

Towards a Global Methodology for Climate Change Impacts on Moroccan's Groundwater Assessment: Berrechid Aquifer Case Study

El Assaoui Naïma¹, Amraoui Fouad²Ph.D Student, Department of Geology, Ain chock Sciences School, Hassan II University, Casablanca, Morocco¹Professor, Department of Geology, Ain chock Sciences School, Hassan II University, Casablanca, Morocco²

ABSTRACT: Over the different IPCC (Intergovernmental Panel on Climate Change) reports, Moroccan's climate trends indicate warming in the future, and decreasing of rainfall and runoff. As a semi- arid to arid country water resources will be vulnerable to climate change in the future, with a threat of important groundwater resources decrease. This climate change phenomenon is generally coupled with the water demand increase especially for agricultural needs. This research aims to propose a global methodology to improve assessment of climate change impacts on Moroccan's groundwater resources, focusing on tools and methods used in this multidisciplinary issue. The proposal approach was based on international benchmark, and outcomes and constraints derived from Berrechid aquifer's studies [1]. [2]. The aquifer studied located in the centre of Morocco, is among many vulnerable Moroccan's aquifers to climate change and water scarcity. Previous studies [1]. [2]. and present work showed a decline of water table of this aquifer even for optimistic scenarios B1 SRES (Special Report on Emissions Scenarios) or RCP (Representative Concentration Pathways) 2.6. Berrechid aquifer was considered as case study to improve methodology based on a link of different models (climate, hydrologic, and flow groundwater), to assess future impacts of climate change on groundwater resources. The climate explorer KNMI from Royal Netherlands Meteorological Institute [3] was used to simulate climate change, the BRGM tool ESPERE [4] was used to simulate recharge variation of the aquifer and finally MODFLOW/GMS [5], [6], was used to simulate the groundwater flow of the aquifer and its response to climate change variation for the period 1980-2035.

KEYWORDS: Numerical model, Recharge, MODFLOW, Methodology, GMS, KNMI, ESPERE, Climate change, Groundwater, Scenarios, RCP, SRES, IPCC.

I. INTRODUCTION

Climate change forecasts from IPCC reports provided that by 2100, Morocco will face a decrease of average annual rainfall by 10 to 30% and an increase of average annual temperature by 1° to 2°C. Aquifer's overexploitation due to the increase of water demand, for urban, agricultural and industrial development; and climate change, has negative impact on groundwater resources. Therefore, different consequences are predicted: natural recharge decrease, water quality decline, salinity intrusion, etc. The majority of Moroccan aquifers are vulnerable to climate changes, and several studies [2], [7] suggested huge decrease of groundwater reserves in the future. Thus it is important to study and analyse the influence of climate change in the future on water resources, for its better management, planning and decision making and particularly for groundwater resources systems like Berrechid's aquifer.

This paper aim is to discuss a global methodology feasibility to improve assessment of climate change impacts on Moroccan's groundwater resources. The proposal approach is based on international benchmark, and outcomes and constraints derived from Berrechid aquifer's previous studies [1]. [2].

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

II. RELATED WORKS

Most of research dedicated to climate change impact on water resources all over the world has been directed to assess the impacts to surface water, but little research has been dedicated to study the response of aquifer's systems to the climate warming impact [17]. These studies were commonly concerned by direct or indirect effects, regarding climate parameters variation, or entropic impacts. Conceptual and numerical mathematical models proliferated during the last decades trying to circumvent certain major difficulties like: the climatic forecasts in the future; the variability of the hydrological cycle components in the future, especially the natural recharge; the interaction between water surface and groundwater; the salt intrusion in coastal aquifers etc.

To evaluate the effects of climate change on the groundwater resources of an aquifer, it is important to take account of several factors: climatic, hydrological, hydrogeological, socio economic etc. Thus, it is difficult but important to develop a global methodology, which integrates all these processes.

Some Moroccan's studies focused on problems related to water resources management in climate warming context [8] [9]. Other research were dedicated to the relationship between climate parameter's variation and water resources decrease, using global or regional climate models, and sometimes based on statistical or dynamical downscaling techniques [10]. [11]. [12]. But, only a little research papers were dedicated to climate change impact on groundwater resources [1]. [2]. [13]. [14]. [15].

Nevertheless different methodologies were proposed and discussed considering different types of aquifers, across the world, trying to develop and improve tools, data bases, approaches etc. We can cite as examples, some relevant research papers from India [16] Canada [17] Australia [18], and USA [19] [20]. Over these studies, we can distinguish two different methodologies: the first one is based on coupling different models (climatic, hydrologic and hydro geological) in a hierarchical top down approach [21] [22]. In this methodology, based on a cascade path output of climate models are used as input of hydrological model, etc. The second type of methodology is based on a fully integrated surface water-groundwater systems [23] [24] coupled to climate model. In this second approach, the challenge is to decrease the cost of computation for large groundwater systems studies. The majority of these publications recommended the use of different climate and hydrologic models, to better assess the range of probable errors of simulations and the reliability of these tools.

III. METHODOLOGY

This methodology should answer some questions, particularly, the choice of:

- The objectives in terms of direct and indirect impacts of climate change on groundwater assessment
- The conceptual models representing (climatology, hydrology, groundwater ,...etc.) of the aquifer
- The scenarios of climate change defining the rates of greenhouse gases for each future period representing short, medium or long terms.
- The climate models to analyse the variability of the climate parameters in the future
- The method of aquifer's recharge analysis with relationship to climate parameters variation
- The integrated model (hydrologic/hydrogeological) or coupled models for water table and reserve of aquifer assessment.
- The methods of errors' analysis generated in the simulation process

This proposal global methodology to assess climate change impact on groundwater studies is commonly based on modelling climate projections, hydrological and groundwater response to those changes. It involves eight steps, in a sequential and iterative approach, as shown in the Fig. 1.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

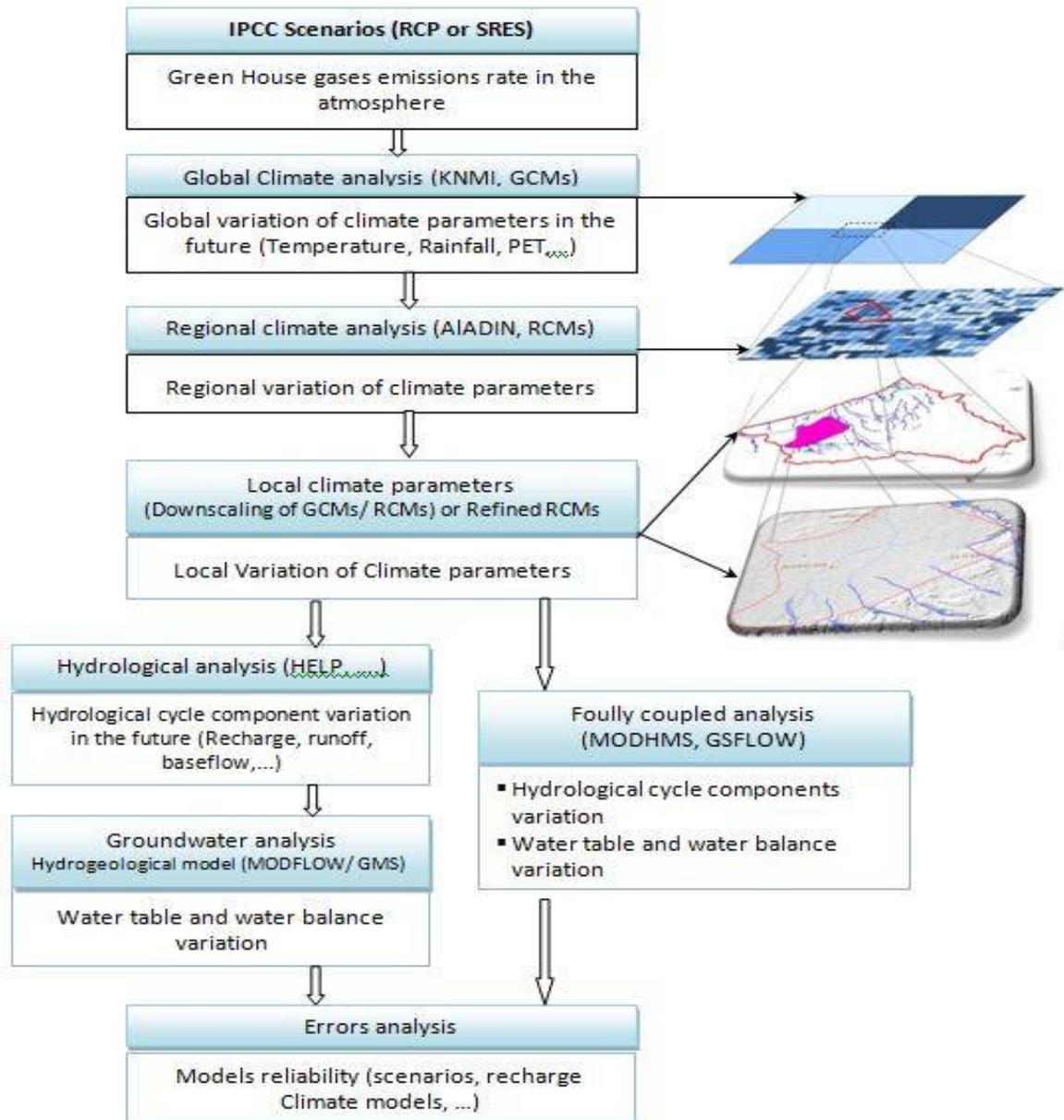


Fig.1 Chart of global methodology

STEP 1: GREEN HOUSE EMISSIONS SCENARIOS

These scenarios of greenhouse gases emissions should represent the future trend of the climate changes for the chosen future periods (2030, 2050, 2100, etc.). Generally IPCC's scenarios are used, considering different situations (optimistic, intermediary and pessimist). These scenarios can be translated in the form of tendency (increase or reduction) to see stability, according to percentages given, on a seasonal or annual scale. For Berrechid aquifer study, both old scenarios SRES [25] and new scenarios RCP [26] were used and compared Fig. 2

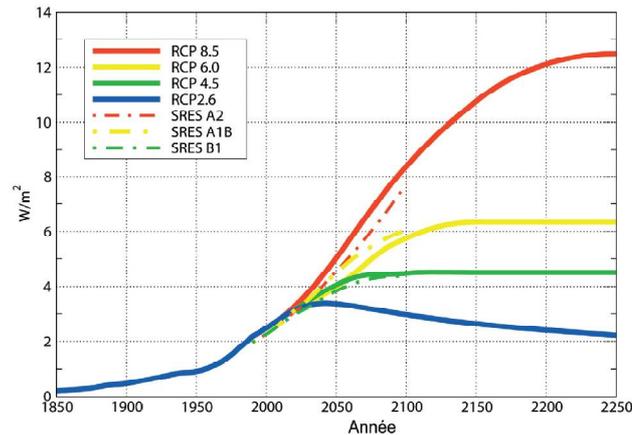


Fig. 2 SRES and RCP scenarios proposed by IPCC (Planton 2013)

STEP 2: GLOBAL CLIMATIC PARAMETERS VARIATION IN THE FUTURE

The variation of climate parameters can be studied using global climate models GCM like HadCM3 [3], [27]. Many research studies recommended the use of different climatic models because of their weak reliability in terms of future climate forecasting, especially rainfall prediction. For Berrechid aquifer's study we used the climate explorer KNMI [3] including CMIP5 (Coupled Model Inter comparison Project Phase 5) [28] which involve more than 40 climate models issued from the fifth IPCC report investigations.

STEP 3: REGIONAL CLIMATIC PARAMETERS VARIATION IN THE FUTURE

The output of global climatic models in terms of climate parameters can be used as input in boundary conditions of Regional climate models RCM like (Aladin-Climate: Moroccan's version) [29]. These models use higher resolution meshes, with space less than 10 km, and containing a better representation of physical processes involved in climate change phenomenon [30].

STEP 4: LOCAL VARIATION OF CLIMATIC PARAMETERS IN THE FUTURE

The output of the GCM or RCM models can be used as input in statistical or dynamical downscaling tools like SDSM [11] or MM5 [12], to better represent the variation of climate parameters on local scale. The meshes are more refined to take into account relevant physical processes like recharge of the aquifer distribution [31]. An alternative to skip this step is the directly use of performing RCM models, with space less than 5 Km.

STEP 5: LOCAL AQUIFER'S RECHARGE VARIATION IN THE FUTURE

Climate parameter's variation will alter natural recharge, commonly considered as proportion of rainfall. Many tools exist in literature can be used [32], like hydrologic models for example HELP, including a recharge module called WHI UnSat [33], [34]). Other models can be used like WetSpa [35]), or EPIC-GRID, SWAP, DPM, PRMS, SWB,RORA, etc. Another alternative is the use of groundwater flow models like MODFLOW [1], [2]. or fully coupled surface water- groundwater models like: MODHMS [36], HydroGeoSphere [46], MIKE SHE [47], etc.. Estimates of natural recharge to Berrechid aquifer were made using the ESPERE software in excel environment by BRGM [4], including different methods for recharge evaluation

STEP 6: AQUIFER'S GROUNDWATER FLOW

Using the output of hydrological or fully coupled models, particularly the aquifer's recharge, evapotranspiration, and runoff, as inputs for hydrogeological models (or integrated models), we can simulate the groundwater flow dynamics of the aquifer in both steady and unsteady regimes. The calibration will be based on a referential or historical period data, especially the aquifer's water table variation in space and time.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

STEP 7: NUMERICAL MODELLING OF CLIMATE CHANGE IMPACTS ON GROUNDWATER

The final calibrated transient groundwater flow model or fully coupled model is used for all scenarios of climate change, to evaluate variability of climate parameter's and aquifer's recharge variation impact on groundwater factors response. We can simulate the climate change impact on groundwater, especially the recharge and water table variation for each future term (short, medium or long), and each scenario. For Berrechid case (step 6 and 7), we used the three dimensional groundwater flow model MODFLOW/GMS [5]. [6].

STEP 8: ANALYSIS OF SIMULATION ERRORS

The greatest errors are allocated to the choice of climatic models, the scenarios of greenhouse gas emission effects, the choice of downscaling method, the aquifer's recharge simulation, etc., as discussed by [12], [18], [34], [37], [38], [39], and [40], [41], [42], [43]. In this previous research, it is generally recommended to use different methods and tools to better appreciate errors of simulation variation.

IV. BERRECHID AQUIFER CASE STUDY

A. DATA ANALYSIS

This aquifer is 1500 Km², located in the Bouregreg Chaouia basin (western of Morocco). The data base used in this study represents different aspects: geology, geomorphology, hydrogeology, hydrology and climatology. The geological map of Berrechid aquifer is shown in Fig.3 [2]

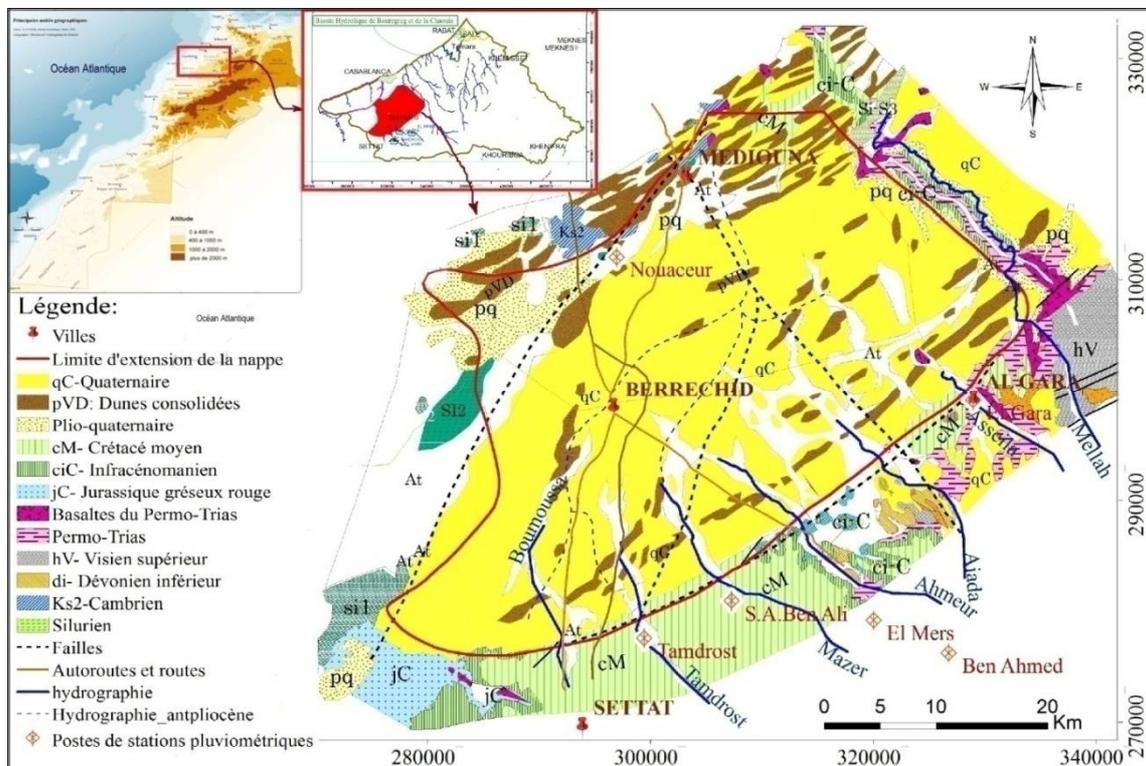


Fig.3 Location map of the study area in Morocco and in Bouregreg Chaouia Basin, and Geology map of Berrechid aquifer (scale 1/500000)

The climatic data from 1965 to 2015 are based on the actualization of monthly and annual precipitations related to stations El Mers, Sidi Ahmed Ben Ali and Tamdrost. The climate explorer KNMI [44], was used to predict climate

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

parameters variation, and to complete some missing data. The variation of average annual climate parameters (temperature, rain and evapotranspiration) for the period 1980-2015 is shown in Fig. 4.

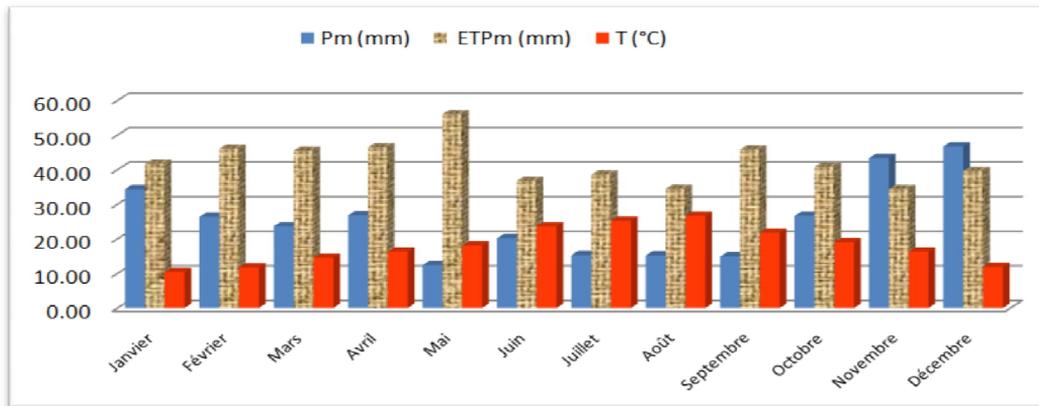


Fig. 4 Monthly averaged climate parameters (1980-2015)

The hydrological network is endoergic and 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. Data related to 40 piezometers of which 29 have measure until 2015 are used Fig.5. A seasonal variation of water table level is observed on all the wells .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. [2] [44]

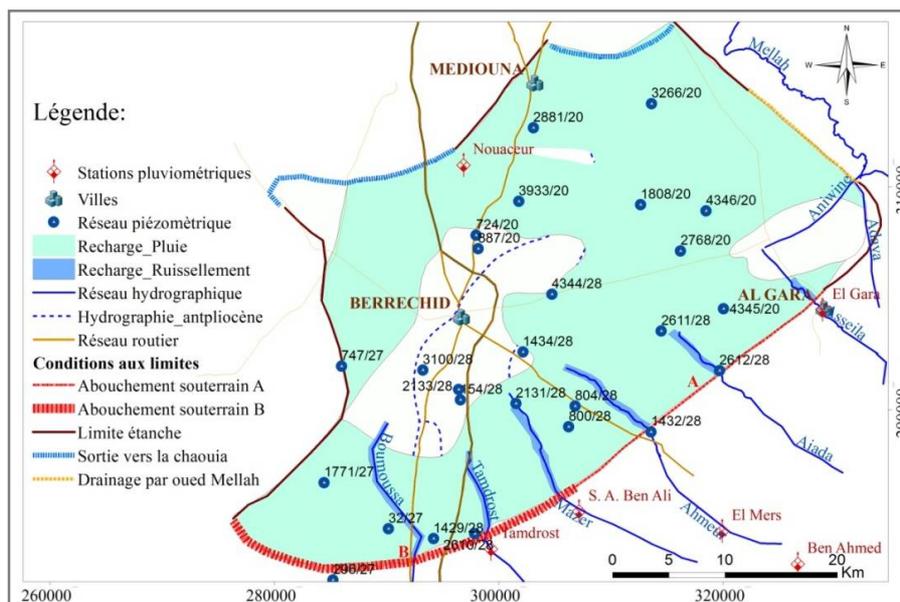


Fig. 5 Piezometric network, recharge zone and boundary limits

B. WATER RESOURCES ALIMENTATION AND BALANCE

The aquifer water resources alimentation is rather variable in time. Those corresponding to direct infiltration of the plain or to the plate run flow are strongly related to raining. The coefficients of variation for the two components are respectively 150 and 100. [2] Fig. 6

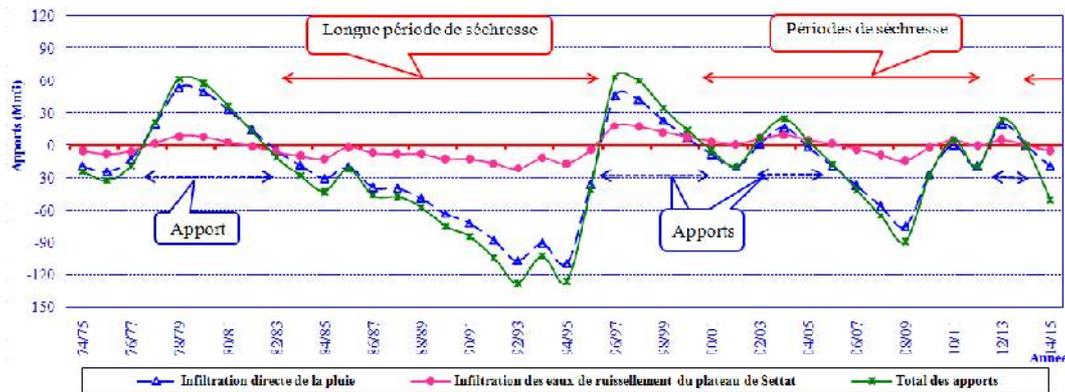


Fig. 6 Cumuli water alimentation variations compared to water alimentation average

As shown in Table 1, the water balance quantification for different periods between 1933 and 2014 is provided. These values are used to compare different methods for recharge estimation using ESPERE software [4]. Fig.6

Water balance components	Water volume for each period balance(Mm3/year)			
	1985 (1933-1983)	2004 (1974-2002)	2009 (1974-2005)	Actuel Balance (1974-2014)
Infiltration by rainfall	31	17	18	19
Infiltration from runoff	8	5.5	4.5	4
Infiltrations from Settat plateau	26	26	26	25
Total of Input	64	48,5	48,5	48
Water Pumping	43	115	135	64
Discharge to Chaouia	17	12.5	12.5	11
Draining to Oued Mellah	4	1	1	1
Total of output	64	128,5	148,5	76
Balance	0	80	100	28

Table1: water balance for periods between 1933 and 2014

C. CLIMATE CHANGE IMPACT ON GROUNDWATER RESOURCES

As discussed above, groundwater resource response to climate change is dependent on many conditions: climatic, hydrologic and hydro geologic. The previous methodology feasibility for Berrechid aquifer as case study will be discussed in next paragraphs.

i. GREENHOUSE GASES EMISSIONS SCENARIOS

As presented and discussed in [45], both SRES scenarios [25] and RCP scenarios [26] were used to simulate climate change in the future. El Assaoui et al. [2], considered SRES (B1, A1B and A1F) to analyse the response of aquifer’s groundwater to climate change impact. Therefore, we consider in this paper RCP scenarios (2.6, 4.5, 6.0 and 8.5), to compare with previous results.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

ii. CLIMATE PARAMETERS VARIABILITY

The global climate is studied by various global climate models using the climate explorer tool KNMI from the Royal Netherlands Meteorological Institute [3]. We have using CMIP5 (Coupled Model Inter comparison Project Phase 5) [28] which consists of more than 40 global climate models GCM issued from the fifth IPCC report. The future period simulated are respectively: short term H1 between 2016 and 2035; Medium term H2, between 2046 and 2065 and long term H3 between 2081 and 2100. In these KNMI simulations we considered all scenarios, periods and seasons. We analysed both variation of climate parameters and comparing results obtained to those corresponding to an historical period 1980-2005. The simulation outputs are in form of parameter's variation maps or chronological series [46]. Fig.7 (a) and (b). showed as examples of KNMI results. The Climate parameters output provided are : Temperature: Max, Min, average °C ; Rainfall mm/year ; PET (Potential Evapotranspiration) mm/year; Relative humidity %; Solar radiation W/m²; Atmospheric pressure (Hpa) ..etc

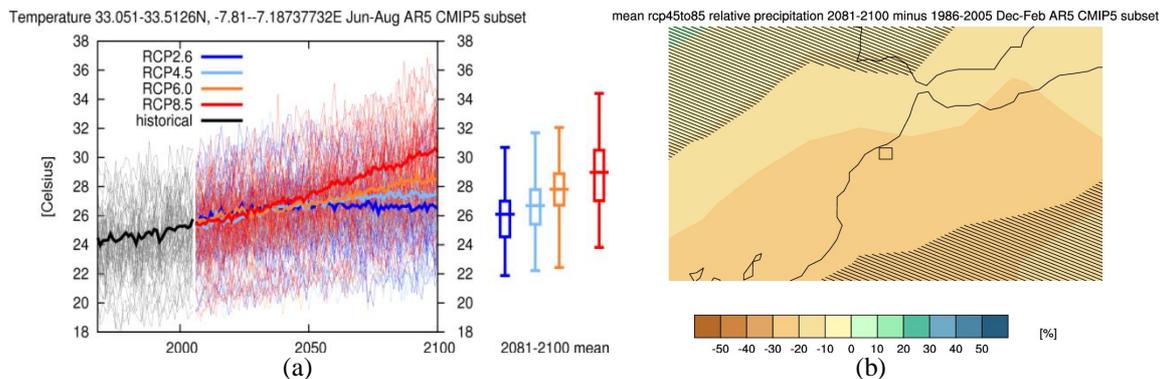


Fig. 7 KNMI example of results (a): chronological variation, (b) relative variation map

The average annual values of climate parameters variation, for each scenario and each period, provided by KNMI are showed in table... .These predictions suggest that rainfall may decrease by 3% for the combination H1/ RCP2.6 and 32% for H3/RCP 8.5. We observed that average annual temperature may increase by 0.67°C for H1/RCP2.6 to 4.31°C for H3/ RCP8.5.The PET may decrease by 0.5% for H1/RCP2.6 to 15% for H3/ RCP 8.5. The Comparison of these results with Wilby and Christensen [11] for the H3 period, showed that RCP 6.0 and A1B scenarios are equivalent, but that, the scenarios RCP 2.6 and RCP 8.5, are more optimistic than SRES B1 and SRES A1F scenarios, as suggested by Planton [45].Other parameters variation was studied using the climate explorer KNMI, like : PET (Potential evapotranspiration), RH (Relative Humidity), SH (Specific humidity) , SR (Solar radiation), Tmax (maximum temperature), Tmin (Minimal temperature),...etc. The average annual variation of these parameters is shown in Figure 9, for each scenario during the period 1980 to 2100. These predictions suggest an increase trend in extreme temperatures trends Tmax and Tmin, a decrease trend of PET and relative humidity, and a weak variation of solar radiation.

Period	PET variation (%)				Rainfall variation (%)				Temperature variation (°C)			
	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
H1	-0,48	-1,48	-1,79	-3,52	2,90	6,00	8,00	10,0	0,67	0,73	0,80	1,13
H2	-0,96	-5,63	-6,22	-8,39	5,10	10,4	14,0	19,0	1,26	1,60	1,61	2,50
H3	-1,09	-5,19	-6,28	-14,7	9,50	15,9	19,5	31,4	1,35	2,36	2,61	4,31

Table 2 : Climate parameter variation per scenario for each simulation period

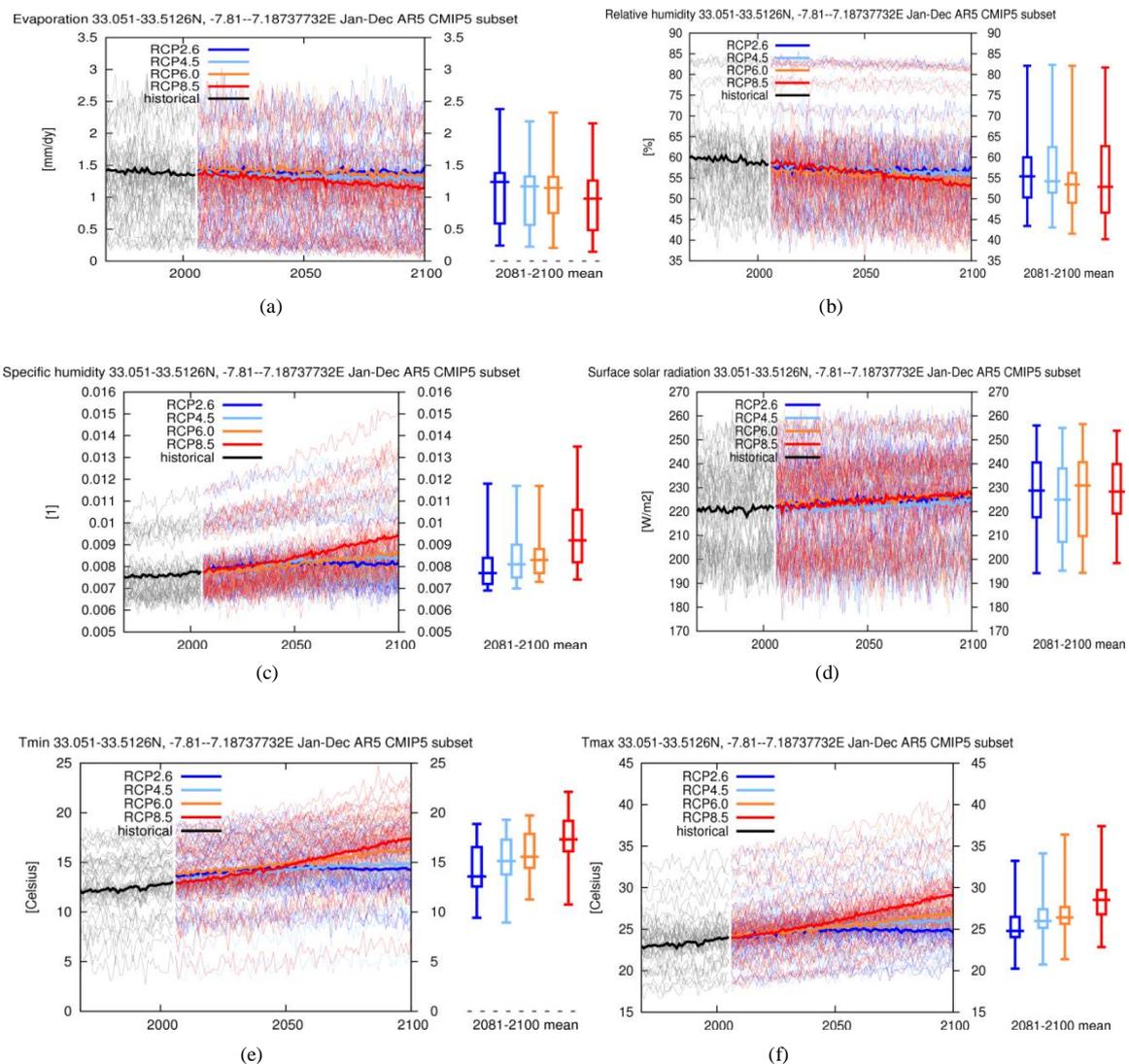


Fig. 8 Other parameter variation between 1980 and 2100 (a) Potential evapotranspiration, (b) Relative Humidity, (c) Specific humidity, (d) Solar radiation, (e) maximum temperature (Tmax), (f) Minimum temperature (Tmin)

iii. NATURAL RECHARGE VARIATION

The increase in temperature and the decrease in rain are prospected to alter groundwater natural causing decline of groundwater resources. Recharge is also a good indicator of groundwater resources potential. As discussed above, the recharge variation during periods H1, H2 and H3 for each RCP scenario was studied using ESPERE software. This flexible tool gives possibility to use different methods (Thornwaite, Turc, Dingman-Hamon, Dingman-Penman, WTF etc.) [4]. The calibration of these methods was based on both referential period 1980 and water balances for different periods Table 1. The Comparison between these methods suggested that TURC method is the more reliable .The other methods are very sensitive to some missed parameters like retention rate, specific yield or culture coefficient. The evaluation of the recharge variation for each scenario RCP or SRES was based on each simulation period .The table 3

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

provide the relative decrease in recharge compared to referential period (1980-2005), using the average value obtained by the used methods or by Turc method. This variation is between -2.5 to -13 mm/year for Turc method and between -3.5 to -25 mm/year for the average value Fig. 9a, 9b and 9c. These results confirm that recharge estimation is very difficult to estimate with a good reliability and that the use of different models is beneficial to better assess this important factor.

	H1/ RCP2.6	H1/ RCP8.5	H3/ RCP2.6	H3/ RCP2.6	H3/ B1	H3/ A1B	H3/ A1F
Turc	-2.5	-6.2	-6.2	-12.5	-5	-8	-13
Average	-3.5	-9.8	-10	-23	-6.7	-11.9	-25

Table 3: Recharge variation in mm/year, per scenario for each period

The Fig. 9 (d), shows the recharge variation for the period H1, using Turc Method or the average of used methods.

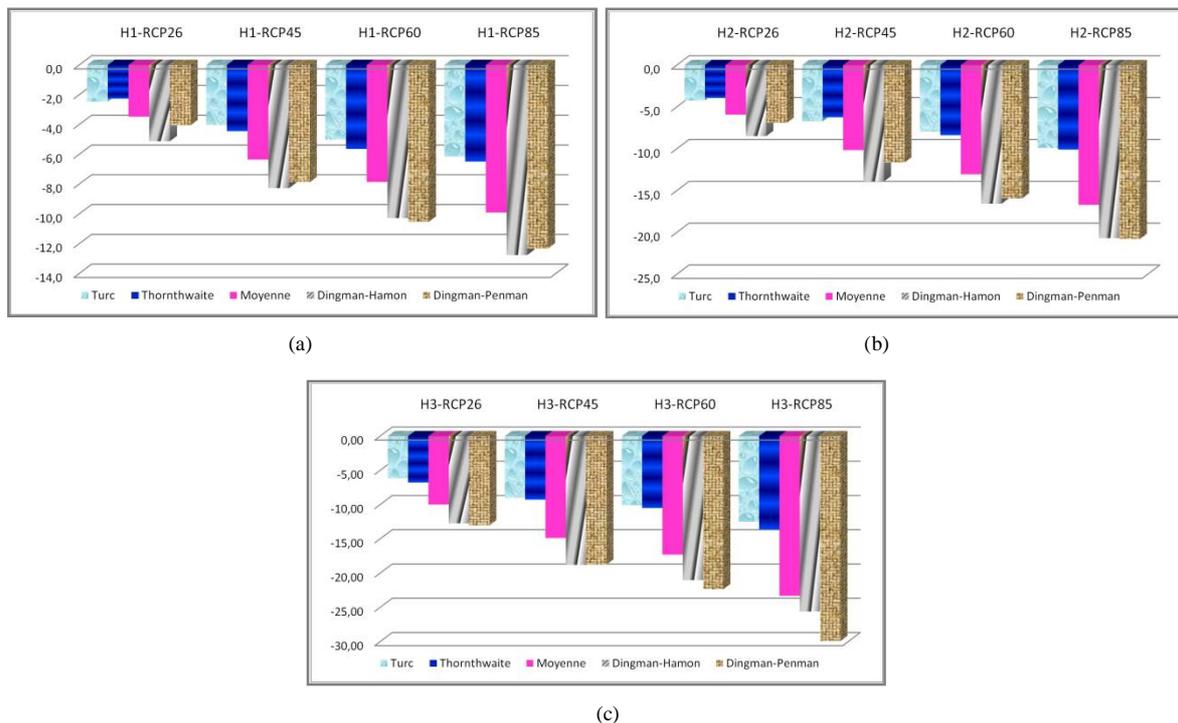


Fig. 9: (a), (b), (c) relative recharge variation per scenario for periods H1, H2 and H3

iv. WATER TABLE VARIATION FOR PERIOD H1 PER SCENARIO

The groundwater flow numerical model developed is based on the USGS's 3D tool, MODFLOW /GMS [5], [6]. The future period considered is H1 to simulate the aquifer head variation. RCP scenarios related to climate changes are used to analyze the climate change impact on Berrechid aquifer's resources. The model calibrated was used considering the recharge variation for each scenario. The model construction and calibration for steady and non steady regimes, was discussed in [2], for period 1980-2025, using SRES scenarios B1, A1B and A1F. In this paper the simulations was

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

extended to 2035, using RCP scenarios. The validation of the model was discussed using actualized data until 2015, for rain, runoff and pumping for agricultural and other uses [44]. These RCP scenarios are used, to evaluate the impact of temperature and raining variations on the Berrechid aquifer piezometry up to 2035. Four scenarios are selected: (1) RCP 6.0 scenario which is equivalent to SRES A1B [45]; (2) RCP 2.6 scenario, which simulates the optimistic situation; and (3) RCP 8.5 which simulates a pessimist situation, similar but lower than SRES A1F. The RCP 4.5 was also considered for comparison.

V. AQUIFER RESPONSE TO CLIMATE CHANGE: SIMULATION AND RESULTS

The assumptions adopted to simulate RCP scenarios are related to the infiltration sites for the H1 period of simulation. This simulation consists to naturally recharge the zone of direct infiltration and the polygons of the rivers. Fig. 5 shows the aquifer recharge and its sources of rainfall alimentation or by streaming [2]. For each RCP scenario simulations the results are synthesized by graphs showing water table variation and charts as isodrawdown, in order to better represent the aquifer response. Running the calibrated groundwater numerical model, for each scenario, we analyzed the water table variation in different wells presented previously.

For the optimistic scenario RCP 2.6 The simulation corresponds to a precipitation's decrease of 2.9 %. Figs. 10 (a), (b) represents respectively the observed and estimated values of piezometers 1808/20 and 724/20 are shown as examples. The map of isodrawdown of the water table is shown in Fig. 12 (a).

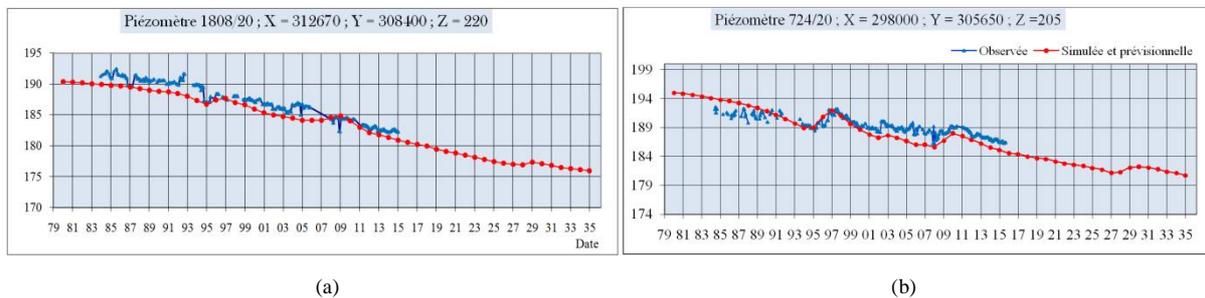


Fig. 10: Water table variation using RCP 2.6 scenario (a) for 1808/20 and (b) for 724/20

For the pessimist scenario RCP 8.5: This simulation corresponds to a precipitation's decrease of 10 %. The figures 11 (a), (b) represents respectively the observed and estimated values of piezometers 1808/20 and 1434/28 as examples. The map of isodrawdown of the water table is shown in fig.12 (b).

It should be noted for the considered scenarios, 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 far away from the zones of irrigation.

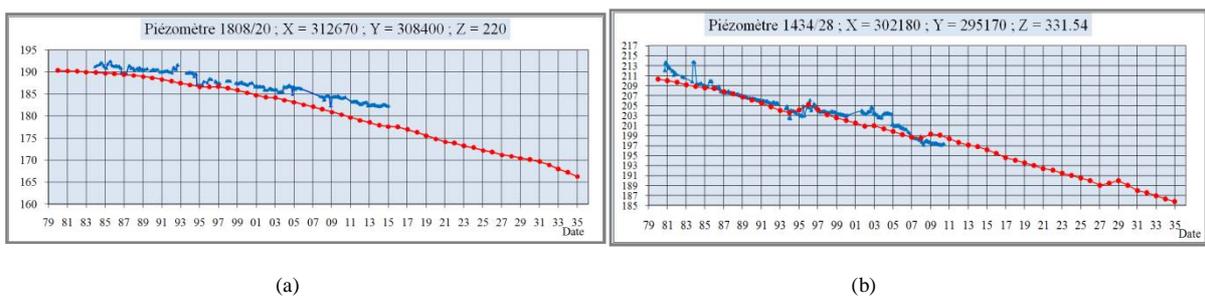


Fig. 11: Water table variation using RCP 8.5 scenario (a) for 1808/20 and (b) 1434/20

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

The figures 12a and 12b shows respectively the Berrechid aquifer variation of piezometry drawdown map corresponding to extreme scenarios: RCP 2.6 and RCP 8.5. 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 IPCC scenarios discussed previously, the values 5m and 18m. These important declining of water level will have a negative impact corresponding to progressive drying of many drillings.

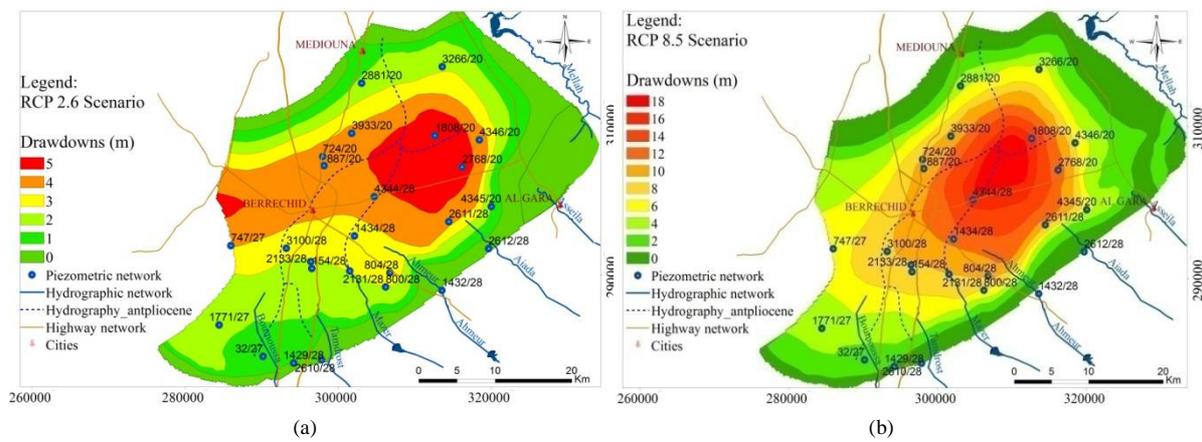


Fig. 12 Water table aquifer's isodrawdown map for extreme scenarios (a) for RCP 2.6 and (b) RCP 8.5

These results confirm those obtained using SRES scenario B1, A1B or A1F [2]. All the simulations suggest that the aquifer's water resources situation is critic and urgent measures could be taken by ABHBC and its customers and partners, to improve the situation.

V. CONCLUSION

The Impact of climate change on groundwater resources requires multidisciplinary research approach involving different aspects (climatology, hydrology, hydrogeology, earth Sciences, socio economy etc.). Two methodologies can be considered, the first one is based on a coupling cascading process, from top to down, beginning with climate model, passing by hydrological and finishing by groundwater flow model. The second approach could be based on coupling climate model with a fully integrated model (hydrological/ hydrogeological). For Moroccan's studies of climate change impact on groundwater we recommend to continue improving climate aspects by developing RCM model like Aladin-Climat [29] and by using statistical downscaling with SPSM tool [11] or dynamic downscaling with MM5 tool [12]. The recharge variation can be improved by developing a hydrologic model like HELP or HMS. Other possibility could be the use of fully linked models like MODHMS or GSFLOW [36]. [42], especially when participating to international projects of cooperation. Therefore, MODFLOW/GMS will continue to be the basic Moroccan's tool for hydro geological modeling due to its international notoriety and flexibility and also to its possibility of linking with other models like HMS, WEAP, SWAT, etc...

Berrechid simulations to assess climate change impact on groundwater resources, using both SRES scenarios [2] or RCP scenarios, suggest a declining tendency of aquifer water at different piezometers indicating a threat of dangerous water resources decrease and risk of water scarcity in the future. This situation is due to climate change impact and to the increase of pumping for agriculture uses. So, different investigations by the Hydraulic agency ABHBC are investigated during the last decade, especially:

- development of non conventional water resources and retaining rainfall water systems, for irrigation, or artificial recharge of the aquifer;
- development of a politic of pumping reduction and control
- Implementation of an aquifer's agreement between the ABHBC agency, different water users and partners, for sustainability management of groundwater resources.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

REFERENCES

- [1] El Assaoui Naima, Amraoui Fouad, "Modélisation hydrodynamique des effets du changement climatique sur la nappe de Berrechid (Maroc)", revue Géologues, Société géologique de France, Numéro 185, Déc. 2015
- [2] El Assaoui Naima, Amraoui Fouad, "Modeling of climate change impacts on groundwater resources of Berrechid aquifer", International Journal of Innovative research in Science, Engineering and technology, Vol.4, July 2015
- [3] Trouet V. et al., "KNMI climate explorer: A web-based research tool for Higher resolution paleoclimatology", Tree-Ring Research 69(1) pp. 3-13
- [4] Lanini S. et al., "ESPERE- A multiple method Microsoft Excel application for estimating aquifer recharge", Groundwater, Issue 2, pp. 155-156, March/April 2016
- [5] 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
- [6] Environmental Modeling research laboratory. "Groundwater Modeling System: GMS Reference Manual", Birmingham, Young University 1999.
- [7] Bouregreg and chaouia watershed Agency (ABHBC), "Inventaire des prélèvements d'eau souterraines à partir de la nappe de Berrechid et élaboration des cartes hydrogéologiques", Technical Report, 2004.
- [8] El Badraoui H. et Berdai M. 2011 "Adaptation du système eau-énergie au changement climatique: étude nationale, Maroc" Plan bleu, PNUE/PAM, Sophia Antipolis
- [9] Moroccan's Ministry in charge of Environment "Étude de la vulnérabilité et d'adaptation du Maroc face aux Changements climatiques : dans le cadre de la troisième communication nationale sur les changements climatiques". PNUD, CEDARS Morocco, 2015
- [10] Driouech F. 2010 "Distribution des précipitations hivernales sur le Maroc, dans le cadre d'un changement climatique: Descente d'échelle et incertitudes" thèse de doctorat Université de Toulouse
- [11] Wilby R... "Climate change scenarios for morocco" Final technical report, World Bank, Sept. 2007
- [12] Jaw T. et al. "Evaluation for Moroccan dynamically downscaled precipitation from GCM CHAM5 and its regional hydrologic response" Journal of hydrology: regional studies 3, 2015, PP. 359-378.
- [13] 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.
- [14] 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.
- [15] Moustadraf et al., "Evaluation of the impact of climate change on the coastal Chaouia aquifer, Morocco using numerical modeling" Hydrogeology Journal, 2008.
- [16] Kumar 2012 "Climate change and its impact on groundwater", International Journal of Engineering and Science, Vol. 1, Issue 5, October 2012, PP. 43-60
- [17] Allen D. and Scibeck J. 2004 "Climate change and groundwater: a modeling approach for identifying impacts And resource sustainability in the British Columbia" Technical report Fraser university Canada
- [18] Barron O. et al. 2011 "Climate change impact on groundwater resources in Australia" Waterlines Report series N 67 December
- [19] U.S. Bureau of Reclamation (USBR) 2014 "Hood River Basin Study: Groundwater modeling and analysis technical memo (Draft)" U.S. Department of the Interior, Pacific Northwest Regional Office, Boise, Idaho, 70 p.
- [20] Pitz C.F. "Predicted impacts of climate change on groundwater resources of Washington State" Environmental Assessment program, department of Ecology, Washington State, Publication 16-03-006, March 2016
- [21] Scibek, J. and Allen, D. M. 2006 "Modeled impacts of predicted climate change on recharge and groundwater levels", Water Resources Research, Vol. 42, W11405, 18p.
- [22] Holman, I.P. et al., 2012 "Towards best practice for assessing the impacts of climate change on groundwater". Hydrogeology Journal, v. 20, p. 1-4.
- [23] Markstrom, S.L. et al., 2012. "An integrated watershed scale response to climate change for selected basins across The United States". U. S. Geological Survey Scientific Investigations Report 2011-5077, 143 p
- [24] Therrien R. et al; 2005 "HydroGeoSphere: A three dimensional model describing full-integrated subsurface and surface Flow and solute transport" groundwater simulation group, university of Waterloo Ontario Canada
- [25] IPCC "Climate change: impacts and vulnerability" Report of the intergovernmental panel on climate change". Cambridge University Press. 2007.
- [26] IPCC 2014 "Impacts adaptation and vulnerability: region Aspects". Cambridge University Press, Cambridge, UK And New York, NY, USA
- [27] Gordon C. et al., "Hadley center coupled version model without flux adjustments", climate dynamics 16(2-3), pp. 147-163
- [28] Taylor, R.G. et al. 2013. "Ground water and climate change". Nature Climate Change, v. 3, p 322-329
- [29] Somot S. et al., "Aladin-climate from the origins to present day", Newsletter N 29 Nov. 2005
- [30] Earman S. et al., "Potential impacts of climate change on groundwater resources-a global review", Journal of water and climate change, Dec. 2011, 2(4) pp. 213-229.
- [31] Fowler H.J 2014 "Downscaling and uncertainty" international conference: Uncertainty in climate change research, an integrated approach. July NCAR/CO Boulder USA
- [32] Healy, R.W., 2010. "Estimating Recharge" Cambridge University Press, Cambridge, UK. 245 p.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

- [33] Scibek, J. and Allen, D. M. 2006 "Modeled impacts of predicted climate change on recharge and groundwater levels", *Water Resources Research*, Vol. 42, W11405, 18p.
- [34] Allen, D. M., Cannon, A. J., Toews, M. W. and Scibek, J.(2010) "Variability in simulated recharge using different GCMs" *Water Resources Research*, Vol. 46.
- [35] Batelaan O. et al., "Wetpass: a flexible, GIS based, distributed recharge methodology for regional groundwater modeling", Sixth IAHS conference, Netherlands July 2001
- [36] HydroGeologic Inc. 2006 "MODHMS: A comprehensive MODFLOW-based hydrologic modeling system version 3" Hydrogeologic Incorporated, Therdon USA
- [37] Kidmose, J. et al., 2013. "Climate change impact on groundwater levels: ensemble modeling of extreme values". *Hydrol. Earth Syst. Sci.*, v. 17, p. 1619-1634.
- [38] Goderniaux P. et al. 2011 "Uncertainty of climate change impact on groundwater resource considering various Uncertainly sources" IAHS publications N 345
- [39] Crosbie, R.S. et al. 2011. "Differences in future recharge estimates due to GCMs, downscaling methods and Hydrological models". *Geophysical Research Letters*, V. 38
- [40] Vaccaro J.J. et al. "Groundwater availability of the Coulumbia Plateau regional Aquifer System", Washington, USGS Professional Paper 1817, 104 p.
- [41] Zhou, Yu, Zwahlen, François, Wang, Yanxin and Li, Yilian 2010 "Impact of climate change on irrigation requirements , in terms of groundwater resources", *Hydrogeology Journal*, Vol. 18, pp. 1571– 1582.
- [42] Surfleet, C.G. and Tullos, D., 2013 "Uncertainty in hydrologic modeling for estimating hydrologic response due to climate change (Santiam River, Oregon)" . *Hydrological Processes*, Vol. 27, No. 3560-3576.
- [43] Wu L. et al. 2014 "Groundwater recharge modeling approach to identify climate change impacts using groundwater Levels from TARNSJO" KTH land and water resources engineering, Royal Society Institute of technology (KTH) Sweden
- [44] ABHBC "Etat de la qualité des ressources en eau", Ministère délégué chargé de l'eau, 2015
- [45] Planton S. et al. "Les nouveaux scénarios climatiques du GIEC", *pollution atmosphérique*, numéro spécial 2013
- [46] Bouchet R.J. et al. "Evapotranspiration potentielle et réelle: domaine d'utilisation; portée pratique", *B.T.I N°238*, pp. 215-223
- [47] Eden J. et al., "KNMI Climate Explorer: A tool for climate analysis", MedCOF training workshop, Madrid October 2015
- [48] Therrien R et al. "HydroGeoSphere: a three dimensional numerical model describing fully-integrated subsurface and surface flow and solute transport" Groundwater simulation group- University of Waterloo, Ontario 2005, 322 p.
- [49] DHI Water and Environment "MIKE SHE user-manual: volume 2, reference guide", DHI software Denmark