Eco. Env. & Cons. 29 (January Suppl. Issue) : 2023; pp. (S262-S271)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2023.v29i01s.041

Simulation and Prediction of Groundwater Dynamics in Nagarjuna Sagar Right Canal (NSRC) Command for Normal and Extreme Groundwater Recharge Conditions

R. Ganesh Babu[1]*. G. Ravi Babu[2], A. Mani[3], P. Prasuna Rani[4] and V. Srinivasa Rao [5]

[1]Department of Irrigation and Drainage Engineering, Dr. NTR College of Agricultural Engineering, ANGRAU, Bapatla 522 101, A.P., India
[2]Department of Irrigation and Drainage Engineering, College of Agricultural Engineering, ANGRAU, Madakasira 515 301, A.P., India
[3]Department of Soil and Water Conservation Engineering, ANGRAU, Dr. NTR College of Agricultural Engineering, ANGRAU, Bapatla 522 101, A.P., India
[4] Geospatial Technology Centre, ANGRAU, Lam, Guntur 522 034, A.P., India
[5] Department of Statistics and Computer Applications, Agricultural College, ANGRAU, Bapatla 522 101, A.P., India

(Received 10 June, 2022; Accepted 3 August, 2022)

ABSTRACT

Groundwater Modeling is the best tool to optimize the different combinations and to select the best combination for sustainable groundwater management. Using computer models, best solution or scenario can optimize by creating model with real conditions. In this study, computer model Visual MODFLOW was applied to Nagarjuna Sagar Right Canal Command area to simulate the groundwater dynamics. The net area irrigated under Nagarjuna Sagar Right Canal is 4.75 lakh ha. The aquifer properties of various layers and boundary conditions were fed in to the model as input for calibration and validation of the model. After calibration and validation, the model was used to predict the groundwater dynamics in the study area using different recharge scenarios. The validated groundwater model was used to predict the groundwater levels in the study area for the years 2020, 2030 and 2040 with different recharge scenarios. Global climate model was used to generate future weather data. MarkSim developed by the International Centre for Tropical Agriculture (CIAT) was used to generate the weather parameters like maximum and minimum temperatures for the years 2020, 2030 and 2040. The different recharge scenarios with average, lowest and highest recharge over the study period and projected evapotranspiration have been used and revealed that the groundwater levels increase with the increase in recharge and decreases with the decrease in recharge. The results revealed that the groundwater depleted area would decrease with the highest recharge scenario and it would increase with the lowest recharge scenario in future. The deeper groundwater table would be expected in future at Chimakurthy and Thalluru villages of Prakasam district and Karempudi and Piduguralla villages of Guntur district in the study area. This condition may be due to the excess utilization of groundwater which is less than the groundwater recharge in particular villages. The construction of rainwater harvesting structures for artificial groundwater recharge in those areas should be carried out immediately.

Key words : *Groundwater modeling, Nagarjuna Sagar Right Canal Command area, groundwater fluctuations, Visual MODFLOW, Calibration, Validation and Prediction.*

Introduction

In India, agriculture is the primary livelihood activity and also the backbone of the Indian economy. Proper management of surface and groundwater resources is essential for the sustainable agriculture. Groundwater is the major source where surface water availability is declining (Mondal and Singh, 2009). For achieving sustainable groundwater resources, a precise and scientific quantitative assessment is essential. Assessment of the groundwater recharges is a basic pre-requisite for the sustainable development of groundwater resources. Depletion of groundwater is the sign of water scarcity and indicates the critical condition of groundwater availability. In this situation, optimal use and artificial recharge of groundwater are the alternatives to overcome water scarcity.

The groundwater flow is a complex phenomenon which varied spatially and also temporally. The development of groundwater has not been uniform throughout India. Some part of India have the intensive groundwater development which causes waterlogging and depletion of groundwater observed in some parts due to over exploitation to meet their water demand. The management for sustainable groundwater resources requires information on the activities and their response. For this purpose, a tool is needed which provides information regarding groundwater condition. Groundwater models are playing an important role in decision making to achieve goals through assessment of groundwater potential and future scenarios. The groundwater flow models can be used for estimating the groundwater system dynamics and to predict the response or impact of the various scenarios. Various groundwater flow models are available and these are providing an effective tool for maintaining sustainable groundwater resources. The calibrated and validated groundwater model can be used to evaluate the impact of various possible scenarios with change in land use land cover on the groundwater flow system for planning, monitoring and maintaining sustainable groundwater resources.

Materials and Methods

Description of study area

The study area, Nagarjuna Sagar Right Canal (NSRC) Command is located between 15^0 18´ N latitude to 16^0 49´ N latitude and 79^0 20´ E longitude to 80^0 25´ E longitude. The NSRC command area gets water from the Nagarjunasagar project, which is constructed across the Krishna River at Nandikonda village, Peddavoora mandal, Nalgonda district, Telangana state. The net area irrigated under Nagarjuna Sagar Right Canal is 4.75 lakh ha. The location map of NSRC Command area is shown in Fig.1. Nagarjuna Sagar Right Canal command covers the 61 mandals of Guntur and Prakasam districts in the state of Andhra Pradesh. Out 61 mandals, 12 mandals are partially covered and 49 mandals are fully covered under NSRC command area. The NSRC command area covers 30 mandals of Guntur district and 19 mandals of Prakasam district.

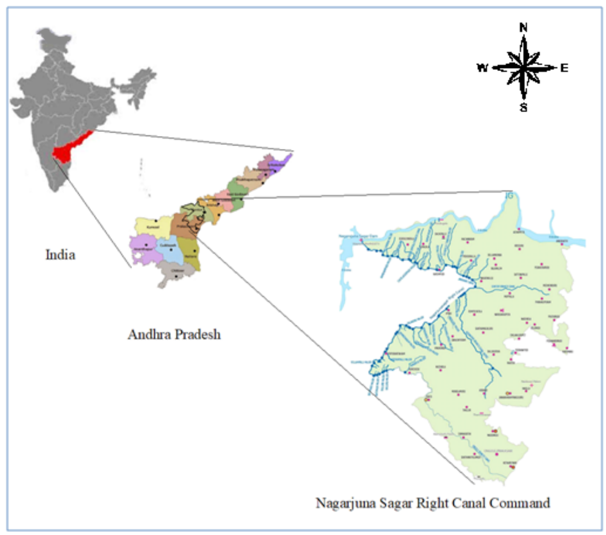

Fig. 1. Location map of the Nagarjuna Sagar Right Canal command

Groundwater modeling

For the present study, Visual MODFLOW 2.8.1 Package is used for simulation of groundwater levels in Nagarjunasagar Right Canal (NSRC) Command. The model domain was selected as 50 rows and 50 columns with three-layered aquifer system. In the model domain, the grids outside the study area were marked as inactive cells as shown in Fig. 2 and it shows the study area with active cells (white coloured cells) and inactive cells (gray coloured cells). Each cell represents 3.8 km x 3.5 km with an area of 1330 ha and the total number of active cells is 821 with an area of 10,91,930 ha which covers the whole study area of 10,85,857 ha. Prepared all input files of boundary conditions to simulate the groundwater dynamics of the study area. In NSRC command area, 39 number of observation wells data were used for the development of groundwater model.

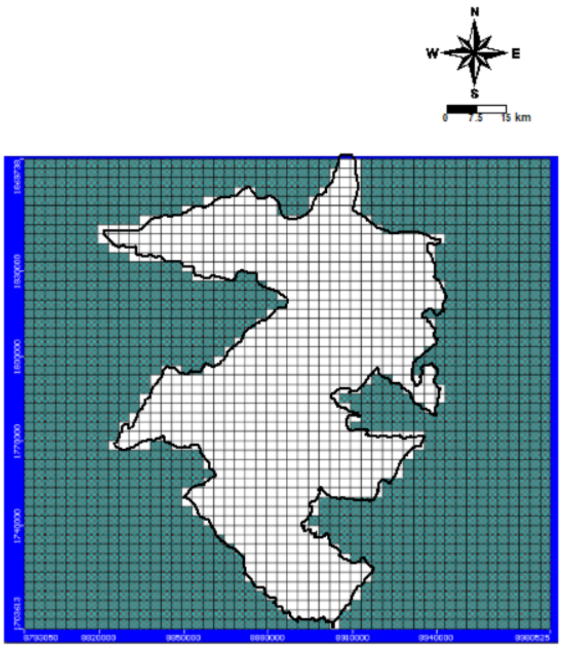

Fig. 2. Grid map of the study area showing inactive and active cells

Governing equations

In the present study, groundwater flow model was developed by using finite difference method with the help of Visual MODFLOW. The theoretical background of this model is presented here. The three-dimensional groundwater flow with constant density through aquifer may be explained by the following partial differential equation.

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]-W=S_s\frac{\partial h}{\partial t} \quad \text{.. (1)}$$

Where,

K_{xx}, K_{yy} & K_{zz} are values of hydraulic conductivity along the x, y and z coordinate axes which are assumed to be parallel to the major axes of hydraulic conductivity.

'h' is piezometric head. W is a volumetric flux per unit volume and represents sources and/or sinks of water.

S_s is the specific storage of the porous material.

't' is time.

Above Equation (Equation 1) describes groundwater flow under the non-equilibrium condition in a heterogeneous and anisotropic aquifer, with hydraulic conductivity along with the co-ordinate directions, i.e. x, y and z directions. The above equation can be explained about the groundwater flow through boundaries with the help of initial head condition and head conditions at the boundaries of the aquifer (McDonald and Harbaugh, 1988).

Modelling of Visual MODFLOW

In this study, groundwater model was used for Nagrajuna Sagar Right Canal Command using Visual MODFLOW. In the present study, a year considered from May to April of succeeding year which contains the monsoon and non-monsoon seasons. As per the groundwater department, the pre-monsoon season observations related to groundwater comes during May month and post-monsoon season observations come during November month of each year. This developed model was calibrated with groundwater heads from 2008-09 to 2012-13 and validated using groundwater heads from 2013-14 to 2016-17. After validation, the model was used to predict groundwater scenario due to future extractions. Predictions were made for the future with different recharge scenarios. The steps or processes involved in groundwater modelling are presented in Fig. 3.

Assignment of Aquifer Parameters

Aquifer properties such as hydraulic conductivity, transmissibility and storage properties of the study area are used for simulation of groundwater levels using Visual MODFLOW.

Boundary conditions

To run the model, at least one boundary condition is necessary for simulation. Initial head levels are provided in 'boundary' act as a reference for calculations. The boundary conditions of the study area like constant head, river head, canal, recharge and evapotranspiration (ET) are prepared and used as input for simulation of groundwater levels using Visual MODFLOW.

Model calibration and validation

The model was calibrated and validated with the historical data from 2008-09 to 2012-13 and 2013-14

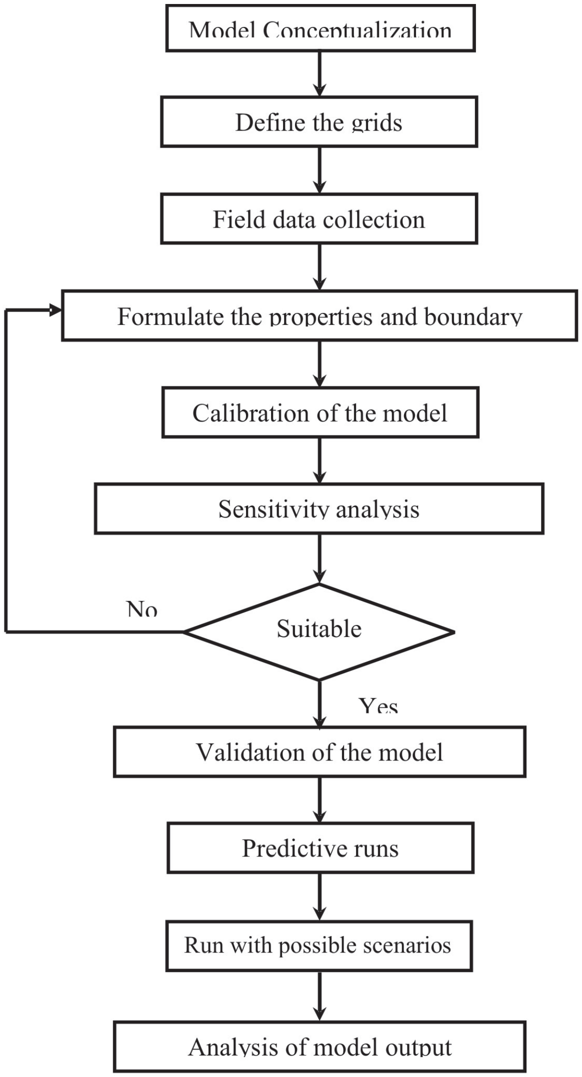

Fig. 3. Flow chart for groundwater modelling

to 2016-17 respectively. The calibration and validation of Visual MODFLOW 2.8.1 is carried out with acceptable statistical measures under steady state and transient condition of the groundwater flow. Sensitivity analysis of model was carried out and found that the model was very sensitive to groundwater recharge in the study area. The calibrated and validated Visual MODFLOW 2.8.1 is used for prediction of groundwater levels in Nagarjunasagar Right Canal Command in future based on the average climatic conditions with existed water management practices.

Model prediction

Using the validated model, groundwater dynamics in future have to be predicted with three scenarios of average, lowest and highest groundwater recharge during the study period. The evapotranspiration (ET) of the study area was estimated using the projected weather data for the years 2030 and 2040. Later validated model used to run for average, highest and lowest recharge during the study period were taken as input and simulated the groundwater dynamics for the years 2030 and 2040.

Forecasting weather data

Different weather generators models are available for forecasting the weather data. MarkSim developed by International Centre for Tropical Agriculture (CIAT) and it is a tool that generates simulated daily weather data specifically designed for use in the tropics, including rainfall, maximum and minimum temperatures and solar radiation. The weather data generated from the MarkSim® DSSAT weather file generator through Climate Change, Agriculture and Food security website: http://gismap.ciat.cgiar.org/MarkSimGCM/. In order to the estimation of the ET during 2030 and 2040, projected maximum and minimum temperatures were used to assess the reference evapotranspiration of the study area.

Results

Model prediction

The validated model can be used to simulate the futuristic aquifer response. In the present study, validated model was used to predict the future groundwater dynamics for the years 2030 and 2040 with average groundwater recharge, highest and lowest groundwater recharges during the study period. The model prediction was carried out the following steps.

Forecasting weather data

In the present study for prediction in future, the evapotranspiration was calculated during monsoon and non-monsoon seasons of 2030 and 2040 using the projecting climate change which affects the crop water requirement (ET_c). The future weather data were generated using online MarkSim DSSAT weather file generator. The generated maximum and minimum temperatures in the study area were depicted in Table 1 and observed an increase in temperatures from 2020 to 2040 with decadal increment in maximum temperature and minimum temperature were 0.34 ^{0}C and 0.40 ^{0}C respectively. The ET of the study area was calculated for the years 2030 and 2040 with projected weather parameters and presented in Table 2 and observed an average increase in estimated ET of the study area with a variation for 2030 and 2040 was 10.36 per cent and 11.29 per cent respectively. The estimated ET was used for the prediction of groundwater levels for the years 2030 and 2040.

Table 1. Projected maximum and minimum temperatures for the years 2030 and 2040

Year	Maximum temperature (^{0}C)	Minimum temperature (^{0}C)
2020	33.78	24.25
2030	34.10	24.64
2040	34.46	25.05

Recharge scenarios

In the present study, validated model was used to predict the future groundwater dynamics for the next 23 years, i.e. from 2017 to 2040 with average groundwater recharge, highest and lowest groundwater recharges during the study period. The highest and lowest groundwater recharge was observed during the years of 2010-11 and 2014-15 respectively. Recharge and evapotranspiration of 2010-11 and 2014-15 years were adopted for prediction run as highest and lowest recharge years. The average recharges and evapotranspiration were calculated. The average recharge during monsoon and non-monsoon seasons for Guntur district was estimated as 2.97 mm d^{-1} and 1.13 mm d^{-1} respectively. Similarly, the average recharge during monsoon and non-monsoon seasons for Prakasam district was estimated as 2.59 mm d^{-1} and 1.24 mm d^{-1} respectively.

Groundwater table fluctuations

The validated Visual MODFLOW used for forecast the groundwater levels for three different recharge scenarios with average, lowest and highest recharge conditions in the NRSC command area. The future groundwater levels were simulated at observation wells with 46 stress periods which equals to six months and observed that the simulated groundwater levels during post-monsoon period were higher than the pre-monsoon period because groundwater recharge from rainfall during monsoon season is high. Higher groundwater levels observed in the scenario with the highest recharge and lower groundwater levels observed in the scenario with the lowest recharge and it can be stated that the recharge increases the groundwater table. Graphical representations of the future simulated depth to water levels with different recharge scenarios were presented in Fig. 4 to Fig. 7.

Discussion

Groundwater fluctuations

The future weather data were generated using online MarkSim DSSAT weather file generator and observed the increase in temperatures from 2020 to 2040 with decadal increment in maximum temperature and minimum temperature were 0.34^{0}C and 0.40^{0}C respectively. Projected weather data for the years 2030 and 2040 will increase the ET of the study area with the declining trend of the groundwater table. The depth to groundwater table increases for the years 2030 and 2040. Higher groundwater levels observed in the scenario with the highest recharge and lower groundwater levels observed in the scenario with the lowest recharge and it can be stated that the recharge increases the groundwater table. Some researchers are also reported the same trend of the groundwater levels and discussed here. Kendy *et al.* (2003) also reported that the recharge from the rainfall influences the groundwater table

Table 2. Evapotranspiration (ET) of the study area for the years 2030 and 2040

Year	Time period	ET_c(mm per day)	Cropped area (ha)	ET_f(mm per day)	Forest area (ha)	ETo(mm per day)	Un-cultivated area (ha)	Average ET (mm per day)
2008 -2016	May to October	2.81	376571	1.96	101099	4.81	608187	3.83
	November to April	3.33	152986	1.62	101099	3.96	831771	3.65
2030	May to October	3.34	376571	2.12	101099	5.30	608187	4.33
	November to April	3.46	152986	1.71	101099	4.29	831771	3.93
2040	May to October	3.37	376571	2.14	101099	5.35	608187	4.37
	November to April	3.49	152986	1.73	101099	4.32	831771	3.96

and it increases with increasing rainfall. Bokar *et al.* (2012) studied the response of groundwater resources and reported the groundwater table condition depends on the rainfall. Neda *et al.* (2010) predicted the aquifer response using visual MODFLOW for different management scenarios and reported as a decrease of 2 m in groundwater level with a decrease of 40% of rainfall.

The groundwater levels are predicted with three different recharge scenarios such as average, lowest and highest recharge conditions for the years 2030 and 2040. The areal extent of depleted areas in future was analyzed using the simulated groundwater levels developed by the model. The projected ET with forecasted weather data was used for prediction of groundwater levels for the years 2030 and

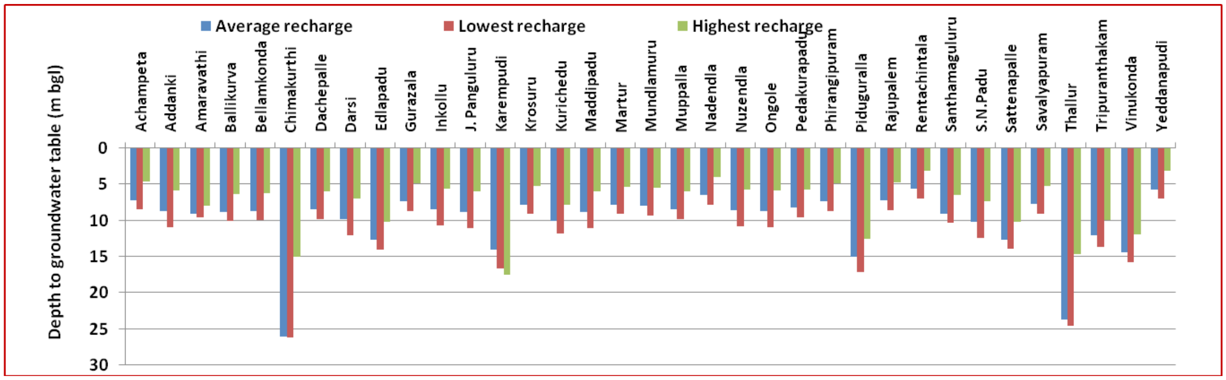

Fig. 4. Comparison of depth to groundwater during pre-monsoon 2030 with average, lowest and highest recharge scenarios

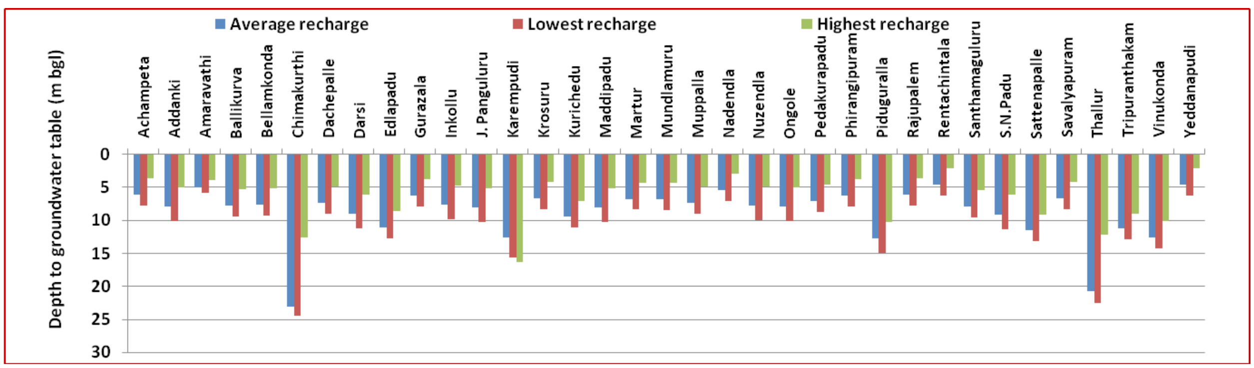

Fig. 5. Comparison of depth to groundwater during post-monsoon 2030 with average, lowest and highest recharge scenarios

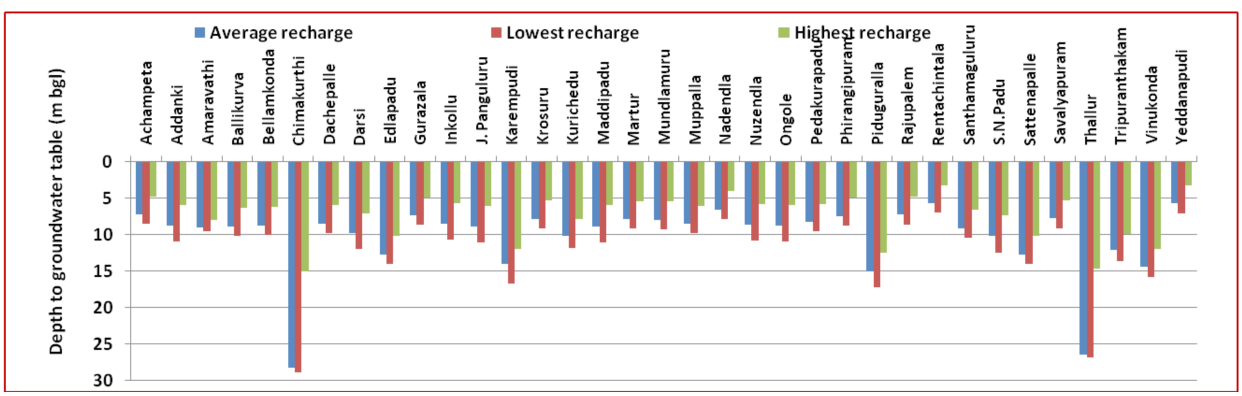

Fig. 6. Comparison of depth to groundwater during pre-monsoon 2040 with average, lowest and highest recharge scenarios

2040. Contour maps of groundwater fluctuations were prepared for pre-monsoon and post-monsoon seasons for the years 2030 and 2040 and presented through Fig.8 and Fig.9. The analysis of these contour maps stated that the declining trend observed in the whole study area with average and lowest recharge scenarios. But the increased groundwater levels were observed with the highest recharge scenario in the study area. The areal extent of the projected depleted areas with different falls was estimated for the years 2030 and 2040 and presented in Table 3.

Average recharge scenario

The declining of groundwater table from the year 2008 with more than 4 m fall was observed in the area of 8,07,376 ha (74.35 per cent) and 8,18,791 ha (75.41 per cent) in the study area during pre-monsoon of the years 2030 and 2040 respectively. Similarly, the groundwater fall more than 4 m observed in the area of 5,71,832 ha (52.66 per cent) and 5,80,768 ha (53.48 per cent) in the study area during post-monsoon of the years 2030 and 2040 respectively. This area is under risk with more falls in the groundwater table in the study area. The declining trend of groundwater table would be expected with average recharge in the study area during 2008 to 2040. The rise in the groundwater table would be expected in little extent with an area of 1,444 ha (0.13 per cent) and 1,301 ha (0.12 per cent) during post-monsoon of 2030 and 2040 respectively. The declining trend of groundwater table would be expected in the study area due to increased ET of the study area in future.

Lowest recharge scenario

The declining of groundwater table from the year 2008 with more than 4 m fall was observed in the area of 10,03,995 ha (92.46 per cent) and 10,06,830 ha (92.72 per cent) in the study area during pre-monsoon of the years 2030 and 2040 respectively. Similarly, the groundwater fall more than 4 m observed in the area of 7,78,623 ha (71.71 per cent) and 7,84,653 ha (72.26 per cent) in the study area during post-monsoon of the years 2030 and 2040 respectively. This area is under risk with more falls in the groundwater table in the study area. The declining trend of groundwater table would be expected with lowest recharge in the study area during 2008 to 2040. The rise in the groundwater table would be expected to little extent which is the negligible area with an area of 506 ha (0.05 per cent) and 434 ha (0.04 per cent) during post-monsoon of 2030 and 2040 respectively. The declining trend of groundwater table would be expected in the study area due to increased ET of the study area in future. The results revealed that the groundwater depleted area would be increase with the lowest recharge scenario in future.

Highest recharge scenario

The declining of groundwater table from the year 2008 with more than 4 m fall was observed in an area of 2,05,794 ha (18.95 per cent) and 2,18,971 ha (20.17 per cent) in the study area during pre-monsoon of the years 2030 and 2040 respectively. Similarly, the groundwater fall more than 4 m observed in an area of 2,16,937 ha (19.98 per cent) and 2,23,911 ha (20.62 per cent) in the study area during post-monsoon of the years 2030 and 2040 respectively. This area is under risk with more falls in the groundwater table in the study area. The declining trend of groundwater table observed in the area of 9,95,253

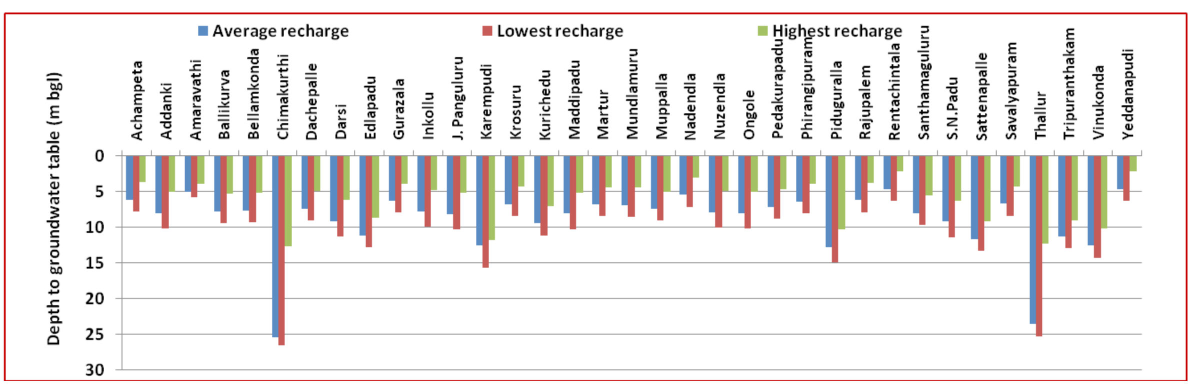

Fig. 7. Comparison of depth to groundwater during post-monsoon 2040 with average, lowest and highest recharge scenarios

Table 3. Areal distribution of depleted areas of the study area during the years of 2030 and 2040 compared with the year 2008

(all areas in ha)

Year	Season	> - 4 m Fall	-2 to -4 m Fall	0 to -2 m Fall	0-2 m Rise	2-4 m Rise	> 4 m Rise	Total geographical area
Average recharge scenario								
2030	Pre-monsoon	807376(74.35)	213139(19.63)	33021(3.04)	32320(2.98)	0(0.00)	0(0.00)	1085857(100.00)
	Post-monsoon	571832(52.66)	282870(26.05)	178474(16.44)	51237(4.72)	1444(0.13)	0(0.00)	1085857(100.00)
2040	Pre-monsoon	818791(75.41)	202714(18.67)	32129(2.96)	32222(2.97)	0(0.00)	0(0.00)	1085857(100.00)
	Post-monsoon	580768(53.48)	282713(26.04)	174169(16.04)	46906(4.32)	1301(0.12)	0(0.00)	1085857(100.00)
Lowest recharge scenario								
2030	Pre-monsoon	1003995(92.46)	56029(5.16)	25555(2.35)	0(0.00)	0(0.00)	0(0.00)	1085857(100.00)
	Post-monsoon	778623(71.71)	223899(20.62)	82363(7.59)	506(0.05)	0(0.00)	0(0.00)	1085857(100.00)
2040	Pre-monsoon	1006830(92.72)	53994(4.97)	24649(2.27)	0(0.00)	0(0.00)	0(0.00)	1085857(100.00)
	Post-monsoon	784653(72.26)	220894(20.34)	79274(7.30)	434(0.04)	0(0.00)	0(0.00)	1085857(100.00)
Highest recharge scenario								
2030	Pre-monsoon	205794(18.95)	521125(47.99)	268334(24.71)	51087(4.70)	30394(2.80)	10336(0.85)	1085857(100.00)
	Post-monsoon	216937(19.98)	282641(26.03)	280943(25.87)	209340(19.28)	88745(8.17)	7487(0.69)	1085857(100.00)
2040	Pre-monsoon	218971(20.17)	523385(48.20)	261468(24.08)	43201(3.98)	31304(2.88)	8633(0.80)	1085857(100.00)
	Post-monsoon	223911(20.62)	285055(26.25)	281696(25.94)	203850(18.77)	84741(7.80)	6705(0.62)	1085857(100.00)

* Percentage of area in brackets

ha (91.65 per cent) and 10,03,824 ha (92.45 per cent) during pre-monsoon of 2030 and 2040 respectively. Similarly, the fall in groundwater table observed in an area of 7,80,521 ha (71.88 per cent) and 7,90,662 ha (72.82 per cent) during post-monsoon of 2030 and 2040 respectively. The rise in the groundwater table observed in an area of 90,604 ha (8.35 per cent) and 82,033 ha (7.55 per cent) during pre-monsoon of 2030 and 2040 respectively. Similarly, the rise in the groundwater table observed in an area of 3,05,572 ha (28.14 per cent) and 2,95,296 ha (27.19 per cent) during post-monsoon of 2030 and 2040 respectively. The rise in the groundwater table would be expected in the areas located nearby the Bay of Bengal due to sea water intrusion into the study area and nearby the river due to the inflow of river water into the study area. Similar way the declining trend of the groundwater table would be expected in the more area of study area due to the ET of the study area in future. The groundwater table rise would be increased in some areas due to the more recharge areas occurred in the low elevated areas.

The results revealed that the groundwater depleted area would be decrease with the highest recharge scenario in future. The deeper groundwater table would be expected in future at Chimakurthy and Thalluru villages of Prakasam district and Karempudi and Piduguralla villages of Guntur district in the study area. This condition may be due to the excess utilization of groundwater which is less than the groundwater recharge in particular villages. The construction of rainwater harvesting structures for artificial groundwater recharge in those areas should be carried out immediately.

Acknowledgement

Authors are thankful to Groundwater Department, Irrigation Department and the Bureau of Economics and Statistics Department for providing the data. Authors are also thankful to Dr NTR College of Agricultural Engineering, Bapatla, 522 101; Agricultural College, Bapatla, 522 101; Acharya N.G. Ranga Agricultural University, Lam, Guntur, 522 034, India.

References

Bokar, H., Mariko, A., Bamba, F., Diallo, D., Kamagate,

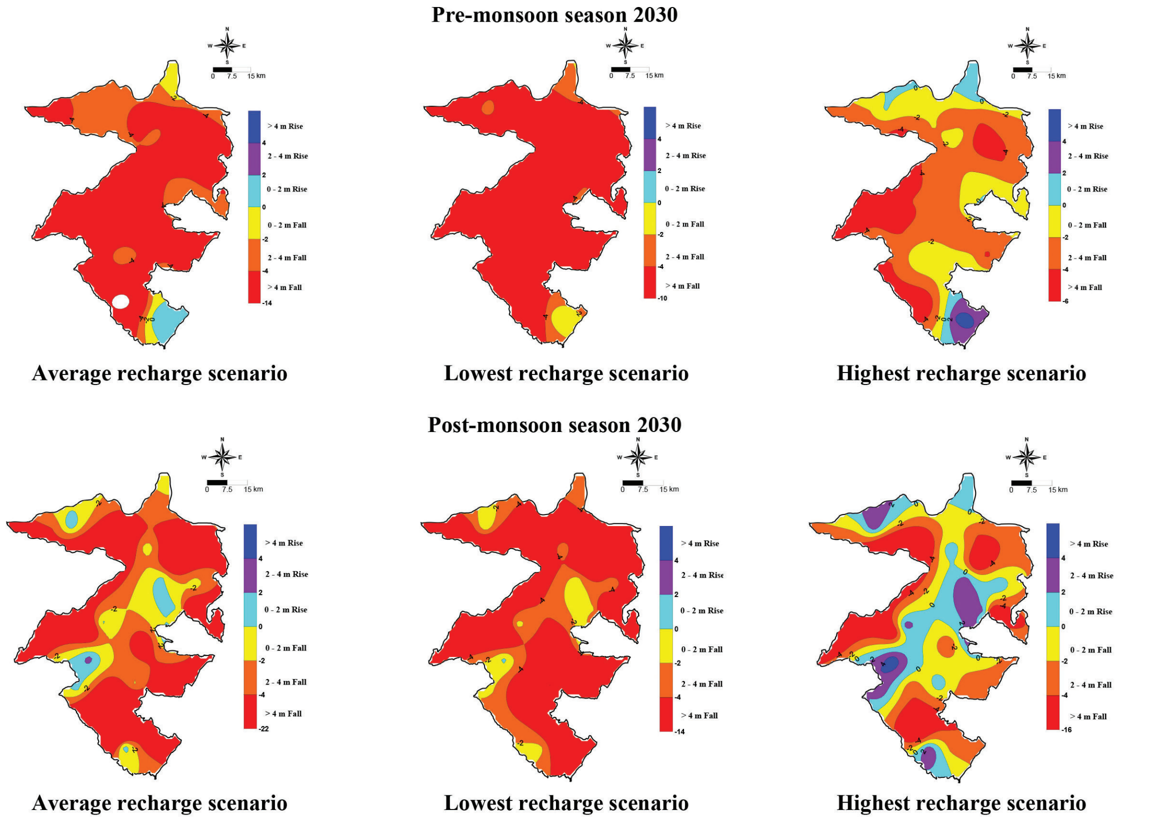

Fig. 8. Groundwater fluctuations in study area during pre and post monsoons from 2008 to 2030 Pre-monsoon season 2040

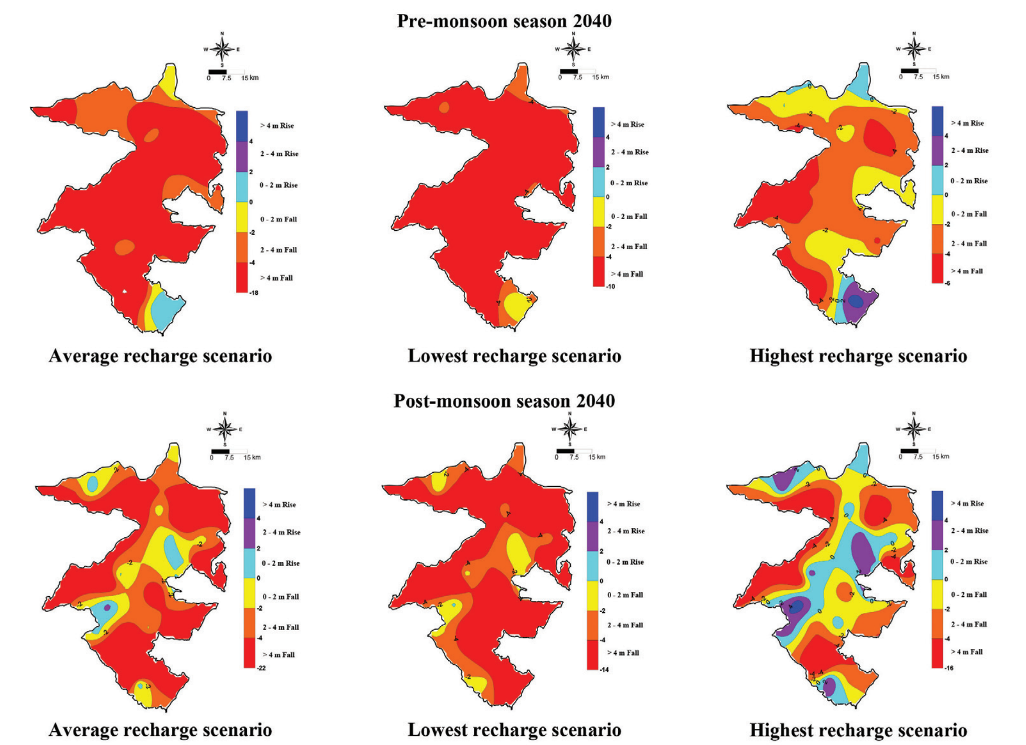

Fig. 9. Groundwater fluctuations in the study area during pre and post monsoons from 2008 to 2040

B., Dao, A., Soumare, O. and Kassogue, P. 2012. Impact of climate variability on groundwater resources in Kolondieba catchment basin, Sudanese climate zone in Mali. *International Journal of Engineering Research and Applications.* 2(5): 1201-1210.

Kendy, E., Marchant, P.G., Walter, M.T., Zhang, Y., Liu, C. and Steenhuis, T.S. 2003. A soil-water-balance approach to quantify groundwater recharge from irrigated cropland in the North China Plain. *Hydrological Processes*. 17: 2011–2031.

Matthew, J.K., Adrian, W.D. and Daan, H. 2015. Quantifying climate and pumping contributions to aquifer depletion using a highly parameterised groundwater model: Uley South Basin (South Australia). *Journal of Hydrology.* 523 : 515-530.

McDonald, M. and Harbaugh, A.W. 1988. *A Modular Three-Dimensional Finite Difference Ground-Water Flow Model: U.S. Geological Survey Techniques of Water-Resources Investigations*. U.S. Government Publishing Office, Washington. p. 1- 586.

Mondal, N.C. and Singh, V.S. 2009. Mass transport modeling of an industrial belt using visual MODFLOW and MODPATH: A case study. *Journal of Geography and Regional Planning*. 2(1): 001-019.

Neda, F., Fereydoon, K. and Hossein, B. 2010. Prediction of aquifer reaction to different hydrological and management scenarios using visual modflow model-case study of Qazvin plain. *Journal of Water Sciences Research.* 2(1): 39-45.