Eco. Env. & Cons. 29 (January Suppl. Issue) : 2023; pp. (S391-S397)
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ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2023.v29i01s.060

Modelling Impact of Cropping Pattern and Urban area on Groundwater Resourses of Nagarjuna Sagar Right Canal Command area using Visual Modflow

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(Received 22 June, 2022; Accepted 17 August, 2022)

ABSTRACT

Groundwater models can be used for the assessment of the impact of the different cropping pattern and change in urban area on groundwater resource and modeling is the best tool to optimize the different combinations or scenarios and to select the best combination or scenario for management of sustainable groundwater resources. In this study, three-dimensional finite-difference groundwater model Visual MODFLOW 2.8.1 was used to simulate the groundwater dynamics in Nagarjuna Sagar Right Canal Command area. The net area irrigated under Nagarjuna Sagar Right Canal is 4.75 lakh ha. Calibration and validation of the model has been carried out and used to predict the static groundwater storage availability in the study area for different cropping pattern scenarios and change in the urban area. The validated Visual MODFLOW 2.8.1 was used to simulate the groundwater dynamics in the study area for the years 2030 and 2040 with different cropping pattern scenarios and change in the urban area. Global climate model MarkSim, which is developed by the International Centre for Tropical Agriculture (CIAT) was used to generate future weather data for the years 2030 and 2040. The impact of change in cropping pattern on storage of static groundwater resource in the study area for the years 2030 and 2040 was assessed with two scenarios of change in rice cropped area decreased by 50 per cent and 100 per cent with this cropped area cultivated equally by the ID crops. These results showed that the lesser storage of static groundwater resources in future lesser. The change in the cropping pattern affects the net recharge of the groundwater which influences the groundwater levels. Increase in paddy area increases the recharge and rise in groundwater level has been identified. In the study area, cropping pattern could be changed from rice crop to other irrigated dry crops to prevent the increase of groundwater resources which leads the water logging condition in the study area. The urbanization is one of the most significant factor considering for assessment of the response on the groundwater levels and availability of static groundwater resources. The groundwater recharge is very less in case of increase in urban area and generates more runoff rather than the intake of rainfall in the ground surface as having the impervious nature. In view of increase in urban area in the study area, the four scenarios are proposed with the combination of 10 per cent and 20 per cent decrease in recharge and 50 per cent and 100 per cent increase in groundwater draft and simulated the groundwater fluctuations for the years 2030 and 2040. The impact of change in the urban area on storage of available static groundwater resource in the study area for the years 2030 and 2040 was assessed with four scenarios combination of groundwater recharge and groundwater pumping. The storage of static groundwater resources would be expected in future lesser than the present storage of static groundwater resources in all scenarios due to increase in urban area as increased in impervious nature of the ground surface. The decline in available static groundwater resources would be expected 6.38 per cent and 7.08 per cent during 2030 and 2040 respectively. The rapid expansion in the urban area and their settlements is also one of the reasons for the depletion of groundwater resources with low recharge and high groundwater draft.

Key words : *Groundwater modeling, Nagarjuna Sagar Right Canal Command area, Static groundwater storage, Visual MODFLOW, Change in cropping pattern and urban area.*

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. 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 has 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. Visual MODFLOW is one of the user friendly and the best groundwater model available. The calibrated and validated Visual MODFLOW 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 Nagarjuna Sagar 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.

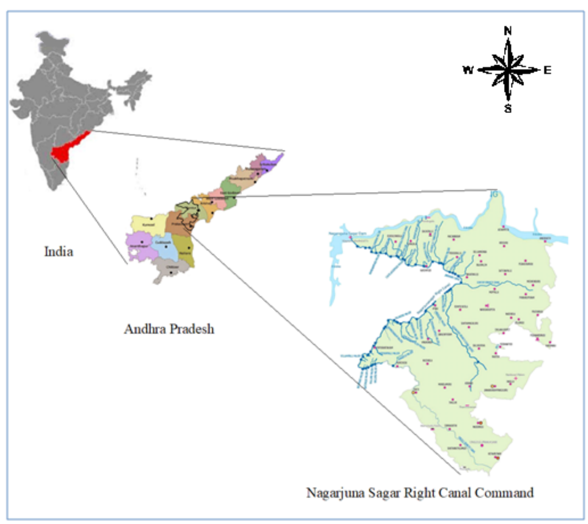

Fig. 1. Location map of the Nagarjuna Sagar Right Canal command

Modelling of Visual MODFLOW

Assessment of impact of cropping pattern and change in urban area on static groundwater storage availability was carried out using Visual MODFLOW 2.8.1 Package for Nagarjunasagar Right Canal (NSRC) Command. The model domain was selected as 50 rows and 50 columns with three-layered aquifer system (Fig. 2).

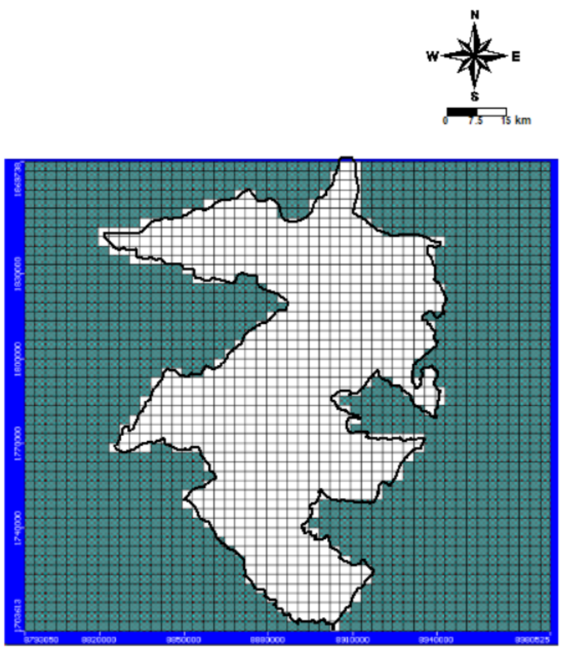

Fig. 2. Grid map of the study area showing inactive and active cells

This developed model was calibrated and validated with observed groundwater levels during 2008-09 to 2012-13 and 2013-14 to 2016-17 respectively. After validation, the model was used to predict the availability of static groundwater storage in future with different cropping pattern and change in urban area. The steps or processes involved in groundwater modelling are presented in Fig. 3.

Model prediction

The validated Visual MODFLOW 2.8.1 was used to simulate the groundwater dynamics in the study area for the years 2030 and 2040 with different cropping pattern scenarios and change in urban area. Global climate model MarkSim, which is developed by the International Centre for Tropical Agriculture (CIAT) was used to generate future weather data for the years 2030 and 2040. 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 and crop evapotranspiration of the different cropping patterns in the study area. The following cropping pattern scenarios and change in urban area was considered for the assessment of impact on static groundwater availability in the study area.

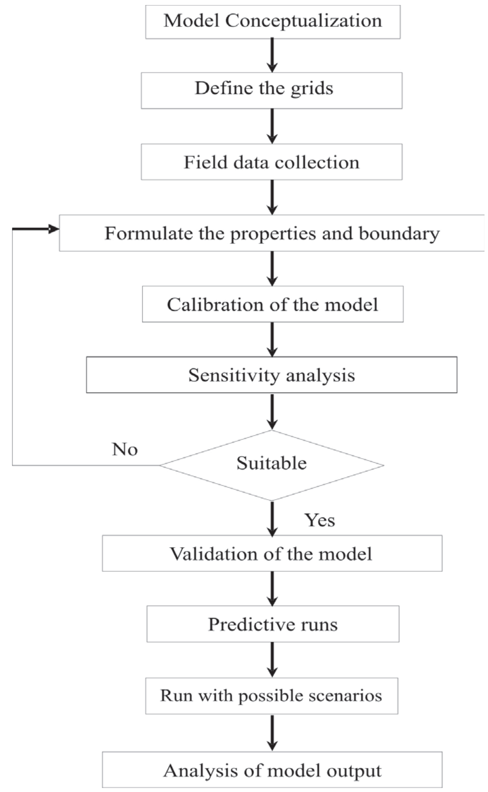

Fig. 3. Flow chart for groundwater modeling

Change in cropping pattern

Cultivation of the crops under the NSRC command area is mainly rice, cotton, chillies, pulses, millets, vegetables etc. Rice is the major crop cultivated in the command area followed by cotton and chillies. Remaining crops like pulses, millets and vegetables are cultivated in the small areas of the command area. Government officials are suggesting to cultivate the Irrigated Dry (ID) crops due to lack of sufficient canal water. Change in the cropping pattern influences the status of groundwater potential. Under this condition, the effect of cropping pattern change from rice to ID crops in the command area is to be analyzed using the validated Visual MODFLOW 2.8.1 model. Two different scenarios of cropping pattern were carried out to evaluate the availability of static groundwater resources in the study area. The proposed scenarios are the change in rice cropped area decreased by 50 per cent and 100 per cent and this cropped area is distributed equally for the cultivation of ID crops like cotton, chillies, millets, pulses and vegetables as follows.

Scenario - 1: Scenario with 50 per cent rice crop converted into ID crops

Scenario - 2: Scenario with 100 per cent rice crop converted into ID crops

Change in the urban area

The urbanization is one of the most significant factors considering for analyzing the response on the groundwater levels. The Directorate of Economics and Statistics (DES), Vijayawada has reported that the area under residential, industrial and other settlements in the Guntur district is 13 per cent of the district geographical area in the year of 2008 and 15.6 per cent in the year of 2017 (DES, 2008a and DES, 2017a). Similarly, the area under residential, industrial and other settlements in the Prakasam district was reported as 9.6 per cent of the district geographical area in the year of 2008 and 10.5 per cent in the year of 2017 (DES, 2008b and DES, 2017b). Development of urban area and its settlements in the last decade was noticed about 20 per cent and 10 per cent of existed urban area in Guntur district and Prakasam district respectively. The groundwater recharge is very less under this circumstance and generates more runoff rather than the intake of rainfall in the ground surface. Urbanization is the most influencing factor on the groundwater levels and its recharge adversely (Graniel *et al.,* 1999 and Karamouz *et al.,* 2011). The urbanization changes the groundwater recharge which leads to low groundwater levels (Khazaei *et al.,* 2004). The annual average recharge was decreased by the urbanization as having the impervious nature (Cho *et al.,* 2009).

From the above literature, it is clearly indicated that the urbanization effects on the groundwater recharge and decreased in groundwater recharge by 10 to 20 per cent can be assumed in the study area due to rapid development of the urban area and their settlements. On other hands, the increasing groundwater utilization would be expected for both domestic and irrigation purposes due to rapidly expanding urban area. These conditions put more pressure on the extraction of groundwater and increase the groundwater pumping (Groundwater draft). Under these circumstances, four scenarios with the combination of groundwater recharge and groundwater draft were proposed to analyze the effect of increased groundwater draft on groundwater resources. The proposed scenarios with the combination of 10 per cent and 20 per cent decrease in recharge and 50 per cent and 100 per cent increase in groundwater draft are as follows.

Scenario - 1: 10 per cent decreased recharge and 50 per cent increased groundwater draft

Scenario - 2: 10 per cent decreased recharge and 100 per cent increased groundwater draft

Scenario - 3: 20 per cent decreased recharge and 50 per cent increased groundwater draft

Scenario - 4: 20 per cent decreased recharge and 100 per cent increased groundwater draft

Results

Model prediction of static groundwater resources

The validated Visual MODFLOW 2.8.1 was used to simulate the groundwater dynamics in the study area for the years 2030 and 2040 with different cropping pattern scenarios and change in urban area. Global climate model MarkSim, which is developed by the International Centre for Tropical Agriculture (CIAT) was used to generate future weather data for the years 2030 and 2040. 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 potential evapotranspiration and crop evapotranspiration for the different cropping pattern scenarios in the study area were calculated for the years 2030 and 2040 with projected weather parameters.

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

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

Cropping pattern scenarios

Cultivation of the crops under the NSRC Command is mainly rice, cotton, chillies, pulses, millets, vegetables etc. Rice is the major crop cultivating in the command area followed by cotton and chillies. Remaining crops like pulses, millets and vegetables are cultivating in the limited areas of the command area. In present study, two different scenarios of cropping pattern were proposed to evaluate the response on groundwater levels with average recharge and groundwater draft. Scenarios with the change in rice cropped area decreased by 50 per cent and 100 per cent with this cropped area cultivated equally by the ID crops like cotton, chillies, millets, pulses and vegetables. The crop evapotranspiration was estimated for this scenario - 1 and scenario - 2 and predicted the groundwater table fluctuations and estimated availability of static groundwater storage for the years 2030 and 2040 using Visual MODFLOW 2.8.1 and presented in Table 2.

The impact of change in cropping pattern on storage of static groundwater resource in the study area for the years 2030 and 2040 was assessed and found that the lesser storage of static groundwater resources in future. In the scenario - 1 with 50 per cent rice convert into ID crops, the storage of static groundwater resources would be expected as 24,72,496.39 ha-m and 24,64,895.39 ha-m for the years 2030 and 2040 respectively. In the another scenario - 2 with 100 per cent rice convert into ID crops, the storage of static groundwater resources would be expected as 21,66,284.72 ha-m and 21,49,996.86 ha-m for the years 2030 and 2040 respectively. The simulated groundwater levels stated that the change in cropping pattern will be affecting on the groundwater levels and static groundwater storage.

Change in the urban area

The urbanization is one of the most significant factors considering for analyzing the response on the groundwater levels. In present study, the following scenarios are proposed with the combination of 10 per cent and 20 per cent decrease in recharge and 50 per cent and 100 per cent increase in groundwater draft and simulated the groundwater fluctuations and estimated the static groundwater storage availability for the years 2030 and 2040 using Visual MODFLOW 2.8.1 and presented in Table 3.

The impact of change in urban area on storage of static groundwater resource in the study area for the years 2030 and 2040 was assessed and found that the lesser storage of static groundwater resources in future. In the scenario-1 with 10 per cent decreased in recharge and 50 per cent increased in groundwater draft, the storage of static groundwater resources would be expected as 21,08,734.29 ha-m and 21,00,047.44 ha-m for the years 2030 and 2040 respectively. In the scenario - 2 with 10 per cent decreased in recharge and 100 per cent increased in groundwater draft, the storage of static groundwater resources would be expected as 20,51,183.87 ha-m and 20,24,037.45 ha-m for the years 2030 and 2040 respectively. In the scenario - 3 with 20 per cent decreased in recharge and 50 per cent increased in groundwater draft, the storage of static groundwater resources would be expected as 20,29,466.73 ha-m and 19,74,088.03 ha-m for the years 2030 and 2040 respectively. Similarly in the scenario - 4 with 20 per cent decreased in recharge and 100 per cent increased in groundwater draft, the storage of static groundwater resources would be expected as 19,74,088.03 ha-m and 19,51,285.03 ha-m for the years 2030 and 2040 respectively. The simulated groundwater levels stated that the change in urban area which influences the recharge and groundwater utilization will be affecting on the groundwater levels and static groundwater storage.

Table 2. Change in the storage of available static groundwater resources with the change in cropping pattern

Year	Depth to groundwater table (m bgl)	The thickness of aquifer below groundwater table (m)	Areal extent (ha)	Specific yield	Available static groundwater resources (ha-m)
50 per cent rice crop convert into ID crops					
2030	7.23	22.77	1085857	0.10	2472496.39
2040	7.30	22.70	1085857	0.10	2464895.39
100 per cent rice crop convert into ID crops					
2030	10.05	19.95	1085857	0.10	2166284.72
2040	10.20	19.80	1085857	0.10	2149996.86

Discussion

Model prediction

The validated Visual MODFLOW 2.8.1 was used to predict the groundwater fluctuations and static groundwater storage availability in the study area for the years 2030 and 2040 with different cropping pattern scenarios and change in urban area.

Change in cropping pattern

Scenarios are imposed for the study of the groundwater table fluctuations and availability of static groundwater storage with the change in rice cropped area decreased by 50 per cent and 100 per cent with this cropped area cultivated equally by the ID crops like cotton, chillies, millets, pulses and vegetables.

The simulated groundwater levels stated that the change in cropping pattern will be affecting on the groundwater levels and static groundwater storage. The decrease in the storage of available static groundwater resources was observed in future and this trend may be due to projected temperatures are high in future at the study area. The groundwater recharge from the rice fields and the rainfall is playing the main role in the development of groundwater resources. Crop water requirement of rice is very higher than the other ID crops. Change in cropping pattern from rice crop to ID crops will affect the net recharge due to decrease the recharge from the rice fields and at the same time ETc of the rice and ID crops. The same behavior observed in the present study area. The change in the cropping pattern affects the net recharge of the groundwater which influences the groundwater levels. Increase in paddy area increases the recharge and rise in groundwater level has been identified. In the study area, cropping pattern could be changed from rice crop to other irrigated dry crops to prevent the increase of groundwater resources which leads the water logging condition in the study area.

Cho *et al.* (2009) explored the response of land use changes on the groundwater table at upper Roanoke river watershed and found that the effect of change of different land use plays main role in recharge of groundwater. High recharge observed in lawn scenario than the open area. Sridhar *et al.* (2018) applied Visual MODFLOW to predict the behaviour of the aquifer of Lower Ponnaiyar watershed, Tamilnadu, India and revealed that the fluctuations of groundwater levels depend on the recharge from precipitation and irrigation. Qadir *et al.* (2016) used the Visual MODFLOW model to Lower Indus basin of Pakistan and found the recharge is the more sensitive than other parameters. Ahmed and Umar (2009) also reported that the recharge component is more sensitive parameter for the Visual MODFLOW.

Change in the urban area

The change in the urban area decreases the net recharge as impervious nature of the ground surface and increase in the utilization of groundwater to meet the demand in the developed urban area. The possible scenarios with the combination of 10 per cent and 20 per cent decrease in recharge and 50 per cent and 100 per cent increase in groundwater draft

Table 3. Change in the storage of available static groundwater resources with the change in urban area

Year	Depth to groundwater table (m bgl)	The thickness of aquifer below groundwater table (m)	Areal extent (ha)	Specific yield	Available static groundwater resources (ha-m)
10 per cent decreased recharge and 50 per cent increased groundwater draft					
2030	10.58	19.42	1085857	0.10	2108734.29
2040	10.66	19.34	1085857	0.10	2100047.44
10 per cent decreased recharge and 100 per cent increased groundwater draft					
2030	11.11	18.89	1085857	0.10	2051183.87
2040	11.36	18.64	1085857	0.10	2024037.45
20 per cent decreased recharge and 50 per cent increased groundwater draft					
2030	11.31	18.69	1085857	0.10	2029466.73
2040	11.82	18.18	1085857	0.10	1974088.03
20 per cent decreased recharge and 100 per cent increased groundwater draft					
2030	11.82	18.18	1085857	0.10	1974088.03
2040	12.03	17.97	1085857	0.10	1951285.03

were imposed and predicted the groundwater fluctuations and availability of static ground water storage. These results demonstrated that the available static groundwater resources are depleted due to the increase in the urban area with low recharge and high groundwater draft. The availability of static groundwater resources is decreasing with all scenarios. The availability of static groundwater resources is depleting from the first scenario to the fourth scenario. The decline in available static groundwater resources would be expected 6.38 per cent and 7.08 per cent during 2030 and 2040 respectively. The rapid expansion in the urban area and their settlements is also one of the reasons for the depletion of groundwater resources.

Embaby *et al.* (2017) also simulated the groundwater levels during 2040 at Northeastern Cairo, Egypt with existing groundwater pumping continuously and found increment in drawdown as 2.52 m at the rate of 0.101 m per annum. Hussein *et al.* (2013) and Rakesh *et al.* (2009) reported that the declining trend of the water table due to the continuous withdrawal of groundwater. Purjenaie *et al.* (2012) also simulated aquifer drawdown using Visual MODFLOW at Sarze Rezvan plain, Iran and reported that the drawdown will be decreased to 6.3 m and 4.5 m with aquifer pumping value decreases 20% and 40% respectively.

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.

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