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SENSITIVITY ANALYSIS OF MODFLOW USED FOR THE SIMULATION OF GROUND WATERTABLE FLUCTUATIONS

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Abstract- We conducted a Sensitivity Analysis of MODFLOW used for the simulation of ground water table fluctuations. Sensitivity analysis involves varying model input parameters and evaluating how model results change with these variations. The study was undertaken in the Krishna western delta to compute the simulation of groundwater table fluctuations using MODFLOW. Water balance study was used for estimation of net groundwater recharge. Simulation of ground water table fluctuations was done for the year 2010 for increased and decreased recharge for both pre and post monsoon seasons. In case of decreased recharge, simulation was done without considering the canal. Groundwater model can play an important role in conducting such studies and analyze the future scenarios. The study area KWD (Krishna Western Delta) is covered between 15^o 32´ N latitude to 16^0 34´ N latitude and 80^0 09´ longitudes to 80^0 55´ E longitude. Sensitivity analysis was conducted by decreasing and increasing recharge component by 10%, 20%, 30%, 40% and 50% to study the sensitivity of the model to recharge. The model MODFLOW is found sensitive to recharge component with an index value ranging from 0.59 to 0.66 for 10, 30, 40 and 50% decrease of recharge and found very less sensitive to 20% with an index of 0.25, from which it can be inferred that an initial decrease of 10% increment after initial 10% reduction did not cause much change in the process of aquifer recharge. For the same temporal limits, if the recharge gets decreased by 20% and henceforth 10% resulted in much sensitivity of the model till 50% reduction.

Keywords- Krishna Western Delta, MODFLOW, Simulation, Sensitivity Analysis.

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Introduction

Groundwater represents one of the most important water sources in India and accounts for over 400 km^3 of the annual utilizable resource in the country. Due to the highly variable nature of the climate, groundwater has become a popular alternative for irrigation and domestic water use across India. Reliance on groundwater resources is particularly strong where dry season surface water levels are low or where wet season flows are too disruptive to be easily tapped. In addition to being accessible, groundwater quality is generally excellent in most areas and presents a relatively safe source of drinking water for Indians in rural and urban centers (www.india.gov.in).

Groundwater model can play an important role in conducting such studies and analyze the future scenarios. Groundwater models can reproduce the most important features of an actual system with a mathematical representation. If constructed correctly, the models represent the complex relations among the inflows, outflows, change in storage, and movement of water in the groundwater system and possibly other important features, Models can be used to estimate the response of the system to various development options and provide insight into appropriate management strategies. However, while using the model, one must remember that computer models are reproduction of the actual system. Judgment of water management professional is required to evaluate model simulation results and plan appropriate actions.

Sensitivity analysis involves varying model input parameters and evaluating how model results change with these variations. Usually sensitivity analysis was performed with respect to four types of parameters: field and state parameters, parameters related to boundary conditions, decision parameters, and parameters related to the numerical algorithm. Examples of field parameters for groundwater modeling include viscosity, transmissivity, conductivity, dispersivity, density, heat capacity, chemical absorption, and reaction rates. State variables include pressure, velocity, and concentration. Boundary conditions parameters are state variables that are specified along the boundary of the area of interest and include pressure, velocity, and concentration.

Sensitivity analysis requires accurate estimates of the derivatives of the model output with respect to the uncertain parameters. The Modular Three- Dimensional Finite-Difference Ground-Water Flow Model (MODFLOW) was used herein to demonstrate the utilization of the methodology in groundwater applications. Among the available codes for numerical estimation of model sensitivities, the authors arbitrarily chose to use the Model-Independent Parameter to demonstrate the use of sensitivity analysis with respect to operation decision parameters such as decreasing and increasing recharge component.

Materials and Methods

Geographical location

The Krishna Delta Irrigation system is one of the earliest major irrigation projects in Southern India. The study area KWD (Krishna Western Delta) is covered between 15^o 32´ N latitude to 16^0 34´ N latitude and 80^0 09´ longitude to 80^0 55´ E longitude. It consists of an ayacut on the river Krishna at the present Barrage site near Vijayawada, Krishna District. The KWD covers 24 mandals (2, 10,000 ha) in Guntur district and 7 mandals (32,000 ha) in Prakasam district in the state of Andhra Pradesh. The location map of Krishna Western Delta is given in [Fig-1].

Sensitivity analysis of the model

Sensitivity analysis involves varying model input parameters and evaluating how model results change with these variations. Sensitivity analysis provides valuable understanding of both model implementation and the underlying physical processes thus providing insight into both system and model behavior. Furthermore, results from sensitivity analyses can guide both model calibration and the prioritization of future data collection plans.

If a computer model is used to simulate some complex process, it is of great interest for both the programmer and the user to make a sensitivity analysis of the system and the program. The sensitivity analysis is also important for verification of the model. Sensitivity analysis usually means that the change in the result owing to changes in the input is investigated. Such an investigation has several important benefits. i) First, the correctness of expert predictions may be tested. ii) Second, unimportant variables or unnecessary model complexity may be revealed. iii) Third, the input data may be ranked with respect to their influence on the result.

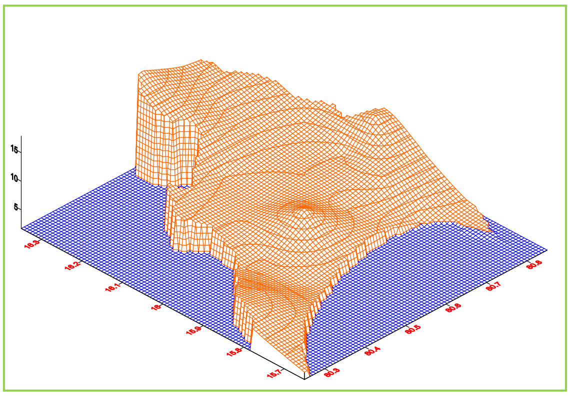

Fig-1 Digital Elevation Model of Krishna Western Delta

Groundwater model can play an important role in conducting such studies and analyze the future scenarios. A linear sensitivity analysis was performed to determine the parameters that were most effective in changing the model output and required careful consideration during simulation. The sensitivity analysis was very useful in ascertaining the significant parameters.

This is analyzed by estimating the value of Relative Sensitivity Index (Sr) of individual parameters.

The Relative sensitivity index (Sr) of the any parameter is estimated by using the following relation.

$$Sr = \frac{(b_2 - b_1)/(b_2 + b_1)}{(p_2 - p_1)/(p_2 + p_1)}$$

In which,

P_1 and p_2 are the possible low and high extreme parameter values under field condition, b_1 and b_2 are the corresponding model outputs.

The value of *Sr* is far from 0 indicates *high sensitivity*, and close to 0 indicates *less sensitivity*.

Results and Discussion

Sensitivity analysis perform with respect to four types of parameters: field and state parameters, parameters related to boundary conditions, decision parameters, and parameters related to the numerical algorithm. Examples of field parameters for groundwater modeling include viscosity, transmissivity, conductivity, dispersivity, density, heat capacity, chemical absorption, and reaction rates. State variables include pressure, velocity, and concentration. Boundary conditions parameters are state variables that are specified along the boundary of the area of interest and include pressure, velocity, and concentration. Decision parameters include allocation of resources to maximize or minimize system output, subject to given constrains. Examples of decision parameters in groundwater modeling include pumping and injection rates, drain elevation, drain conductance, etc., Optimization of the decision parameters results in maximum utilization and preservation of the aquifer. Grid spacing is an example of a numerical model parameter. This work presents, as an example, sensitivity of an independent variable with respect to with increased and decreased groundwater recharge.

Simulation of water table fluctuations was done for the year 2010 for increased and decreased recharge by using the MODFLOW. In case of decreased recharge, simulation was done without considering the canal. Sensitivity analysis for recharge was performed for several input parameters; namely hydraulic conductivity, storage coefficient, transmissivity, pumping rate and specific yield. [Table-1&2] shows the detailed sensitivity analysis of the model under increase and decrease of the average annual recharge.

Decreasing recharge by 10%, 20%, 30%, 40% and 50% in KWD area

This was carried out for the year 2010 by reducing the original recharge component of the year by the corresponding proportions like 10%, 20%, 30%, 40% and 50% for both the pre-monsoon and post monsoon periods. The results were presented through the [Fig-2&3]. The sensitivity index was calculated based on the sensitivity analysis, to study the sensitivity of the model MODFLOW to a parameter.

The minimum input, maximum input and minimum output and maximum output values were considered for calculation of sensitivity index, which ranges between 0 to 1. The model MODFLOW is found sensitive to recharge component with an index value ranging from 0.59 to 0.66 for 10, 30, 40 and 50% decrease of recharge and found very less sensitive to 20% with an index of 0.25, from which it can be inferred that an initial decrease of 10% increment after initial 10% reduction did not cause much change in the process of aquifer recharge. For the same temporal limits, if the recharge gets decreased by 20% and henceforth 10% resulted in much sensitivity of the model till 50% reduction. The statistical analysis results were presented through [Table-1]. Between pre-monsoon and post-monsoon prediction, the post-monsoon period prediction with decreased recharge is found more sensitive with a sensitivity index of 0.63 to 0.66.

Table-1 *The sensitivity index of the model MODFLOW for decreased recharge by 10 to 50% on 2010*

Recharge decreased by		Minimum Input Value (p1)	Maximum Input Value p2	Minimum Output Value (b1)	Maximum Output Value (b2)	Sensitivity Index (Sr)
10%	pre	-7.93	11.5	-6.27621	11.98464	0.59
	post	-3.31	12.35	-0.49855	11.84079	0.63
20%	pre	-7.93	11.5	-1.7321	11.92195	0.25
	post	-3.31	12.35	-0.56269	11.77795	0.64
30%	pre	-7.93	11.5	-6.40634	11.85927	0.62
	post	-3.31	12.35	-0.62682	11.71511	0.64
40%	pre	-7.93	11.5	-6.47142	11.79658	0.63
	post	-3.31	12.35	-0.69096	11.65227	0.65
50%	pre	-7.93	11.5	-6.53652	11.73376	0.65
	post	-3.31	12.35	-0.75511	11.58943	0.66

Table-2 *Recharge increased by 10 to 50 % on 2010 Pre and Post Monsoon*

Recharge Increased by		Minimum Input Value(p1)	Maximum Input Value p2	Minimum Output Value (b1)	Maximum Output Value (b2)	Sensitivity Index (Sr)
10%	pre	-7.93	11.5	-6.14606	12.11	0.56
	post	-3.31	12.35	-0.3703	11.96647	0.61
20%	pre	-7.93	11.5	-6.081	12.17269	0.55
	post	-3.31	12.35	-0.30618	12.02931	0.61
30%	pre	-7.93	11.5	-6.01595	12.23537	0.54
	post	-3.31	12.35	-0.24206	12.09215	0.60
40%	pre	-7.93	11.5	-5.9509	12.29805	0.53
	post	-3.31	12.35	-0.24206	12.09215	0.60
50%	pre	-7.93	11.5	-5.88585	12.36072	0.52
	post	-3.31	12.35	-0.11388	12.21762	0.59

Increasing recharge by 10%, 20%, 30%, 40% and 50% in KWD area
The model MODFLOW was subjected to sensitivity analysis to increased recharge and found to have sensitivity index value ranging from 0.52 to 0.61, from which it can be inferred that the model is much sensitive to increased recharge change in the process of aquifer recharge. For the same temporal limits, if the recharge gets decreased by 20% and henceforth 10% resulted in much sensitivity of the model till 50% reduction. The statistical analysis results were presented through [Table-2]. Between pre-monsoon and post-monsoon prediction, the post-monsoon period prediction with increased recharge is found more sensitive with a sensitivity index of 0.59 to 0.61 where as for pre-monsoon, it is 0.52 to 0.56.

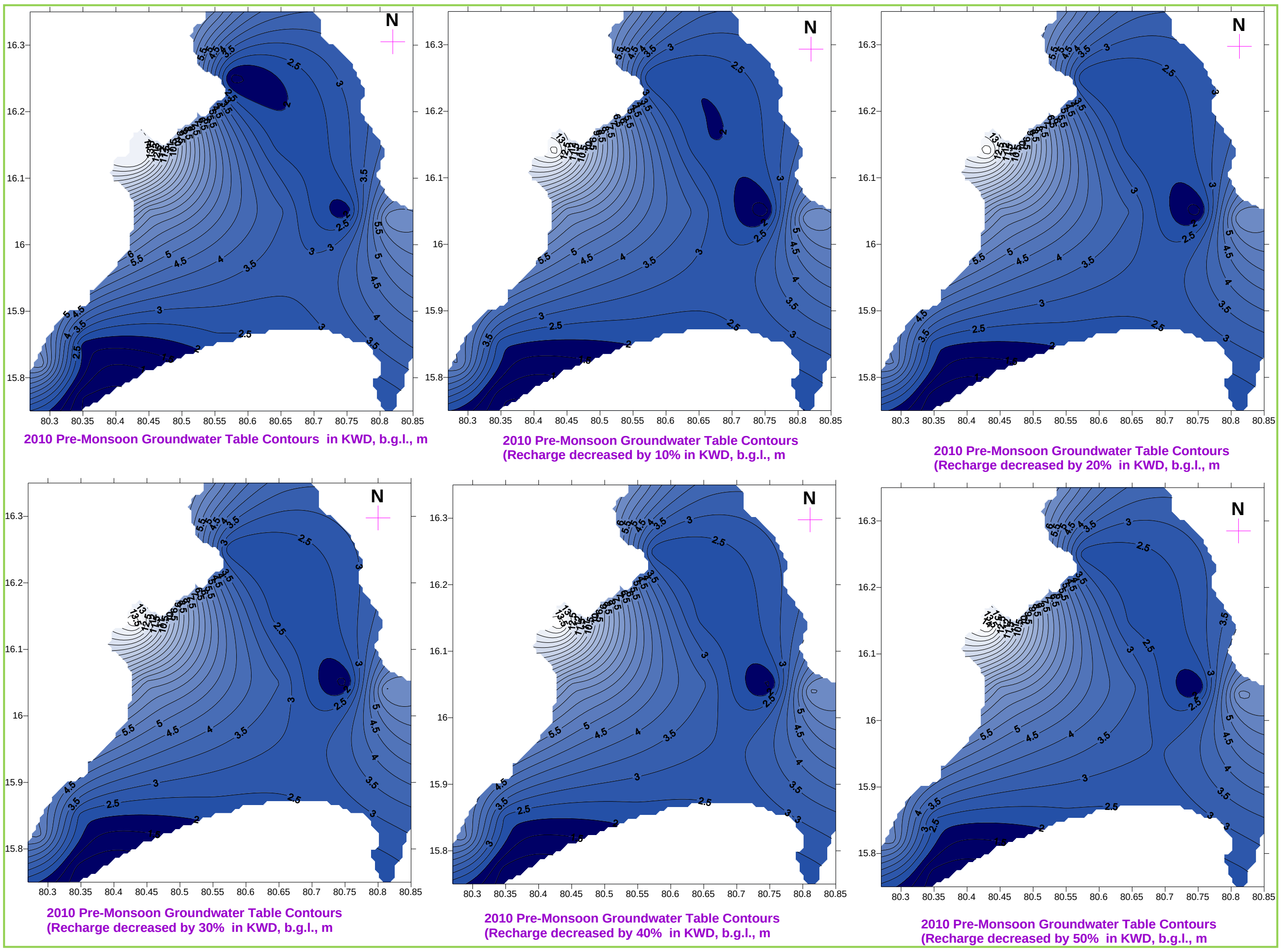

Fig-2 Change in groundwater table contours (b.g.l., m) of Krishna Western Delta in the year 2010 (Pre Monsoon) due to decrease in recharge by 10 to 50 % (Dark Region refers to waterlogged area).

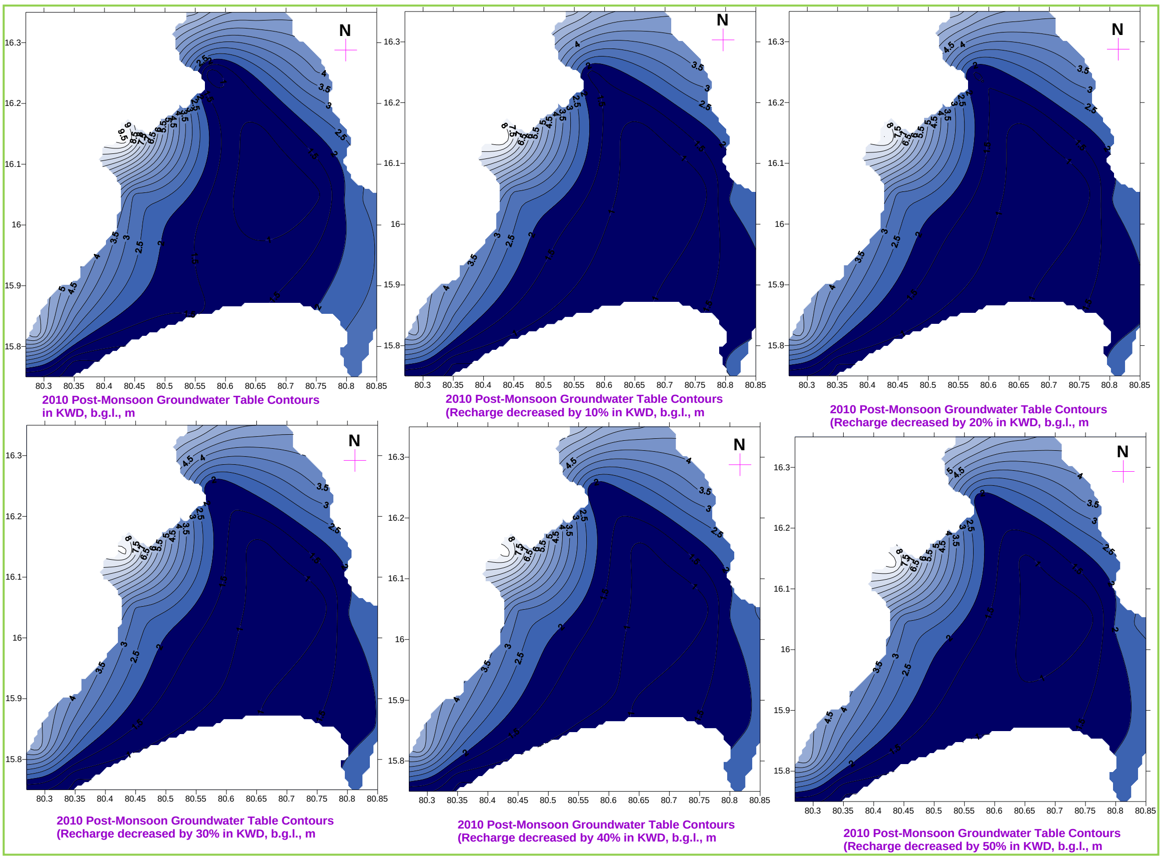

Fig-3 The change in groundwater table contours (b.gl., m) of Krishna Western Delta in the year 2010 (Post Monsoon) due to decrease in recharge by 10 to 50 % (Dark Region refers to waterlogged area)

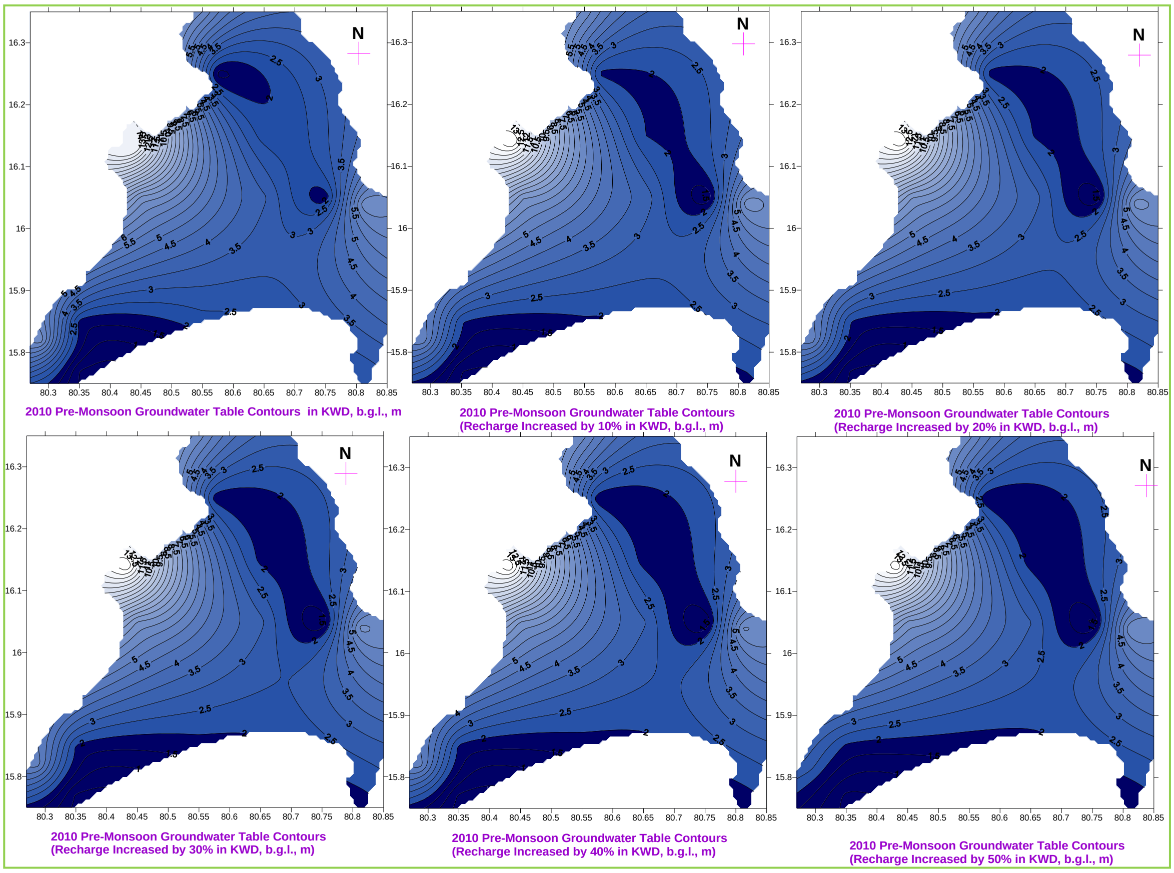

Fig-3 The change in groundwater table contours (b.g.l., m) of Krishna Western Delta in the year 2010(Pre Monsoon) due to increase in recharge by 10 to 50 % (Dark Region refers to waterlogged area).

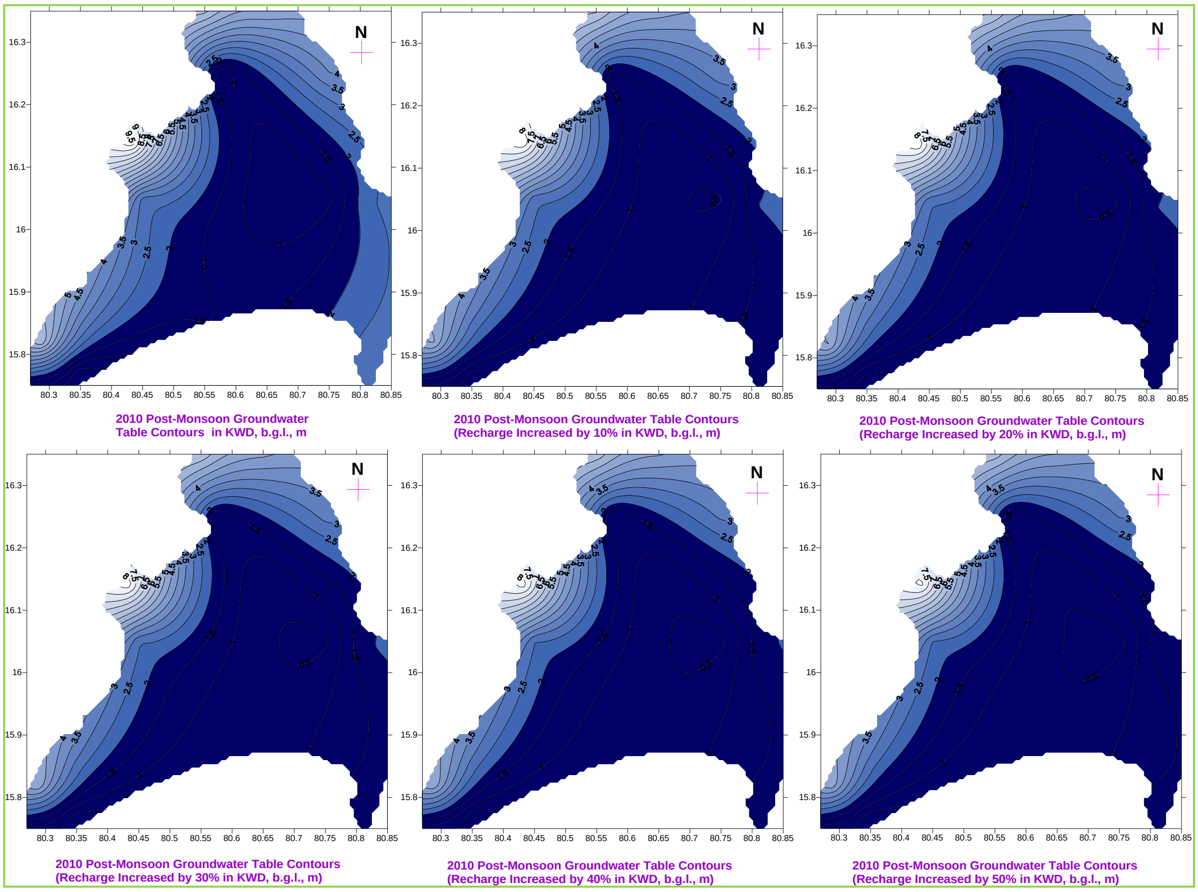

Fig-4 The change in groundwater table contours (b.g.l., m) of Krishna Western Delta in the year 2010 (Post Monsoon) due to increase in recharge by 10 to 50 % (Dark Region refers to waterlogged area).

Conclusion

Groundwater table fluctuations for the years 2010 were simulated using MODFLOW. The results of the model were in close agreement with the observed groundwater table fluctuations. The sensitivity analysis was carried out with increased recharge i.e., by increasing the recharge by 10%, 20%, 30%, 40% and 50% for the year 2010 and was continued with decreased recharge by 10%, 20%, 30%, 40% and 50% for the year 2010.

The presented work illustrates the great promise offered by automatic differentiation for analytically computing derivatives. The results of this work demonstrated that analytical calculations are more accurate, take less time to compute, and their values are not functions of the size of perturbations the analyst has chosen to use, or the method of differentiation. As a result, automatic differentiation provides great benefits for sensitivity analysis.

The model MODFLOW is found sensitive to recharge component with an index value ranging from 0.59 to 0.66 for 10, 30, 40 and 50% decrease of recharge and found very less sensitive to 20% with an index of 0.25, from which it can be inferred that an initial decrease of 10% increment after initial 10% reduction did not cause much change in the process of aquifer recharge. For the same temporal limits, if the recharge gets decreased by 20% and henceforth 10% resulted in much sensitivity of the model till 50% reduction. Between pre-monsoon and post-monsoon prediction, the post-monsoon period prediction with decreased recharge is found more sensitive with a sensitivity index of 0.63 to 0.66.

The model MODFLOW was subjected to sensitivity analysis to increased recharge and found to have sensitivity index value ranging from 0.52 to 0.61, from which it can be inferred that the model is much sensitive to increased recharge in the process of aquifer recharge. Between pre-monsoon and post-monsoon prediction, the post-monsoon period prediction with increased recharge is found more sensitive with a sensitivity index of 0.59 to 0.61.

References

[1] Abu-El-Shar W.Y and Hatamleh R.I. (2007) *Jordan Journal of Civil Engineering*, 1(2),153-172.

[2] Ahmed I. and Umar R. (2009) *Journal of Earth System and Science*, 118(5), 507–523.

[3] Arora A.N. and Goyal R. (2012) *Journal of Hydraulic Engineering*, 18(1), 45-53.

[4] Bisht D.C.S. Raju M.M. and Joshi M.C. (2009) *Computer Modelling and New Technologies*, 13(2), 16–23.

[5] CGWB (1994) *Ground Water Resource of India, Central Ground Water Board, Ministry of Water Resources, Govt.of India, Faridabad.*

[6] CGWB (2007) *Ground Water Information Book Prakasam District (2004-2005). Central Ground Water Board, Ministry of Water Resources, Govt.of India, Faridabad*.

[7] CGWB (2007) *Ground Water Information Book Guntur District (2004-2005). Central Ground Water Board, Ministry of Water Resources, Govt.of India, Faridabad*.

[8] Cho J., Barone V.A. and Mostaghimi S. (2009) *Agricultural Water Management*, 96, 1-11.

[9] Langevin C.D. (2003) *Ground water*, 41(6),758-771.

[10] Lee H.W., Chen P.W. and Lee H.R. (2006) *Environmental Geology*, 51, 73–82.

[11] Dwivedi R.S., Sreenivas K. and Ramana K.V. (1999) *International Journal of Remote Sensing*, 20(8),1589-1599.

[12] FAO (1998) *Crop Evapotranspiration: Guidelines for computing crop water Requirements., FAO irrigation and Drainage paper* 56: 57 – 139.

[13] GEC (2009) *Ground water resource estimation methodology, Report, Ministry of water resources. Government of India, New Delhi, India*.

[14] Hill M.C., (1992) *A computer program (MODFLOWP) for estimating*

parameters of a transient, three-dimensional, ground-water flow model using nonlinear regression, U.S. Geological Survey Open-File Report 91.
[15] Jyrkama M.I., and Sykes J.F. (2006) *Water Resources Research,* 42,1-11.
[16] Koirala S., Yamada H.G., Yeh P.J.F., Oki T., Hirabayashi Y. and Kanae S. (2012) *Journal of Japan Society of Civil Engineers*, 68(4), 211-216.
[17] Kushwaha, R.K., Pandit M.K. and Goyal R. (2009) *Journal Geological Society of India*, 74, 449-458.
[18] Martins J.R.R.A., Ilan Kroo, and Juan J. and Alonso (2000) *An Automated Method for Sensitivity Analysis Using Complex Variables*, *AIAA*-2000-0689.
[19] Michael A.M. and Ojha T.P. (1999) *Principles of Agricultural Engineering, Volume II. Jain Brothers, New Delhi*, pp: 462 – 463.
[20] Murthy V.V.N. (1998) *Land and Water Management Engineering, Kalyani publishers. New Delhi, India*.
[21] Njamnsi N.Y. and Mbue N.I. (2009) *Journal of American Science*, 5(2), 83-90.
[22] Park C.K., Park K.J., Lee K.S., Bae D.S., and Cho H.J., Development of an Efficient Algorithm for Dynamic and Design Sensitivity Analysis of Railway Vehicle Systems.
[23] Safavi H.R., Darzi F. and Marino M.A. (2010) *Water Resource Management*, 24,1965–1988.
[24] *Sambaiah A., Singh D.K., Bhattacharya A.K. and Singh A.K. (2004) Journal of Agricultural Engineering,* 41(2),130-145.
[25] Singh J. and Kumar R. (1982) *Groundwater simulation model for a shallow water table aquifer. Improvements of methods of long term prediction of Variations in Groundwater Resources and Regimes Due to Human Activity.* 136:233-240.
[26] Takounjou A.F., Gurunadha Rao V.V.S., Ngoupayou J.N., Nkamdjou L.S. and Ekodeck G.E. (2009) *African Journal of Environmental Science and Technology,* 3(10), 341-352.
[27] Van asch TH.W.J. and Buma J.T. (1997) *Earth Surface Processes and Landforms*, 22, 131–14.
[28] Varni M.R. and Usunoff E.J. (1998) *Hydrogeology Journal*, 7,180–187.
[29] Vircavs V. and Veinbergs A. (2010) *International Workshop advances in Statistical Hydrology*, 23, 1-5.
[30] Weiss, R., Shurpali,N.J., Sallantaus, T., Laiho, R., Laine, J. and Alm,J. 2006. Simulation of water table level and peat temperatures in boreal peatlands. *Ecological Modelling*. 192: 441–456.
[31] Xunhong, Chen and Xi Chen (2003) *Journal of Hydrology,* 284, 270–284.
[32] Yeh F.H., Lee H.C., Chen F.J. and Chen P.W. (2007) *Water Resources, 34(2),153-162.*