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Research Article

CALIBRATION AND VALIDATION OF THE DEVELOPED GROUNDWATER MODEL FOR NAGARJUNA SAGAR RIGHT CANAL COMMAND AREA

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, Bapatla, 522 101, Acharya N.G. Ranga Agricultural University, Lam, Guntur, 522 034, India
[2]Professor & Head, Department of Irrigation and Drainage Engineering, Dr NTR College of Agricultural Engineering, Bapatla, 522 101, Acharya N.G. Ranga Agricultural University, Lam, Guntur, 522 034, India
[3]Associate Dean & Professor, Dr NTR College of Agricultural Engineering, Bapatla, 522 101, Acharya N.G. Ranga Agricultural University, Lam, Guntur, 522 034, India
[4]Principal Scientist & Head, Geospatial Technology Centre, Acharya N.G. Ranga Agricultural University, Lam, Guntur, 522 034, India
[5]Professor & University Head, Department of Statistics and Computer Applications, Agricultural College, Bapatla, 522 101, Acharya N.G. Ranga Agricultural University, Lam, Guntur, 522 034, India
*Corresponding Author: Email - ganipatnaik@gmail.com

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Abstract: Modelling is the best tool to optimize the different combinations and to select the best combination. Using computer models, best solution or scenario can optimize by creating model with real conditions. In this study, three dimensional finite difference modelling program namely Visual MODFLOW applied to Nagarjuna Sagar Right Canal Command area to simulate the groundwater dynamics. The Nagarjuna Sagar Right Canal (NSRC) Command area is located between 15°18´-16°49´ North latitudes and 79°20´-80°25´ East longitudes. The net area irrigated under Nagarjuna Sagar Right Canal is 4.75 lakh ha. The aquifer properties of various layers, boundary conditions, observation and pumping well data, recharge and evapotranspiration conditions were fed in to the model as inputs. The model was calibrated and validated to predict the groundwater dynamics in future. Model calibration was performed under steady state and transient state conditions as the good agreement between observed and calculated groundwater levels with acceptable statistic measures. Validation of the model was carried out and found good agreement between observed and calculated groundwater levels with acceptable statistic measures. 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 of the study area for planning, monitoring and maintaining sustainable groundwater resources in the study area. The output of the developed model could be used for further groundwater modelling studies in the study area.

Keywords: *Groundwater modelling, Nagarjuna Sagar Right Canal Command area, Visual MODFLOW, Calibration and validation*

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Introduction

In India, demand on water is increasing day by day due to enormous increasing in population. On other hand, the rapid increasing in urbanization in India as a part of development which increases the high water demand to meet requirements for domestic and industrial purpose. Groundwater resource is playing important role where surface water is not sufficient [1]. Development and management of sustainable groundwater is a difficult task to meet the needs of increased population. The availability of surface water is insufficient due to deficit rainfall. Then the groundwater is the alternate to meet the water needs. Depletion of groundwater resources is indicating the water scarcity. The nature of the groundwater levels should be understood for planning and monitoring the groundwater resources. In present study, an attempt is made to develop the groundwater modelling to Nagarjuna Sagar Right Canal Command area. In present study, Visual MODFLOW 2.8.1 Package is used for the calibration and validation of developed groundwater model to assess the groundwater fluctuations. A groundwater model was developed using MODFLOW for Indira Gandhi Nahar Pariyojna, Stage-I, Rajasthan and carried out the calibration with Root Mean Square Error (RMSE) value of 1.49 m[2].The numerical models MODFLOW and SWAT applied to Ramganga sub-basin and calibration of MODFLOW was performed with Root Mean Square Error (RMSE) of 4.6 m and normalized RMS of 2.7 percent [3]. The difference between predicted and measured groundwater levels should be less than 10% of the variability for calibration [4]. Many researchers were developed groundwater model using Visual MODFLOW and calibration was performed [5-9].

Material and methods

Groundwater model was developed for Nagarjuna Sagar Right Canal Command area using Visual MODFLOW.

Study area

The Nagarjuna Sagar Right Canal (NSRC) Command area is located between 15°18´ - 16°49´ North latitudes and 79°20´ - 80°25´ East longitudes. 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].

Groundwater modeling

Modelling is the best tool to optimize the different combinations and to select the best combination. It is the best tool to study the results of different combinations. Using mathematical equations, numerical models were developed. Later, computer models were developed using different computer languages.

Using computer models, best solution or scenario can optimize by creating model with real conditions. Visual MODFLOW is one of the finest software for groundwater modelling.

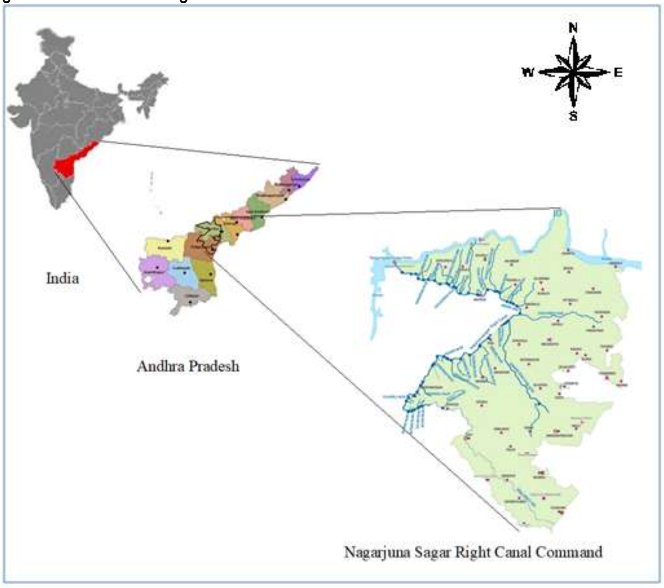

Fig-1 Location map of the study area

Visual MODFLOW

MODFLOW is a MODular 3-dimensional groundwater FLOW model developed by the United States Geological Survey (USGS) written in FORTRAN 77 language [10]. This software package widely used by hydro geologists, allows both steady-state and transient simulations. In present study, Visual MODFLOW 2.8.1 ground water modeling package is used to quantify ground water-surface water interaction. Visual MODFLOW was developed using MODFLOWcode system and modified by Waterloo Hydrologic software, Waterloo, Ontario, Canada. Using Visual MODFLOW, model was calibrated with existing site conditions and was validated.

Governing equations of Visual MODFLOW

Visual MODFLOW uses the following governing equations for simulation of groundwater dynamics.

Continuity equation

The continuity equation is used to solve the finite differences method with block cantered approach. The continuity equation is expressing the balance of groundwater flow for a cell as below.

$$\sum_i Q_i = S_s \frac{\Delta h}{\Delta t} \Delta V \quad (1)$$

Where,

Qi = Flow rate into the cell (L^3T^{-1})

S_s = A term equivalent to specific storage (L^{-1})

V = Volume of the cell (L^3)

Δ h = Change in head over a time interval (L) and

Δ t = Change in time (T)

Darcy's equation

Darcy's law is a primary tool for groundwater flow modeling. Darcy's law is expressed the relationship of liquid flow through a porous medium. Darcy's law can applicable for groundwater flow in the aquifer. As per the Darcy's law, flow rate of the groundwater is directly proportion to the cross-sectional area of the aquifer and the hydraulic gradient. Hydraulic conductivity of the aquifer is the proportionality constant of Darcy's law as mentioned below.

$$Q = \frac{-KA(h_2-h_1)}{L} \quad (2)$$

Where,

Q is the volumetric flow (L^3T^{-1})

K is the hydraulic conductivity of the material in the direction of flow (LT^{-1})

A is the cross-sectional area perpendicular to the flow (L^2)

h_1-h_2 is the head difference across the prism parallel to flow (L) and

L is the length of the prism parallel to the flow path (L)

Finite difference equation

In the present study, ground water 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.

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right] + \frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right] - W = S_s\frac{\partial h}{\partial t} \quad (3)$$

Where,

K_{xx}, K_{yy} & K_{zz} are values of hydraulic conductivity along the x, y & 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.

Development of Model

Groundwater model was developed for the Nagarjuna Sagar Right Canal (NSRC) Command area using Visual MODFLOW. For the present study, model domain was selected as 50 rows and 50 columns. Later inactive cells were selected for distinguish the study area in the entire model domain as shown in [Fig-2] and it shows the study area as active portion with white coloured cells.

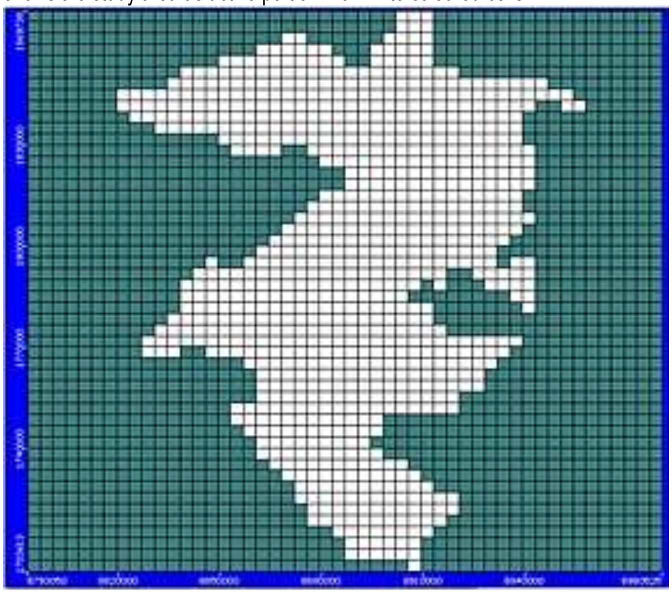

Fig-2 Grid map for the study area in Visual MODFLOW

Assigning inputs to developed groundwater model

The following parameters were assigned to developed groundwater model as input.

Import elevations

Elevation of ground surface was imported using 'Import Surface' option in 'txt' or ASCII (X,Y,Z) format. 'X' and 'Y' are representing the geographical position of the location with latitude and longitude respectively and 'Z' represents the elevation at that particular location. After importing ground surface, bottom elevation of the layers has been imported into the model.

Observation wells

Depth to water levels of the observation wells are collected from the groundwater departments of Guntur and Prakasam districts, Government of Andhra Pradesh and this head observations used to monitor the groundwater levels. Adding head observation wells to the model as shown in [Fig-3].

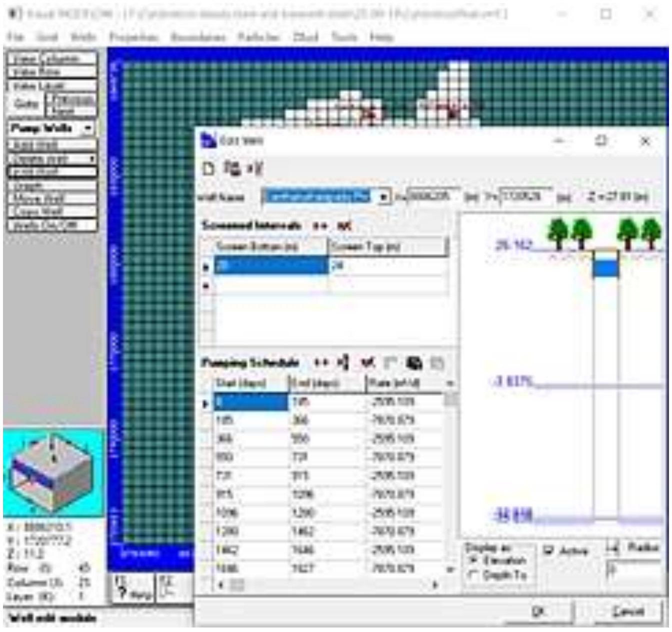
Fig-3 Addition of observation well to the groundwater model

Pumping wells

Pumping wells are added to the groundwater model and assigned the groundwater exploration in m3 d-1 as shown in [Fig-4].

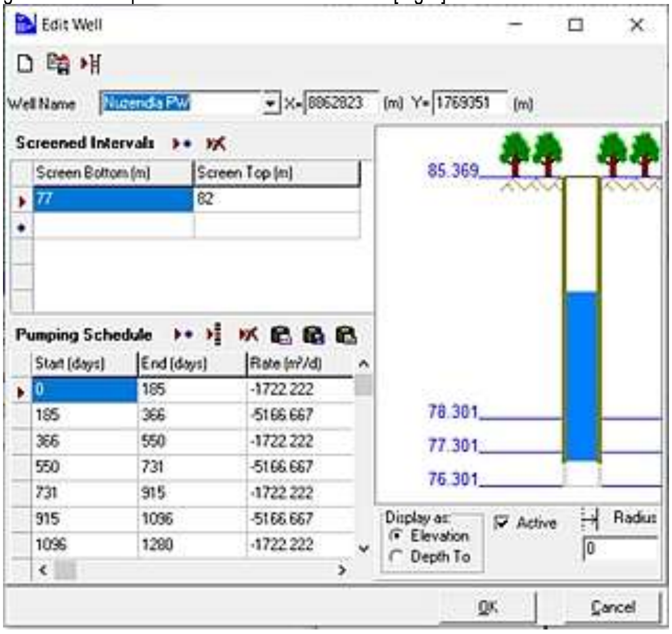

Fig-4 Addition of the pumping well to the groundwater model

Aquifer properties

Hydraulic conductivity and storage properties of aquifer system was assigned based on the geological formation type as shown in [Fig-5].

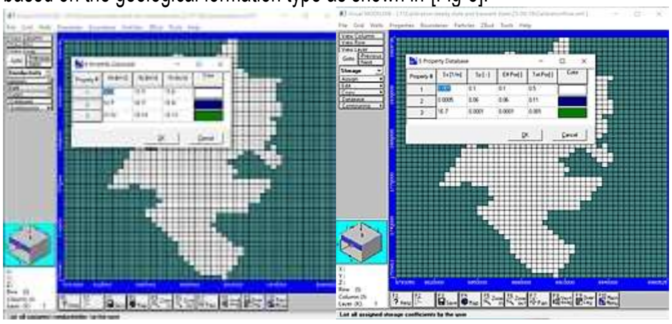
Fig-5 Assigning aquifer properties for different layers

River and Constant head boundaries

Bay of Bengal is existed at the Southern-East boundary of the study area. In this study, water level at Bay of Bengal is added as constant head and is assigned as zero. Krishna river is passing through the northern boundary of the study area. Grids filled with red colour represent the constant head boundary and blue color represents river boundary as shown in [Fig-6].

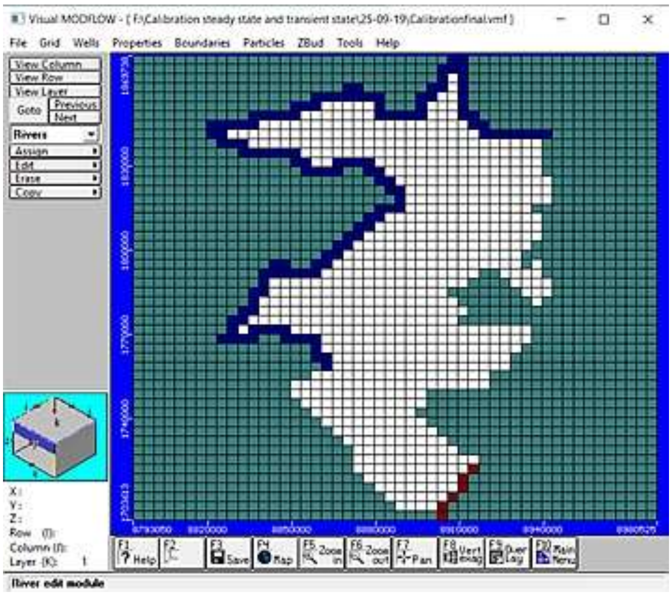

Fig-6 Assigning the boundary conditions of the study area to the groundwater model

Recharge and Evapotranspiration

Major portion of the groundwater is due to recharge from rainfall, canal seepage, excess irrigation and storage tanks existed in the study area. Daily rainfall data was compiled and calculated average annual rainfall of the study area as 786 mm. Recharge was calculated by deducting the runoff water from the rainfall of the particular years and assigned to groundwater model. Similarly, evapotranspiration (ET)of different cropped areas and land use pattern of the study area was estimated and assigned to groundwater model.

Calibration

Model was calibrated in both steady state and transient state using groundwater levels data from 2008-09 to 2012-13. The calibration of the model has been done by changing the aquifer properties of the study area until matched the simulated with measured groundwater levels with acceptable statistical measures.

Validation

In the modeling process, the developed model performance is justified by validation. Calibrated model was validated by existing data from 2013-14 to 2016-17. Validated model can be used to assess the aquifer response with respect to different scenarios for maintaining sustainable groundwater resources.

Results and Discussion

The study was mainly intended to identify the suitable aquifer properties of the groundwater flow system in the study area using Visual MODFLOW. Groundwater recharge from rainfall is the main source for the groundwater. The topography of the study area had a tremendous influence on groundwater flow.

Model calibration

Developed model was calibrated using groundwater level data obtained from 39 wells located in the Nagarjuna Sagar Right Canal Command. The groundwater levels during pre-monsoon, 2008 (May, 2008) was taken as initial heads for the model calibration. Groundwater level data from 2008-09 to 2012-13 was used for calibration under steady state and transient state conditions.

The results of the model calibration for steady state and transient state conditions showed that the good agreement between observed and calculated groundwater levels acceptable statistical measures as shown in [Table-1]. Output obtained from the calibration in steady state and transient state is shown in [Fig-7].

Table-1 *The statistical measures of steady state calibration of the model*

S	Statistical measures	Steady state calibration	Transient calibration
1	Mean Error, m	0.555	-1.367
2	Mean absolute, m	1.843	1.568
3	Standard Error, m	0.378	0.245
4	Root Mean Square Error, m	2.394	2.038
5	Normalized RMS, %	1.94	1.719
6	Coefficient of determination (R^2)	0.995	0.996
7	Nash-Sutcliffe Efficiency Coefficient (NSE)	0.995	0.993

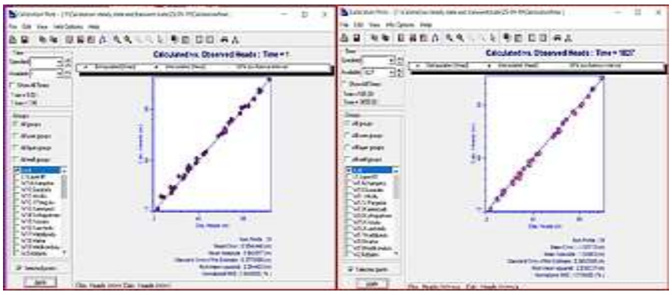

Fig-7 Output of the calibration under steady state and transient state conditions

Thus, model was calibrated in steady state condition by assigning suitable aquifer properties as shown in [Table-2].

Table-2 *Suitable aquifer properties of different layers in the study area during calibration*

Layer number	Hydraulic conductivity			Storage properties			
	K_x (m/s)	K_y (m/s)	K_z (m/s)	Ss (m^{-1})	Sy (--)	Effective porosity (--)	Total porosity (--)
1	1 E-5	1 E-5	1 E-6	0.001	0.1	0.1	0.5
2	1 E-7	1 E-7	1 E-8	0.0005	0.06	0.06	0.11
3	1 E-12	1 E-12	1 E-13	1 E-7	0.0001	0.0009	0.001

Validation

Validation of the calibrated model is necessary to ascertain the predictive capability of the calibrated model and to have a greater confidence in the calibrated model. In present study, groundwater levels from 2013-14 to 2016-17 was used for the validation process. The results of the model validation in transient state condition showed that the good agreement between observed and calculated groundwater levels acceptable statistical measures as shown in [Table-3]. Output obtained from the validation in transient state is shown in [Fig-7].

Table-3 *The statistical measures at the end of the of transient validation period*

S	Statistical measures	Values
1	Mean Error, m	-0.908
2	Mean absolute, m	1.333
3	Standard Error, m	0.263
4	Root Mean Square Error, m	1.861
5	Normalized RMS, %	1.586
6	Coefficient of determination (R^2)	0.997
7	Nash-Sutcliffe Efficiency Coefficient (NSE)	0.997

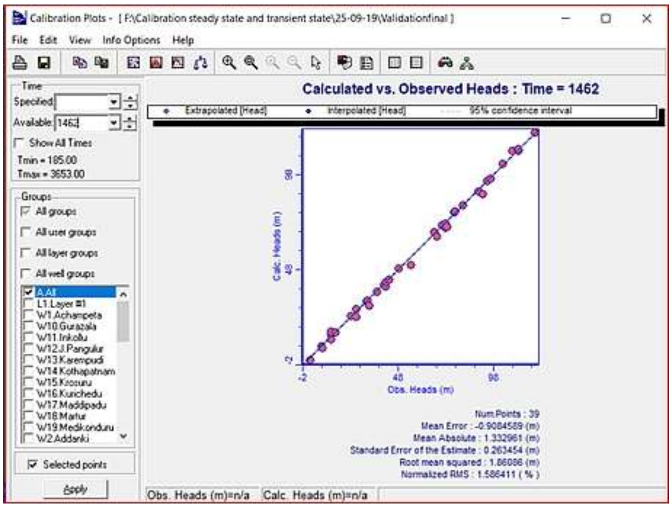

Fig-7 Output of the validation under transient state calibration

Conclusion

A groundwater model to Nagarjuna Sagar Right Canal Command area has been developed by using Visual MODFLOW 2.8.1. The horizontal and hydraulic conductivity of the three layers, constant head and river boundary conditions were fed as inputs to the groundwater model. Groundwater recharge of the study area for study period was calculated using the existed data on rainfall, canal releases and other storage structures like tanks. Evapotranspiration was estimated using the existed cropping pattern and land use in the study area. These groundwater recharge and evapotranspiration were assigned to the groundwater model. Model calibration was performed under steady state and transient state conditions as the good agreement between observed and calculated groundwater levels with acceptable statistic measures. Validation of the model was carried out and found good agreement between observed and calculated groundwater levels with acceptable statistic measures. 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 of the study area for planning, monitoring and maintaining sustainable groundwater resources in the study area. The output of the developed model could be used for further groundwater modelling studies in the study area.

Application of research: This article has been prepared with the objective of giving information's on application of groundwater model to Nagarjuna Sagar Right Canal command area to assess the groundwater fluctuations. The investigations of the research used for the purpose of planning, decision making and execution of activities in the command areas to maintain the sustainable groundwater resources.

Research category: Groundwater Engineering.

Abbreviations: NSRC-Nagarjuna Sagar Right Canal, USGS- United States Geological Survey, RMS – Root Mean Squared, RMSE – Root Mean Square Error, NSE - Nash-Sutcliffe Efficiency, ET–Evapotranspiration

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***Principal Investigator or Chairperson of research: Dr G. Ravi Babu**
University: Acharya N.G. Ranga Agricultural University, Lam, Guntur, 522 034
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Author Contributions: All authors equally contributed

Author statement: All authors read, reviewed, agreed and approved the final manuscript. Note-All authors agreed that- Written informed consent was obtained from all participants prior to publish / enrolment

Study area / Sample Collection: Nagarjuna Sagar Right Canal Command area.

Cultivar / Variety / Breed name: Nil

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number:

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