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REVIEW

A broad review on the usage of modular three-dimensional finite-difference groundwater flow model for estimating groundwater parameters

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Abstract
Modeling groundwater is a significant paradigm in hydrology application, which supports human life and agricultural land in a wide range. Thus, groundwater modeling is more helpful in the hydrological system. Moreover, the crucial part of groundwater modeling is artificial recharging, which helps estimate groundwater levels. Also, the process of the recharge system differs based on ground conditions. Besides, spatial representations are explained in a graphical structure to estimate groundwater mapping. Henceforth, the drawn graphical representation illustrates the ground condition with its density. Furthermore, the MODFLOW model is mostly utilized to design the graphic structure. Also, this present review has collected areas of ground-level data including Varanasi, West Bengal, South Korea, Africa, Jordan, Italy, and Beauraing. So, several existing works are discussed related to the Varanasi district. Finally, several chief parameters are discussed in tabular and graphical formats. Also, systematic future works are recommended in conclusion section. Thus, this review supports the researchers in discovering past difficulties and better solutions for the future.

Keywords Aquifer mapping · Artificial recharge · Groundwater · Groundwater estimation · Groundwater parameters

Introduction

The advancements of the groundwater system framework are mostly utilized for environmental applications (Pathak and Dodamani 2019). In general, the methods of groundwater modeling are based on mathematical spatial distribution (Singh et al. 2020). Also, the aim of spatio-distribution is to characterize the parameters of groundwater (Nayyeri et al. 2020). Thus, the parameters of groundwater are utilized to evaluate the climate conditions and rainfall rate (Zhao et al. 2020). Moreover, the parameter estimation of groundwater (Bobba et al. 2000) typically has some of the following elements such as

- Direction flow
- Aquifer geometry
- Heterogeneity
- Bedrock

Furthermore, groundwater framework applications contain a water balance method to estimate ground resource quantity (Raju 2012). Besides, the execution of the groundwater framework is processed with the support of software selection (Sargaonkar et al. 2008), calibration modeling (Verma and Rakshit 2012), designing input parameters, and sensitivity analysis (Mohan et al. 2011). The input elements design or parameters contain specific area details like boundary, direction, elevation, hydrocondition, etc. (Chaurasia et al. 2013). Consequently, the characterized input parameter is given to the calibration frame to investigate groundwater resources (Kumar et al. 2014). Finally, the calibration outcomes reveal the condition of a particular area (Singh et al. 2006). Based on the field conditions, the sensitivity score is calculated, and then successive measurements (Yang et al. 2022) of the utilized model are evaluated with other conventional approaches (Tripathi and Vishwakarma 2015).

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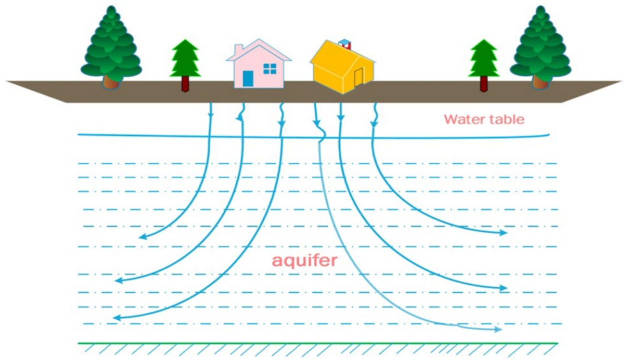


Fig. 1 Aquifer mapping

Besides these, the scheme MODFLOW (Mishra et al. 2014) is utilized in groundwater applications to record the ground aquifer stream level (Maurya et al. 2017). Moreover, the fundamentals of aquifer mapping are elaborated in Fig. 1. MODFLOW is a three-width finite component (Raju 2007) utilized to broadly assess groundwater resources and their quantity (Olea et al. 2018). Also, the ground aquifer contains nitrate substances in the range of 0.0005 to 1mg/l (Nistor et al. 2020). Moreover, the ground aquifer's chief components are fluoride substances that usually happen as natural substances (Gupta and Bishwas 2008). Hence, fluoride concentration varies based on the specific study region (Singh et al. 2013). Some chemical substances are analyzed with groundwater parameters to estimate the ground conditions accurately. Besides, the review of the groundwater level monitoring has been described for few regions like Varanasi, West Bengal, South Korea, Africa, Jordan, Italy, and Beauraing. Finally, the statistical analysis tools and results are discussed in this present review study.

Materials and methods

Artificial renew frame systems are the engineering applications for ground aquifer management. The critical focus of artificial recharge is to restore the awkward water and reuse it (Dubey et al. 2014). Also, the aquifer must have adequate flow (Tang et al. 2022). Moreover, artificial system renewal is mostly utilized to improve sewage water quality. Then the refined aqua is used for other purposes (Shukla and Raju 2008). The artificial recharge framework is separated into dual channels that are off-channel and in-channel frameworks (Raju et al. 2011). Furthermore, the floodplain or the most streambed wet zone tends (Pande et al. 2022; Hughes et al. 2022) to move the underground surface's dirty water. Herman Bouwer (2002) did broad research in hydrology based on artificial recharge objectives (Daniel et al. 2022). One of the artificial recharge schemes is applied in the dam zone to validate the research procedure (Sbai 2020). Usually, a few dams cover a small area, and some others cover a large area (Puttiwongrak et al. 2022). Also, some dams are occupied with fresh water and some with the sewage water. So conducting the validation with the recharge system is a crucial task (Mohan et al. 2022).

In the region of West Bengal, the annual percentage of rainfall measure is 1500 mm. Besides, the maximum recorded precipitation period is from 6 months to 8 months (Sahu and Jhariya 2022). The density measure of the West Bengal ground aquifer is designed in Fig. 2 (Chowdhury et al. 2010). Besides, the resource of the ground aquifer is estimated with the help of remote sensing technology (Puttiwongrak et al. 2022). Also, numerous spatio graph models are designed for groundwater tables to assess the level of underground water (Zaremehrjardy et al. 2022; Rafiei et al. 2022). Thus, Chowdhury et al. (2010) developed an efficient recharge frame system to investigate the groundwater resource and sewage water. The estimated sewage or awkward water is filtered using a specific artificial recharge tool (Gupta and Bharagava 2021). Hereafter, the filtered aquifer is utilized for other purposes (Zhao et al. 2022a, b). Once the estimated values are gathered, they are trained to the Geographic Information System (GIS) model simultaneously, and thus the graphical representation is obtained (El-Hadidy and Morsy 2022).

MODFLOW-based ground aquifer framework

Analysis of ground parameters in groundwater system is termed as MODFLOW. Usually, the MODFLOW is a fixed data format combined with a GIS system (Dzierzbicka-Glowacka et al. 2022); also, the purpose of using MODFLOW software is to achieve better visualization of ground parameters (Sbai 2020).

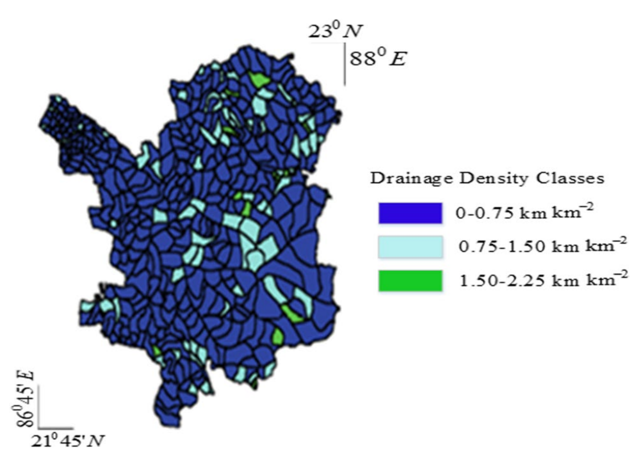


Fig. 2 Density of drainage in West Bengal

One of the critical parameters in ground aquifer modeling is evaporation which affects the groundwater up to a specific distance from the water ground table (Singh 2005). Also, here the recharge frame is processed with the support of the MODFLOW technique (Jimenez et al. 2022; FitzGerald et al. 2022). Finally, the estimation results are described in the form of graphs and map illustrations with the help of the ArcGIS tool and MODFLOW (Abdelmoneem 2022). The adopted area for this specific research is Varanasi city (Omar et al. 2019). Moreover, the ground aquifer is investigated using the MODFLOW recharge framework. Also, the Varanasi region of research is shown in Fig. 3 (Omar et al. 2019).

The scheme evaluates ground aquifer based on aquifer balance by the approach of MODFLOW (Ahamad et al. 2018). A multi-pool storage map-reading component is advocated instead of single mapping storage in the groundwater pool (Das et al. 2018). By this method, the constraint associated with the suspension time is optimized, inspecting the association between replicated renews and perceived groundwater stages (Zhao et al. 2022a, b). This process's last frame is to equate replicated groundwater in the watershed rivulet pour using estimated groundwater planes (Chakraborty et al. 2022a, b). The calculated annual renewal amount is likened to separate MODFLOW-based recharge validation (Madhav et al. 2018). The exact quantification of refresh measures is a key process for a suitable management scheme (Samandra et al. 2022). Various analyses were designed to validate the recharge measure (Tapia-Villaseñor et al. 2022); the structured analysis is also processed with diverse time-space intervals (Chaurasiaet al. 2018). In water reserve inquiries, groundwater replicas are utilized to feign the aquatic stream in the wide-term characteristics of an aquatic under numerous administration systems (Wang et al. 2022; Gumuła-Kawęcka et al. 2022). Moreover, the schemes of inspecting ground aquifer renewal systems are based on

Fig. 3 Area of Varanasi

hydroparameters that include the depth of ground aquatic, density, etc. (Harris et al. 2022).

The ground's resource gets varied and polluted due to changing weather conditions which result in awkward water on the ground surface (Xing et al. 2022).

For an exact ground aquatic, designing an explained knowledge system is needed to solve the hydroparameters (Ebrahimi et al. 2022). Besides, an effective groundwater system process is evaluated with the help of mathematical schemes (Chaurasia et al. 2018). Also, the mathematical flow functions are based on time and depth parameters. Besides, numerous spatial-based temporal graph representations are designed to calculate the ground characteristics (Rao et al. 2012).

- Spatial scheme distribution is the most satisfactory model to investigate the level of groundwater.
- Moreover, the measure of recharge is a process based on key attributes such as
  - Geology
  - Vegetation
  - Elevation
  - Land slope

But there are no specific methods for the steady analysis of the recharge system. The conventional model of groundwater table has not gained a better measure of exactness in groundwater detection (Caligaris et al. 2022). Also, the standard schemes mostly suffer from restricted limitations (Zhan and Zlotnik 2002). So that, numeral approaches are implemented, including deep learning and machine learning (Madhav et al. 2018). To estimate the level and resources of groundwater, knowledge about soil characteristics is more crucial (Mulligan and Charette 2006). Besides, the soil association map representation of South Korea is detailed in Fig. 4 (Chung et al. 2010). Thus, before investigating the ground level initially, soil behavior is determined and represented by some spatial graphs (Zhao et al. 2020). The simulation of aquifer recharge is calculated within the fixed correlation metrics to elaborate the period delay. Here, Chung et al. (2010) estimated the spatial pattern basin pole changes utilized with map illustrations. Because of groundwater exhaustion, its administration and preservation events become demanding issues in the current situation (Hassan et al. 2022). These probable events can be evaluated by the expansion of diverse replicas for flow modeling of groundwater simulation. Besides, the modeling of groundwater has efficient resource assessment of both quality and quantity stages (Chakraborty et al. 2022a, b). Groundwater replica can forecast the prospect characteristics of the system framework if the circumstance remains identical or differ based on the specific condition (Ahamadet al. 2018). An excellent

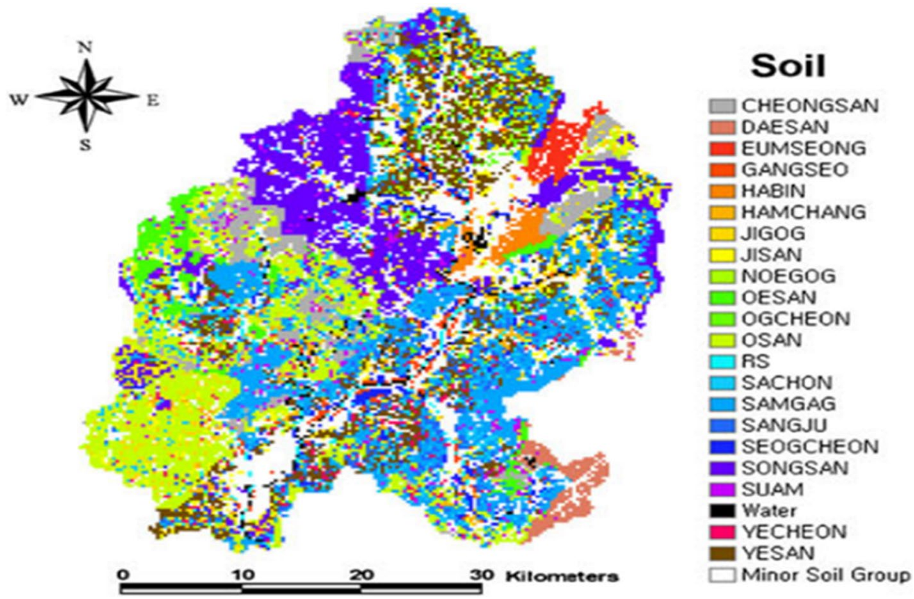


Fig. 4 Soil association map of South Korea

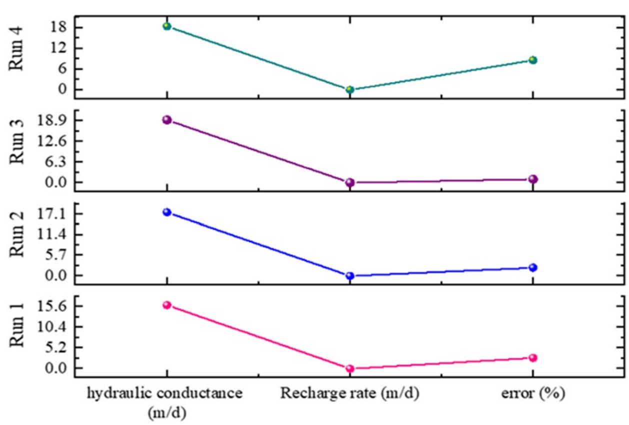


Fig. 5 Key parameter estimation of Varanasi

theoretical replica should explain the actuality straightforwardly, which satisfies the designing parameters and administration necessities.

In addition, Omar et al. (2019) projected calibration procedures to diminish the variation while comparing the real area condition. Moreover, in this replica, the input parameters differ so that the site's condition must be characterized precisely. Furthermore, the error in the replica is estimated, and other possible values are entered to estimate the hydraulic conductivities, which are revealed in Fig. 5.

Aquifer mapping

Procedure mapping is essential to manage and protect the groundwater model. The vulnerability of intrinsic components is based on hydroconductance to study the saturated area (Singh and Singh 2018). Moreover, the decision-making framework includes a combination of hazards and maps. The estimation of distribution vulnerability is more difficult in the ground modeling framework. Furthermore, all map illustrations describe an identical measure of vulnerability in plain alluvial, while lesser vulnerability measure is recorded in the Mt. Massico region (Luiso et al. 2018). The groundwater pollution risk was estimated for the Pan African area by Ouedraogo et al. (2016). The designed map described that the groundwater was highly polluted in West Africa, and the recorded water table was also shallow. Also, the sensitivity calculations represented impact removal in the groundwater model. The hydraulic conductance and recharge framework might also cause a wide variation in pollution risk and vulnerability mapping. Besides, the process aquifer mapping is processed with the support of nitrate concentrations. The validation of vulnerability based on the intrinsic measure was a superimposition of numerous maps reflecting the hydroparameters (Table 1).

Mishra et al. (2019) made a **comprehensive** analysis of solid waste in the Varanasi area. The depth of the aquifer is elaborated in Fig. 6. Furthermore, groundwater pollution is described in this investigation, and several control measures were established to reduce solid waste. Besides, the cluster investigation is a better statistical process to validate the quantity of groundwater. The potential analysis is used with a drastic model to estimate the amount of fresh water and sewage water (Senerand Davraz 2013). The attained graph finally revealed the percentage of fresh and dirty water. Here, six kinds of drastic parameters were studied with a temporal graphical model. The polluted fields are separated into three stages,

- Naturally vulnerable region

Table 1 Merits and limitations of aquifer modeling approaches

References	Method	Advantages	Disadvantages
Bouwer (2000)	Aquifer recharge	It helps to calculate the available space for surface storage	If the ground surface is hard, then it gains very less calculation accuracy
Chowdhury et al. (2010)	GIS with aquifer recharge	It has a remote sensing function to gather the ground statistics It has gained a better accuracy rate for ground statistic analysis	If the amount of data are large, then it takes too much time to complete the process
Omar et al. (2019)	Aquifer recharge MODFLOW	The rate of recharge system is estimated based on recharge capacity	If the ground surface is hard, then it has gained significantly less capacity
Chung et al. (2010)	MODFLOW	This method is functioned based on a 3D representation Because of 3D visualization, the estimation of groundwater resources is more accurate	Time complexity
Luiso et al. (2018)	Aquifer mapping	The mapping approach helps to map the aquifer at ground level	It has gained significantly less accuracy
Ouedraogoet al. (2016)	Nitrate concentration-aquifer mapping	The use of nitrate concentration improves the accuracy of aquifer mapping	High cost than conventional schemes
Mishra et al. (2019)	Cluster analysis	The approach cluster analysis supports massive statistics analysis	But it takes more time to design
Sener and Davraz (2013)	Potential analysis	The estimation is functioned to record the amount of fresh and dirty water The approach drastic is utilized to evaluate the data	Complex in structure
Gogu and Dassargues(2000)	Drastic comparative analysis	Here, the maps are created for vulnerability areas It has attained high accuracy measures	It takes more time duration to complete the comparative analysis
Werner and Gallagher (2006)	Assessment and mapping	Exact vulnerability assessment GIS is utilized for graphical analysis	Only the method is applicable for less quantity of data
Rizeei et al. (2018)	Parametric method	The critical parameters of the ground are validated with a high exact measure The groundwater parameters are validated with the use of precipitation levels	It has gained significantly less accuracy for broad statistics
Raju et al. (2011)	Geological analysis	The climate variation of both pre- and post-monsoon is described systematically	It has pertained less integrity measures
Singh et al. (2015)	Hydrochemistry	The percentage of irrigation aquatic is estimated It mostly supports for agricultural land to plant crops	Complex in analysis
Raju et al. (2009)	Examination of hydrology	The level of the aquatic condition under the ground is estimated Moreover, the study is carried with a broad hydrology assessment	It required more time duration for analysis

- Protection area
- Disaster area

Usually, the vulnerable zone is susceptible to bedrock, subsoil, and soils—moreover, the approaching semi-quantitative and resource quantity analysis uses mapped statistics. Also, the vulnerability of groundwater is a subtle element

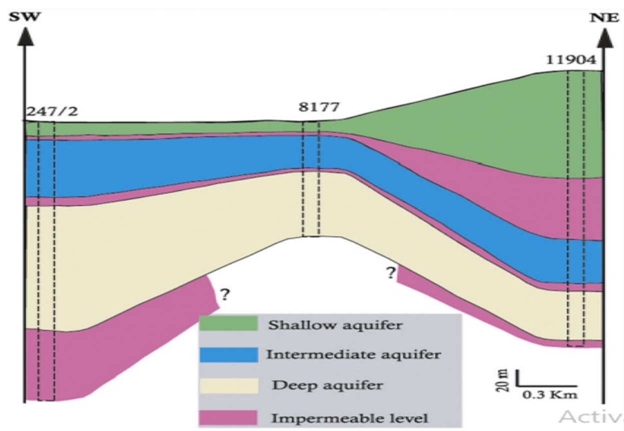


Fig. 6 Aquifer depth estimation

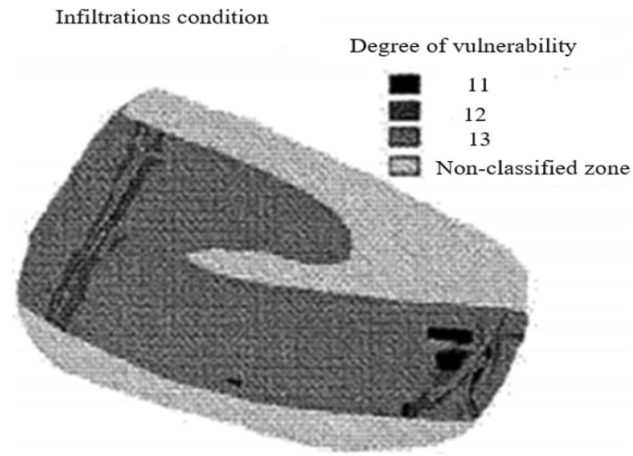


Fig. 7 Beauraing area parameter map

(Werner and Gallagher 2006). The statistics of ground aquatic are shown in Table 2, and its advantages and limitations are described in Table 1.

Groundwater parameter estimation with MODFLOW

Besides, the comparative analysis of groundwater is described graphically. Based on parameter change, the shape of graphs differs. Also, for different approaches, different graphs are designed (Gogu and Dassargues 2000). Subsequently, the vulnerability measure is calculated in different scenarios like high, medium, and low.

The initial analysis level is to validate the effect assessment. The assessment details are exposed in three graphs (Rizeei et al. 2018). Moreover, the weighting parameters of each area are differed based on its groundwater resources. The water utilized for drinking is colorless in nature and free from microorganisms—the pH analysis of groundwater amidst 6.9 to 7.9. The separation of groundwater for irrigation is processed with the usage of pH values (Singh et al. 2015). The expansion of resource groundwater has maximized manifold in wide range plains. In complicated multi-frame alluvial foundations, the lightest phreatic water is most susceptible to anthropogenic contamination and highly vulnerable to saline intrusion.

Moreover, the groundwater framework in the alluvium is enclosed as it covers chemical adjustment influences and trends. Also, aquatic chemistry awareness is significant to measure the value of ground aquifers to understand the irrigation for domestic needs (Sbai 2020). Thus, the beauraing area parameter map is described in Fig. 7. The hydrogeological examination was supported to get knowledge about natural aquatic elements and their mode of operations. The thickness of clay and sand manages the accessibility of the underground aquifer in the alluvial area. The liberation of adulterated groundwater streams might result from a wide range of surface aquifers. Besides, the quality of aquifers plays a crucial task in agricultural lands because the dirty water may spoil the agricultural fields.

The terminated manipulation of ground aquatic has adversely exaggerated the ground aquifer model in Varanasi zone feature relations. Moreover, the qualitative investigation aquifer revealed the comprehensive corrosion of extent bounces in the zone of Varanasi area. The depressing aquatic table augmented existence, and the hardness of poisonous toxic metals indicates the quality degradation of the ground aquifer. A complete exertion of the ground aquifer framework contains

- Administrator
- Policy fabricators
- Social campaigners
- Mutual masses
- Academicians

Results and discussion

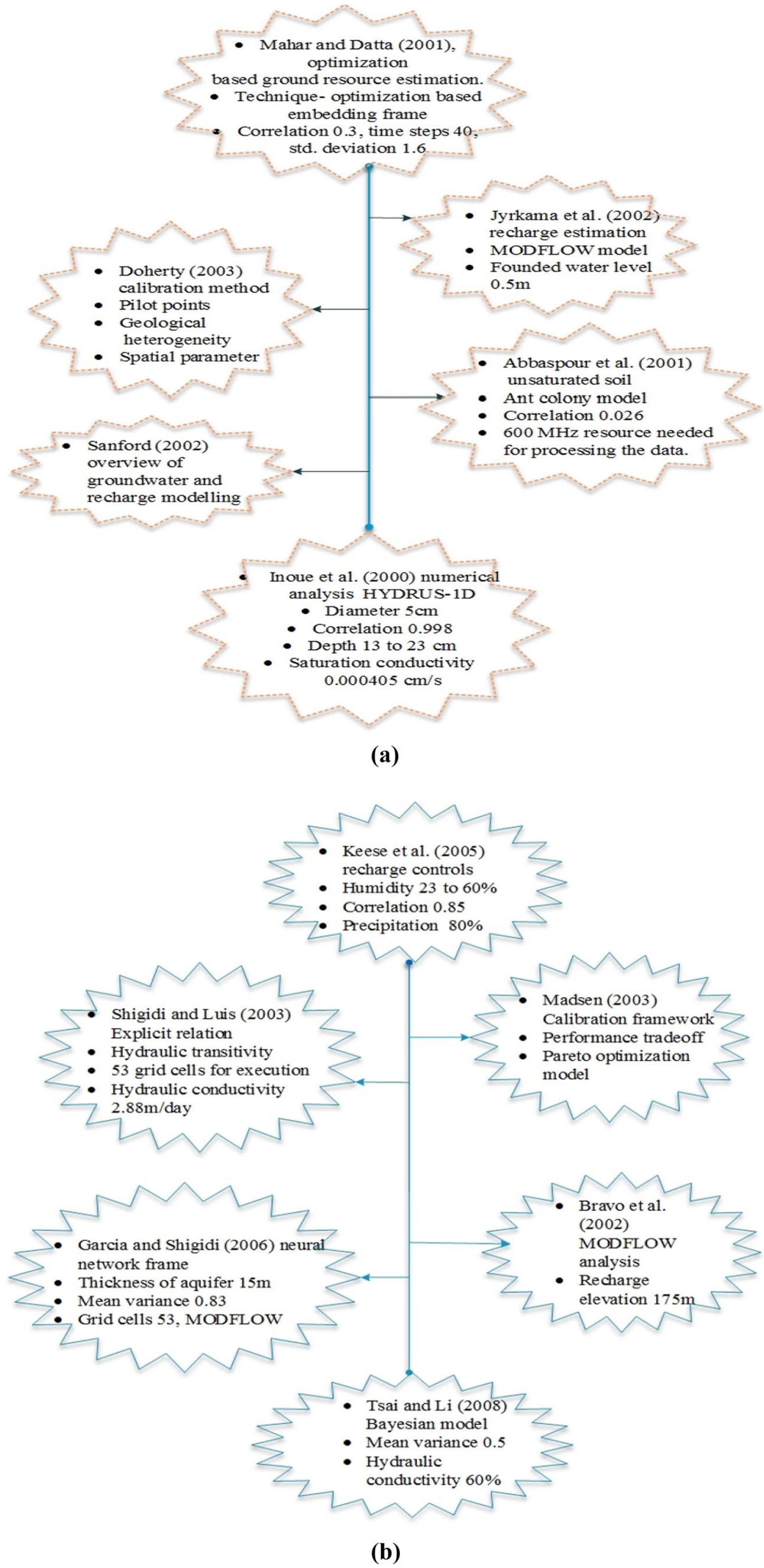
A novel index frame for framing the groundwater stage time sequence and the behavior of drought conditions is explained. In all frameworks, the modeling of the ground aquifer is designed based on rainfall rate. Moreover, by the recorded precipitation rate, the climate parameter variations are validated. Several frame systems of groundwater modeling for different regions are estimated differently.

The groundwater parameter validation by some research methods is elaborated in detail in Fig. 8. Moreover, the concentration of salt in minerals is calculated using the present electric-based conductance of water. Attaining a huge conductance measure might result in a high concentration of ionic substances.

Table 2 Statistics about groundwater parameters

References	Methods	Rain fall in dry condition (%)	Area	Recharge device depth (wide/ depth) (m)	Pumped time (min)	Correlation	Evapo-ration (%)	Rainfall (mm)	Annual (%)	Recharge filter cylinder diameter (m)
Bouwer (2000)	Aquifer recharge frame	0–2	–	1/5	30	0.26	50	30–50		30
Chowdhury et al. (2010)	Aquifer recharge frame with GIS	1–3	West Bengal	3/6	–	0.78	20	5–10	40	40
Omar et al. (2019)	Aquifer recharge modflow	1.5–20	Varanasi	33/101	180	0.008	–	96–290	55	-
Chung et al. (2010)	MOD FLOW	18	South Korea	0.9/0.95	1	0.86	30	144–342	69	
Luiso et al. (2018)	Aquifer mapping	–	–	60	3	0.58	40	100	88.5	200
Ouedraogo et al. (2016)	Nitrate concentration based aquifer mapping	13	Africa	0–7	10	0.36–0.65	–	225	37	14
Mishra et al. (2019)	Cluster analysis	12	Varanasi	76	15	6.9		480		–
Sener and Davraz (2013)	Potential analysis	20	Jordan	10–25		0.7	50	200	84	60
Gogu and Dassargues (2000)	Drastic comparative analysis	15		15	10	0.3	75	500	85	75
Werner and Gallagher (2006)	Assessment and mapping	12	Italy	5	15	0.26	–	100	30	25
Rizeei et al. (2018)	Parametric method	17	Beauraing	18–40	–	0.76	80	90	40	80
Raju et al. (2011)	Geological study	16	Varanasi	3/7	17	0.6	50	80	80	75
Singh et al. (2015)	Hydrochemistry	29	Varanasi	1.43	–	0.5	70	–	90	–

Fig. 8 Performance analysis of some groundwater modeling schemes



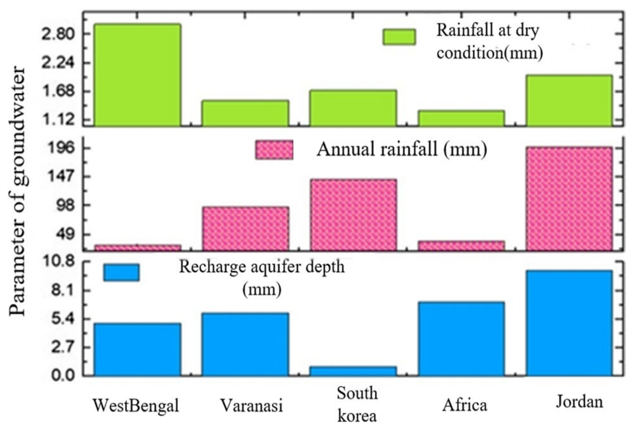


Fig. 9 Rainfall rate and aquifer depth of some research works

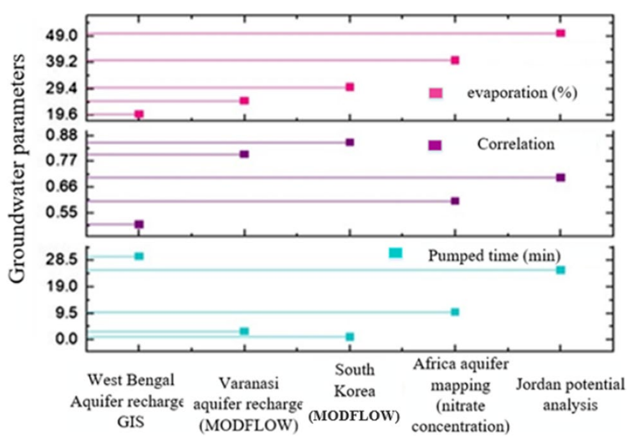


Fig. 10 Key metrics evaluation of several research mechanisms

The behavior hardness of water occurs due to the anions and cations. Henceforth, the measure of aquifer depth and rainfall is detailed in Fig. 9. Moreover, the polluted water in agricultural land might cause severe diseases for the living organisms. For the groundwater investigation, the range of both post-and pre-monsoon is evaluated.

Also, the chemical substance of the ground aquifer is calculated with the support of pH assessment evaluation. Mostly, the pH assessment validation is processed to find the present alkaline elements in the ground aquifer.

The chief metrics of ground aquifer modeling are detailed in Fig. 10. Based on these calculated vital metrics, the modeling of the ground aquifer is processed efficiently. Thus in Fig. 10, the required chief metrics are discussed and evaluated for different regions under diverse climatic conditions.

Summary

Several discussions revealed that a recharge system is crucial to investigate the groundwater levels from the comprehensive review articles. Also, the process of artificial recharge frame is differed based on the ground hardness and conditions. After estimating the ground conditions, the spatial distribution graphical representation is designed to point out the ground conditions. The measure of chemical components is higher before the rainfall season while compared to the post-monsoon period.

Conclusion

Several metrics and limitations are discussed to frame groundwater modeling. Most research works unveil that structuring the framework to estimate groundwater is difficult and complicated. Furthermore, some of the models have attained more time to complete the process.

The groundwater flow model is based on the unstructured gridding technique that involves the rectilinear grid, categorized as octree, voronoi, and quadtree grids. Moreover, these models are based on the MODFLOW engine that describes the difficulties of heterogeneous generations for both single and multilayer. This developed model can support the groundwater flow model iterative updating from the rectilinear grid to the unstructured grid model. The groundwater flow modeling is an important and essential tool to conceptualize the hydrogeological functions and predict groundwater pollution. Thus, the MODPATH and optical MODFLOW model are utilized to implement the groundwater flow model's direction and pollutant fate. In this model, visual MODFLOW is used to identify groundwater flow direction, path lines, and forecast the leachate contamination in the Ganga River at Varanasi, West Bengal, South Korea, Africa, Jordan, Italy, and Beauraing.

Additionally, this paper utilized a modular 3D finite variation of groundwater MODFLOW, which established attaining several difficulties of undefined boundary situations. Hence, this article discussed several topics like aquifer mapping, artificial-based recharge system, MODFLOW system frame, etc., in regions like Varanasi, Korea, Africa, etc. Furthermore, the parameters of the ground were evaluated and presented in the graphical and tabular model. So, in future framing, the optimized deep learning-based neural model will improve the groundwater estimation accuracy.

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Declarations

Conflict of interest The authors declare that they have no potential conflict of interest.

Ethical Approval All applicable institutional and/or national guidelines for the care and use of animals were followed.

Informed Consent For this type of study formal consent is not required.

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