparing the computed values with the measured values related to thehead of several wells controlled by the ABHBC [3]. Many tests of pumping were carried out in the area to release the values of the hydraulic conductivity of the different geological formations of the area. They vary from 5*10-6 to 10^{-2} m/s. These variations are mainly due to the lateral changes of facies. They were adjusted in the model for better reproducing measurements observed of piezometry. Three weather stations were used for the estimate of the recharge (effective infiltration). It was calculated according to the formula of Thorntwaïte [3]. The evapotranspiration was estimated according to the Turk formula [8].

The figures 10(a), (b), (c), (d),(e) and (f) represents respectively the observed and estimated values of piezometers 565/19, 804/28, 1771/27, 2768/20, 2881/20 and 154/28.







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Fig.10 Observed and simulated piezometric levels of the wells

The results obtained for the calibration of hydrodynamic model in unsteady regime (Fig.10) shows that measured and simulated piezometry are in good agreement as well, on the tendency level of or on the numerical values. The model reproduces correctly episodes of drought and rainy as well as the effect of pumping .The coefficients of hydraulic conductivity obtained during the calibration vary with space.

However the results show some differences between the simulated values and those observed in certain cases, like:

- The central zone at the commune of Lahsasna where irrigation is by pivots [9]. In this zone we observe a notable decline of the piezometrichead due to the effect of water pumping for irrigation and for water supply (well154/28).

- The zone where the aquifer is captive, the piezometers' head dropped systematically then were stabilized on a certain value (well 1771/27). This is explained by the fact that the storage and destocking capacity of the aquifer are governed by the effective porosity.

- The well 800/28, a weak variation of the piezometric level, due to its situation close to the south zone of the aquifer alimentation.

So the decline of the piezometrichead is important on all the points of observation taken in consideration and watches the dangerous tendency of the continuous deficit of the renewablewater resources of the aquifer.

This decline can be explained by the reduction in precipitations (effective recharge) and by the increase in pumping which are badly planned in the zone of study. We observe an average decline of the piezometrichead of 6 meters between 1980 and 2003 with a maximum value (Fig.8) reaching 20 meters in some places (well 154/28) and 1434/28 (ABHBC).

The discharges calculated by the model are comparable with those calculated by the ABHBC. The quantities of water entering in the domain calculated by the model are about 110567 m^3 /day. They are distributed as: 38,4% come from the recharge (effective infiltration, the water for irrigation return and the infiltration on the drains(wadis)), and 61,6% from the aquifers of the South . Therefore, the quantity of water flow leaving the system, are distributed as: 76,2% correspond to the take off by the exploitation works and 23,8% contribute to the groundwater reserve andflow out of model by the Northern border.

IV.3 EFFECTS OF THE CLIMATE CHANGES: IPCC SCENARIOS

Three scenarios of the IPCC (Intergovernmental Panel on Climate Changes) [2] were used, to evaluate the impact of temperature and raining variations on the Berrechid aquifer piezometry up to 2099. Three scenarios of IPCC are selected: (1) the IPCC reference scenario A1B; (2) B1scenario, which shows the small variation of temperature; and (3) A1F1, scenario corresponding to maximum temperature increase.

Table 1 shows the precipitations' variation from one season to another and the annual variation for A1B scenario. In this study, an average of the precipitation' variation was taken into account.



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Season	Temperature response (°C)		Rain %		
	Interval	Average	Interval	Average	
Dec-Jan-Feb	1.7-4.6	2.6	-16 à +6	-6	
March-April-May	2.0-4.5	3.2	-24 à -2	-16	
June-July-August	2.7-6.5	4.1	-53 à -3	-24	
Sept-Oct-Nov	2.3-5.2	3.3	-29 à -2	-12	
Annual	2.2-5.1	3.5	-27 à -4	-12	

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Table 1: Scenario A1B example [2]

The temperature increase with such value will have important consequences on the water resources alimented by precipitations which constitute a main entrance data of the hydraulic assessment.

The natural water alimentation of the Berrechidplain is ensured by: Infiltrationsdue to the effective rain;Surface waters infiltration coming from Settat plateau;Undergroundwatercoming from the plateau of Settat to the plain.

WATER RESOURCES ALIMENTATION

The aquifer water resources alimentation is rather variable in time. Those corresponding to direct infiltration of the plain or to the plate runflow are strongly related to raining. The coefficients of variation for the two components are respectively 150 and 100.



Fig. 12.cumuli water alimentation variations compared to water alimentation average

It is obvious that in terms of aquifer recharge the variations of the effective runoff head from one year to anotherhave an important influence on thewater volume available and consequently on the aquifer potential. So if periods of drought are prolonged as it was the case during the Eighties and Nineties, the estimates of the exploitable water resources should be re-examined downwards. The mode of the water alimentation is then irregular and variable. The effective rainfall is the sum of the surface run-off and the infiltration used to evaluate the natural recharge of the unconfined aquifer. It is thus calculated from the rainfall by withdrawing the fractions which are taken in account for evaporation and perspiration evaluation. It is thus important to well evaluate the really evapotranspirated part [3] The effective rainfall is calculated for the seven selected stations. The following data were used for calculations of:

- Precipitations using annual step of time;



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- Temperatures deduced from correlations with altitudes, as indicated in table 2:

	Nouaceur	S. A. Ben Ali	ElMers	Tamdroust	Settat	ElGara	Benahmed
Z (m)	195	324	448	306	330	360	600
T (°C)	14.5	13.75	13.25	14	13.75	13.5	11.75

Table 2. Correlation between altitudes and temperatures

There is strong inter annual variability for all the stations which are induced by inter annual fluctuations of precipitations. In the same way effective rains vary with the position considered in the field of study.

The low values of the effective rain corresponds to Tamdrost and Nouaceur stations, where the averages are respectively of 11.8 and 14.4, whereas the highest median values are respectively 37 and 32 for Benahmed and El Gara stations (fig. 13).

IPCC Scenario	Temperaturemodification (°C)	Precipitationdecrease in (%)	Recharge decline in (%)	Type ofScenario
B1	1.1	6	9	Weak
A1B	2.8	12	19	Average
A1F1	6.4	38	47	Extreme

Table 3.shows a percentage of the recharge decline for three selected scenarios.

The Turk formula [8] was used to estimate directly the real annual evapotranspiration (ETR) such as it was revised and adjusted with the climatic context of the area in reference to the master plan (SBOT).

SIMULATION OF THE AQUIFER RESPONSE TO CLIMATE CHANGE IPCC SCENARIOS

The assumptions adopted to simulate IPCC scenarios relate respectively to the infiltration sites and to the period of simulation which varies from 1980 to 2025.

Simulation consists to recharge the zone of direct infiltration and the polygons of the rivers.Fig.14 shows the aquifer recharge and its sources of rainfallalimentation or by streaming. These zones are:

Precipitation zone of direct infiltration which covers an area of 1229 km² where the aquifer is free; also silts covers a surface plain of approximately 280 km² and make so that the aquifer is confined. The endoreic nature of the plain and the absence of a developed hydrographic network as well as the short time of stagnation of water in the depression make that the effective rain is regarded as completely infiltrated.

Polygons of the drains where the aquifer recharge is ensured by infiltration or flood spreading, of part of surface waters coming from Settatplateau from with a rate of 80%.

The recharge data corresponding to the different scenarios of the water head assigned to the model and the polygons surfaces of Berrechid plain recharge are presented in table 4 (Fig.3):

Scenarios	Rain Infiltration (10 ⁻¹⁰ m/s)	Surface waters Infiltration (10 ⁻¹⁰ m/s)				
		Boumoussa	Tamdrost	Mazer	Ahmer	
Area km ²	1229.34	7.330	4.590	5.845	7.024	
B1	1.94	4.39	14.80	5.35	-35.50	
A1B1	1.72	3.90	13.20	4.76	-31.10	
A1F1	1.13	2.55	8.64	3.12	-20.40	

Table 4.showsthe Aquifer recharge for each scenario



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For each IPCC scenario simulation results are synthesized by graphs of piezometric variation and charts of Isodrawdown for the period 2003-2025, in order to better represent the aquifer response.

Scenario B1: This scenario corresponds a precipitation's decrease of 9 %. The figures 13 (a), (b), (c) and (d) represents respectively the observed and estimated values of piezometers 1771/27, 3235/20, 804/28, 1808/20, for the IPCC scenario B1. We observe a continuous tendency of a water table level declining with a variation between 3 m (piezometer 1771/27) and 7 m (piezometer 1808/20).



Fig 13.Piezometric variation for the IPCC B1scenario - Observed - Simulated and predicted

Scenario A1B: This scenario corresponds to a precipitation's decrease of 19 %. The figures 14 (a), (b), (c) and (d) represents respectively the observed and estimated values of piezometers 724/20, 1771/27, 1434/28, 804/28, for the IPCC scenario A1B. According to the sectors and the practised activities, the predictable water table decrease between 2003 and 2025 vary from 4 m (piezometer 1771/27) to 10 m (piezometer 724/20).





(c)

(d)



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Fig. 14. Piezometric variation for he IPCC A1Bscenario - Observed - Simulated and predicted

Scenario A1F1: This scenario corresponds to a precipitation's decrease of 47 %. The figures 15 (a), (b), (c) and (d) represents respectively the observed and estimated values of piezometers 2881/20, 1771/27, 1434/28and 804/28for the IPCC scenario A1F1. It should be noted for the three *scenarios* considered, that piezometer 804/28 shows a great shift between the levels observed and those simulated. This is due to the fact that this piezometer is located at the underground inflow along the phosphates plateau border and at the same time fir away from the zones of irrigation.





The figures 16 (a), (b), and (c) shows respectively the Berrechid aquifer variation of piézomètrie corresponding to scenarios B1 A1B and A1F1.

The effects observed for the scenarios considered show a significant continuing declining of the aquifer's water level. This decrease can reach respectively for the tree IPCC scenarios B1, A1B1, A1F1 the values 6, 14, and 24m. These important declining of water level will have a negative impact corresponding to progressive drying of many drillings.



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Fig.16. Berrechid aquifer variation of piezometry by 2025 with comparison with the forcasting simulation for IPCC scenarios

V. CONCLUSION

Coupling numerical modeling with regular measurement of both the aquifer piezometry and the , variation of water used for drinking water supply or agriculture, allows a help for decision making in terms of management and planning of groundwater.

The numerical model developed in this study was based on Modfow-GMS for the simulation of the aquifer hydrodynamics and on IPCC scenarios to introduce climate change impact modeling. Different simulations show the impact of these climate changes on the groundwater resources.

The numerical modeling shows a declining tendency of aquifer water head from 1 to 25 m at the piezometers used by the Agency of BouregregHydraulic Basin. The maximum values were noted on the aquifer central zone where the agricultural pumping is most important.

The general tendency, which emerges from the piezometricheadevolution in wellsaccording to the different IPCC scenarios considered, watch that the effect of the recharge reduction, implies a piezometricheaddecline. What also shows that the renewable fresh groundwater resources are reduced considerably.

The study showed that some places will be drained quickly even compared to more conservative scenarios in terms of climate change.



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It would be thus important to study the prospects for voluntarist aquifer restoration. For this purpose, several scenarios can be planned such for example adequate water installations to support the artificial recharge (dams) or by episodically restricting reduction of pumping (years with excess water alimentation) or by coupling these two actions.

REFERENCES

- [1] Bates B.C. "Climate change and water", IPCC edition, Genève 2008
- [2] IPCC "Climate change: impacts and vulnerability". Report of the intergovernmental panel on climate change.Cambridge, UniversityPress 2007.
- [3] Bouregreg and chaouiawatershed Agency (ABHBC), "Synthèse des études antérieures et actualisation des données hydrogéologiques de la nappe de Berrechid", Technical report,2004.
- [4] ElAssaoui Naima, Amraoui Fouad, El Hajji Kacem, "Contribution à la gestion intégrée de la nappe de Berrechid (Maroc)", ACRH conference, Quebec, Canada, 30 April 2009
- [5] El ASSAOUI Naima."Utilisation des outils SIG au niveau de la gestion et la planification des eaux souterraines (nappe de Berrechid)",Masterthesis, Ain Chock Science school, casablanca,2010.
- [6] Environmental Modeling research laboratory, "Groundwater Modeling System GMS Reference Manual Birmingham", Young University 1999.
- [7] Bear Jacob, "Hydraulics of groundwater", McGraw Hill, 1979.
- [8] Turc L., "Nouvelle formule pour le calcul du bilan de l'eau ", Comptes Rendus des Sciences de l'Académie des Sciences, France, 1951.
- [9] Bouregreg and chaouiawatershed Agency(ABHBC), "Inventaire des prélèvements d'eau souterraines à partir de la nappe de Berrechid et élaboration des cartes hydrogéologiques", Technical Report, 2004.
- [10] Anonymous, « Ressource en eaux du Maroc tome2, plaine et bassins du Maroc atlantique", Hydraulics Direction, Rabat, Morocco
- [11] McDonald, M.G. and Harbaugh, A.W.," A modular three-dimensional finite-difference ground-water flow model: Techniques of Water-Resources Investigations ", United States Geological Survey, Book 6, Chapter A1, pp. 586,1988
- [12] Fowler H.J and al.,« Modeling the impacts of projected future climate change ", Cambridge University Press, 2007.
- [13] El assaoui Naima, AmraouiFouad, El hajji Kacem, "Toward a better management of Berrechid basin (Morocco), and a development of a Decision Support System for groundwater management".WSTA 9th Golf Water Conference "Water Sustainability in the GCC Countries"Muscat, Sultanat Oman,2010
- [14] Carneiro J.F and al. ,« Evaluation of climate effects in a coastal aquifer in Morocco using a density dependent numerical model », Environmental Earth Sciences, 2010.
- [15] Morocco Hydraulics Direction, "Etude de la plaine de Berrechid, description et analyse ", Rabat, 1979.
- [16] Goderniaux and al., "Hydrogeological model to assess climate change impacts on groundwater reserves", Hydro geological Journal 2009
- [17] Jilali A. and al. ,"Impact of climate change on Figuig Aquifer using a numerical model: oasis of eastern Morocco", Journal of Biology and Earth Sciences , 2014.
- [18] Kholtei S. andal., "Contamination des eaux souterraines de la plaine de Berrechid dans la région de la Chaouia au Maroc par les métaux lourds" Vecteur Environnement, 2003.
- [19] Moustadraf Jala, "Evaluation of the impact of climate change on the coastal Chaouia aquifer, Morocco using numerical modeling". Hydrogeology Journal ,2008.