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Geospatial Tools and Techniques for Ground Water Management: A Review

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Abstract: Groundwater is the primary natural resource for drinking, irrigation, agriculture, and industrial purposes and the fresh groundwater reserves are rapidly depleting. There has been a significant increase in the usage of potable water globally due to the growing needs of the world population. Annually, there are lots of fluctuations in the levels of groundwater which has to be analyzed frequently to manage groundwater resources efficiently. But, detecting and analyzing them manually is a tedious process. The geospatial techniques help the users to store, conserve and manage groundwater resources effectively. This paper addresses, various geospatial modelling techniques involved for the analysis of groundwater resources. In today's world, there are many geospatial techniques developed to understand the availability of groundwater from which commonly used 10 tools and techniques of groundwater analysis are discussed in this paper to help the researchers working in this environment. Data, tools, methods, software used and their application to determine groundwater resources are conversed to gain knowledge on the quantity and distribution of groundwater. Diversified literature reviews on groundwater analysis were studied to analyze the groundwater, using geospatial techniques. The ten tools and techniques discussed in this study are Weighted overlay analysis, Analytic Hierarchy Process (AHP), Visual Mod flow, SWAT- MODFLOW, Spatial interpolation, Kriging method, LISA (Local Indicators of Spatial Autocorrelations), GRACE, GS FLOW, and Hydrus-1D. All these techniques are analyzed by working in the geospatial environment of Remote Sensing (RS) and Geographic Information Systems (GIS). It is found that satellite images, existing thematic maps, water levels, and aquifer data acquired from various organizations have been used to assess groundwater quantity. These tools and techniques have enabled to understand the importance of evaluating and monitoring the groundwater resources and also the data required to investigate and identify potential sites to prevent groundwater depletion. This study helps the users to explore the scenario for future planning of groundwater resources in an efficient manner. Hence, it is befitting for us to explore various techniques and methods for the proper exploration, management, consumption, and conservation of groundwater.

Keywords: Groundwater, Geospatial tools and techniques, Groundwater management.

Introduction

Water availability in almost one-third of the earth's surface in arid and semi-arid regions of the world cannot be efficiently used to quench the thirst of all living organisms. The main source of groundwater is the infiltrated water through the pores of the land surface. The infiltration of surface water depends on the type of soil strata which contribute to groundwater. This groundwater resource acts as the major source for irrigation, drinking, agriculture, and industry purposes in India. As the groundwater is limited to the zones of fractured and weathered rocks, there are constraints to the availability of groundwater. A study by U.N. Environment program shows that the construction industry consumes 30% of fresh water and generates 30% of the world's effluents. India has mostly hard rocky terrain, as a result, most regions in India are water scarce leading to the extreme conditions of over-pumping and an increased number of bore wells in many regions. Many of the states in India may be suffered, if proper measures to manage groundwater are not done. Then there will be a serious life-threatening crisis involving all the sections of our society. The frequent failure of monsoons due to global warming and over-exploitation of groundwater leads to the hasty decline of groundwater levels in many segments of India. There is a decline in the groundwater table due to the overconsumption and over-exploitation of water. To accommodate the needs of all the people and also looking into future endeavors we need to explore groundwater potential zones. A groundwater potential zone is defined as an area where the occurrence of groundwater is comparatively high or low. This study focuses on ten geospatial tools and techniques including, weighted overlay analysis, analytical hierarchy process (AHP), visual mod-flow, SWAT-MODFOW, spatial interpolation, kriging method, LISA, GRACE, GSFLOW and Hydrus-1D. To demarcate the suitable zones for artificial recharge of groundwater, geospatial tools, and modeling techniques help to categorize and determine LULC changes, geology, geomorphology, aquifer and terrain characteristics. These techniques help the users for the innovative planning, management, and utilization of groundwater resources. LULC changes provide information of various features such as vegetation, built-up area, barren land, and water bodies available on the earth surface. Geology parameter gives information of rock layers which lie beneath the earth surface, whereas porosity determines its capacity for infiltration. Geomorphology involves the study of the physical features of our earth using geospatial data acquired from various resources. Terrain characteristics will help the user to understand the topography of the land surface. Geospatial data containing information about the physical and biological components has been integrated together to get a futuristic planning model. Analytic Hierarchy Process (AHP) is the widely used method and has been successfully applied with the RS-GIS technique to assess the groundwater potentiality in various regions. Geographic information system helps us to form a framework for gathering managing and analyzing data helping us to interpret the influences of various parameters. Recent practices such as the application of geospatial tools and techniques are extremely convenient to extract the potential zones of groundwater for a larger area. The speed at which the groundwater exploitation has occurred will not allow the water table to recover its losses. This resulted, in shallow aquifers to dry up and created drought-like circumstances over large portions of the country and the world which leads to a global crisis and therefore needed to be addressed immediately. Therefore, this study helps to understand the ten geospatial tools and techniques available to analyze groundwater exploration procedures nationally and internationally.

Tools and Techniques

Weighted overlay Analysis

Weighted overlay analysis is a technique applied for common measurement for a given set of weightages according to the influence of the parameters and inputs to create an integrated analysis. The factors which are affecting the analysis of the study may not be equally influencing all the parameters. To overcome this, we assign weights to different factors in the analysis. Various techniques to assign the weights are pairwise comparison, trade of analysis, rating, and ranking. The principle of overlay analysis is created based on the overlay of georeferenced cell in a layer through the georeferenced cell of another thematic layer. The weight which we give to the thematic layers will be assigned against a common scale which results in the integration of all thematic layers to get an ultimate output layer. The total weighted index of influencing weight value is obtained by multiplying the scale weight with the percentage of each class. Weighted overlay analysis is generally performed to investigate the groundwater potential zones. Geospatial data used to analyze weighted overlay analysis is toposheets, soil map, geology, geomorphology, and rainfall data from various government departments such as Public Works Department (PWD), aquifer details such as specific yield, porosity, permeability, and transmissivity are gathered from Central Groundwater Board (CGWB). Digital Elevation Model (DEM), Soil data and Land use Land cover (LULC) can be collected from online resources such as USGS earth explorer, BHUVAN, EARTH DATA, Indian Remote Sensing, and GIS websites etc. The multiple factors involved to analyze weighted overlay analysis are rainfall, drainage, slope, soil, geomorphology, geology, lineaments, lithology, land-use land- cover, permeability, specific capacity and transmissivity. The data collected is enhanced and digitized in Arc GIS Software to generate various thematic maps such as slope, drainage density, lineament density, lithology and rainfall, etc., with the data management tools of ArcGIS. From this analysis potential zones of groundwater are classified into four groups such as poor, moderate, good, and excellent, or into five categories such as very low, low, medium, high and very high zones. This method is beneficial to establish potential zones of groundwater and the abstractions of groundwater can be conserved, managed, and planned in an improved way (Surjit Saini et al., 2012, S.P. Rajaveni et al., 2017, Suganti et al., 2018, Janiella et al., 2019).

Analytic Hierarchy Process (AHP)

The multi-parametric evaluation process which involves complex decision-making and criteria relating to the goal of a process. It is mainly used in site selection and suitability analysis of factors affecting the due course of the process. In this process factors, variables and alternatives are given to analyze the model. This method helps us to solve complex problems involving hard numbers. Also, in understanding the problem and to arrive at a result. This result is obtained by choosing the best-suited value. Lots of research is done using multi-criteria analysis-based AHP to identify potential sites of groundwater using RS and GIS techniques. The research initiative is taken to detect potential groundwater recharge zones using RS and GIS techniques. AHP has been used to locate the potential zones of groundwater and later a LSTM (Long Short-Term Memory) model is created to forecast seasonal groundwater levels in the potential groundwater recharge zones for the forthcoming five years (Ahmed et al., 2020). Differently ranked potential values of groundwater recharge are identified to analyze multi-criteria AHP and Catastrophe theory (CT) with seven thematic layers such as precipitation, lithology, soil, slope, drainage, land use, and groundwater level distribution parameters. Finally, both the methods AHP and CT were observed and compared and have predicted that CT is more accurate (Minea et al., 2022). Groundwater potential zones were identified and delineated to enhance groundwater resources and the geospatial thematic maps for parameters such as drainage, topography, lineament, geomorphology, geology, rainfall, soil, land use and land cover are generated and weighted overlay analysis was applied to attain groundwater potential areas. With the multi-criteria decision-making technique and to allow pairwise comparison criteria of AHP was used to generate a groundwater potential map. The reclassification of the groundwater potential map is made into five classes as very low, low, moderate, high and very high. In addition to this, results were validated using water level well yield data for pre-monsoon and post-monsoon seasons. The results were found to have good correlation with one another (Thiyagarajan et al., 2020). With the aid of remote sensing and GIS techniques, groundwater potential zones were assessed by analyzing available spatial data such as geomorphology, geology, and soil maps. Lineament, LULC maps were generated using LANDSAT-8 Satellite image. The SRTM DEM data was used to prepare terrain characteristics in the form of slope and drainage maps. Later all these maps are converted to raster format and AHP is applied to rank, weight and reclassify the maps using the ArcGIS environment. Overlaying the maps was made to generate a groundwater prospect map and the groundwater potential zones were divided into 5 classes from very poor to very good. Later, the cross-correlation coefficient method is applied to rainfall, well yield, and groundwater level data to validate the results (Ajay Kumar et al., 2020).

Visual MODFLOW software

Hydrogeologists use this software to understand the behavior of the groundwater by taking into account the lithological, soil properties, drainage systems, and flow parameters. It also includes the information about the contaminants of the given groundwater area. This software is efficient and fast, it has power data visualization, multiple models can be efficiently managed, the software is completely integrated with GIS, and flexible grid options are also available. Visual MODFLOW is a graphical user interface for the USGS MODFLOW. For its user-friendly features, popular among hydrogeologists and is a commercial Software. MODFLOW 6 is the latest version of visual mudflow released in 2022. Researchers can generate the groundwater model using MODFLOW 6 as it has multi-tasking capabilities to perform multiple types of models in one single simulation. The surface water flow model is coupled with numerous local-scale groundwater models. The step-by-step procedure of groundwater model development suggested by Anderson and Woessner in the year 1982 is demonstrated. The first step is to characterize the hydrogeological features. The second is to conceptualize the model development. Thirdly to select the model software, the fourth step is to calibrate and verify the model. Later the sensitivity analysis is evaluated for alternatives of predictive simulation and to check the monitoring performance of the model. A review on the previous research of Visual MODFLOW is also explained from the year 1999 to 2016 (Hariharan et al., 2017). Geospatial and groundwater modelling techniques have been used to delineate suitable sites for the artificial recharge of groundwater. Data preparation of thematic layers is made for SRTM-DEM, LISS-IV, and aquifer parameters were prepared from pumping test data and during the field visit well inventory data is collected to integrate all the parameters using weighted overlay analysis in the GIS environment to generate artificial recharge potential zone map. Considering local conditions and terrain characteristics drainage network map is superimposed onto the artificial recharge zone map. To model and determine potential zones of groundwater for artificial recharge, visual MODFLOW flex software is also utilized. For creating simulations of modeling the groundwater zones, material such as specific yield, hydraulic conductivity, aquifer thickness, water level and lithology is used. Lastly, a comparison of groundwater modeling zones and artificial recharge zone map is carried out to validate artificial recharge zones. At the same time, the impact of discharge to surrounding aquifers is also determined as a case study. Thereby groundwater modeling and geospatial techniques were proved to be efficient to delineate and implement the suitable site selection of groundwater artificial recharge zones (Avtar Singh et al., 2019). The flow dynamics of groundwater using MODFLOW in shallow aquifer systems have been assessed in recent studies of research. Outflow discharge from the aquifer system to stream networks and inflow discharge from the stream networks into the aquifer system in a different time period was perceived for monsoon, post-monsoon and pre-monsoon periods as the extraction of groundwater is different in different seasons. A single-layer model is abstracted based on lithology, geology, groundwater level data sets and river boundary conditions. Through the aid of Visual MODFLOW software, the conceptual model is translated into a numerical model. The model is gridded into rows and columns and each cell consists of 600m X 600m blocks. With the help of an ASCII file the ground elevation and layer elevation data are imported into Visual MODFLOW. Hydraulic head data is collected from CGWB and the calibration and validation of the model is made to analyze annual, monsoon, pre-monsoon, and post-monsoon head data. Boundary conditions of head-dependent flux boundary are determined based on the study area of the river flowing in that region. Hydrological parameters such as evapotranspiration, specific yield, hydraulic conductivity and its corresponding vertical conductivity is considered during the calibration of the groundwater model. Calibration of the model is made through a trial-and-error process to maintain steady-state conditions. Later the model is run for the no. of years required based on the study. When the computed head value is nearer to the observed head value the simulation of the groundwater is assumed to be a good fit (Behera et al., 2022).

SWAT MODFLOW

It is an integrated hydrological model that couples SWAT land surface procedures with spatially explicit groundwater flow developments. QSWATMOD is an open source QGIS-based graphical user interface that enables to link SWAT and MODFLOW, run SWAT-MODFLOW simulations, perform calibration and validation to view the results. Estimation of groundwater recharge was made by integrating SWAT and MODFLOW models. The Hydrological Response Units (HRU) generated in the SWAT model are replaced with MODFLOW cells by applying SWAT MODFLOW interface to reproduce the groundwater head distribution and artificial recharge rates. Geospatial data such as LULC, DEM, Soil, slope, rainfall and aquifer parameters such as aquifer thickness, specific yield, and hydraulic conductivity data are collected from the available sources. Groundwater recharge rates of seasonal and decadal trends are assessed and the model is calibrated and validated using groundwater levels and stream flow data (Loukika et al., 2019). QGIS-based graphical user interface QSWATMOD is applied and evaluated to generate SWAT - MODFLOW models. QSWATMOD comprises of pre-processing modules to create input data for model execution, configuration modules to utilize SWAT-MODFLOW options and post-processing modules to assess and interpret model results. As QSWATMOD is an open source that increases the number of users worldwide and acts a valuable tool to assist, create and manage SWAT-MODFLOW models (Seonggyu et al., 2019). Quantification of the streamflow response to groundwater abstractions for irrigation or drinking water at catchment scale using SWAT and SWAT-MODFLOW is analyzed. Implementation of the widely used semi-distributed hydrological model SWAT and a recently integrated Surface-subsurface model SWAT- MODFLOW is applied in both SWAT and SWAT-MODFLOW to test the groundwater abstraction scenarios (Wei Liu et al., 2020, Yunging Xuan, 2018). Water balance components in irrigated agricultural watersheds were determined using SWAT and MODFLOW models. SWAT model is used to determine the time of irrigation and fixed amounts for each Hydrological Response Unit (HRU) on daily basis. Model assessment criteria, RMSE (Root Mean Square Error), and NRMSE (Normalized Root Mean Square Error) for the simulated groundwater level were evaluated and the simulation of surface water flow at the basin outlet is also predicted. Geological characteristics such as permeability, LULC, slope and soil units such as soil depth, soil texture of the study area are tabulated. To simulate the groundwater recharge and river flow the recharge and river packages of the MODFLOW model are used. Recharge rates obtained by the SWAT model are imported into the MODFLOW recharge package (Shima Nasiri et al., 2022).

Spatial Interpolation

The interpolation involves the calculation and locating the position of an unknown data point or area by using and creating a relationship between the known and the unknown positions. Other forms of data that can be estimated using interpolation include precipitation, elevation, water table, snow accumulation, and population density. To generate a continuous map suitable interpolation approach has to be employed to optimally estimate the values at those sites where no samples or measurements were taken. There are many interpolation methods. Spatial data interpolation methods are of different types, such as TIN (Triangulated Irregular Networks), IDW (Inverse Distance Weighted) method, RBF (Radial basis functions) Trend Surface analysis, Kriging and polynomial techniques. In recent studies, analysis of Spatio-temporal variation of groundwater levels is done using IDW by collecting location and depth to water level data. Groundwater recharge and their variations were analyzed for annual, pre-monsoon, and post-monsoon seasons of observation wells near the rejuvenated tanks (Chakilam Sree Laxmi Pavani et al., 2022). Spatio-temporal analysis of groundwater levels for a long term by applying

IDW spatial interpolation analysis using GIS techniques is detected. Along with spatial analysis trend analysis and Sen's slope estimator test was also performed to compare the results. The analysis was made for annual, pre-monsoon and post-monsoon seasons (B. Anand et al., 2019). ArcGIS geo-statistical module is utilized to determine the variability of Spatiotemporal groundwater levels. Different interpolation models were evaluated by IDW, GPI (Global polynomial interpolation), LPI (Local polynomial Interpolation), TSPLINE, OK (Ordinary Kriging), SK (Simple Kriging), and UK (Universal Kriging) to generate the groundwater level model, absolute errors, mean errors and root-mean-square errors are calculated for each method to choose the best-fit model. The spatial interpolation technique can be applied to analyze many other factors such as hazard mapping, estimating soil moisture, rainfall and missing rainfall data, the spatial distribution of soil, mapping of physical and hydro-physical properties of soil and many more methods (Yong Xiao et al., 2016).

Kriging Method

Kriging is one of the spatial interpolation techniques applied to address various geospatial problems. Groundwater level variations are geospatially analyzed using the Kriging method to explicitly investigate the spatial distribution of groundwater levels and crucial zones. Groundwater level data of monitoring locations is collected and variogram models are been plotted for the data collected and three Kriging method models such as exponential, spherical and gaussian are used for analysis. Variogram is half of the variance sum of the increment that is the regionalized variables Z(x) at the x and x+h. The usual theoretical variogram which fits the function model are exponential, spherical, power function, gaussian and logarithmic function model. The best variogram model is gained by comparing four statistical goodness-of-fit measures (RMSE, ME, ASE, RMSS). The Ordinary Kriging is finally applied in the ArcGIS platform to predict the analysis of water levels and their variance. To evaluate the accurateness of predicted spatial-level differences, ordinary kriging, cross-validation technique is applied (Rasel et al., 2019). Framework for upgrading groundwater level monitoring network and piezometric levels two linear kriging methods is used i.e., Ordinary Kriging (OK) and Empirical Bayesian Kriging (EBK) to interpolate the scattered dataset. From cross-validation results, EBK is found to be the best-fit method. Accurate groundwater level distribution maps were generated to delineate the high-risk zones of seawater intrusion. As additional well information had to be added to estimate the potential zones, the highest priority indices and the density sampling network tool were added to investigate the observation network. The DSN tool and priority index is applied to predict the standard error (Bouhout et al., 2022).

LISA (local indicators of spatial autocorrelation)

LISA involves the correlation between the surrounding area and then data for the given area is calculated. When an area with unsymmetrical boundaries or boundaries with a lot of fluctuation is required to be calculated then the information of the areas surrounding the given area must be taken into account involving spatial correlations which indicate the local points of data. The LISA Cluster Map depicts significant sites that are color-coded according to the type of spatial autocorrelation. The LISA for each observation indicates the amount to which similar values are clustered spatially around that observation. Concepts of LISA can also be determined to map salinization and its trace elements in the groundwater, spatial correlation of tourism, logistics, and cultural industry, analysis of covid-19 cases, spatial patterns of vegetation fragmentation, drought hot spot analysis, and spatial distribution analysis of seismic activity and many more. It is observed that, the research work using LISA for analyzing the groundwater levels is very less. Therefore, this method can be used and studied further to increase the usage of LISA techniques in groundwater analysis. To assess the groundwater quality and its availability geospatial techniques were applied to sustainable groundwater management. Depth to water level and electrical conductivity data is collected for the study area. Later statistical analysis, gradient analysis, surface interpolation, and LISA techniques were used to analyze the availability and quality of groundwater (Gunaalan et al., 2018).

GRACE (Gravity Recovery and Climate Experiment)

GRACE mission is first introduced by NASA to directly measure groundwater storage from space. Scientists can evaluate changes in the amount of water stored in a region by perceiving changes in the earth's gravity field. More than 10 years of data is provided by GRACE for scientific research analysis.

At the global scale GRACE satellite observations are incorporated into NASA's Catchment Land Surface Model (CLSM) to generate time series of the groundwater storage. Evaluation using in situ data of 4000 wells has shown that GRACE data assimilation has improved the simulation and correlation of groundwater, and by reducing estimation errors at the level of regional and point scales. Affirmative effects of GRACE data assimilation are established using observed low-flow data. Permeability factors are also examined for the performance of GRACE and CLSM data assimilation. But, while simulating realistic groundwater fluctuations of groundwater for intensive groundwater extraction, GRACE data assimilation failed to compensate for the withdrawal scheme of groundwater in CLSM. Twelve months of precipitation anomalies in low and mid-altitude areas are simulated under CLSM (Bailing Li et al., 2019). Groundwater storage (GWS) change was assessed with RL05 land data product which can be accessed from the GRACE satellite. Global Land Data Assimilation System (GLDAS) is used to derive canopy water storage, Soil moisture, NOAH, and snow water equivalent was subtracted from Terrestrial water storage (TWS) for extracting the groundwater component and its storage in different parts of Indian regions. GRACE/GLDAS has obtained total groundwater storage in cm and the Global positioning system (GPS) has derived vertical distortion of the International GNSS services (IGS) station at IISc Bangalore. GWS mapping values achieved by the GRACE mission are accurate (Tandrila Sarkar et al., 2020). Spatio-temporal groundwater storage variations are estimated using GRACE satellite data. To assess the uncertainty of GRACE – TWS anomalies, variance variability, time and space of GRACE GWS anomalies Generalized Three-Cornered Hat Method (GTCH) and Empirical Orthogonal Function (EOF) analysis is used (Shoaib Ali et al., 2022).

GS Flow

GS FLOW is a coupled Groundwater and Surface-water FLOW model constructed based on the incorporation of the USGS Modular Groundwater Flow Model (MODFLOW-2005 and MODFLOW-NWT) and the USGS Precipitation-Runoff Modeling System (PRMS-V). GSFLOW was established to simulate and model coupled groundwater/surface water flow in one or more watersheds by concurrently simulating flow across the land surface, saturated and unsaturated materials, subsurface, and within rivers, streams, and lakes. The driving aspects for GSFLOW simulation are climate data consisting of estimated precipitation, solar radiation, air temperature, groundwater stresses (such as withdrawals), and boundary conditions. A conceptual framework of model characterization, transference and data linkages, model calibration and sensitivity analysis procedures of GSFLOW are discussed to reduce the time and efforts required to generate and link the models (Chao Chen et al., 2018). A MODFLOW groundwater system is developed and coupled with the PRMS model and the integration of hydrogeologic features were represented. The conceptual model of GSFLOW was applied to case study of MODFLOW by coupling MODFLOW with PRMS. Data linkages were assigned to water percolation, evapotranspiration, and streamflow. Later the model is calibrated and sensitivity analysis is performed to check the impacts of surface/subsurface water interfaces on the integrated system. (Chao Chen et al., 2018). GSFLOW model is used to map the interflow potential and the validation of index-overlay weights. To assess the interflow potential and quantify the interflow in the downstream area of the river, interflow potential was first evaluated based on the modified index-overlay model, using AHP to compute the weights and ratings of the selected factors. Then the GSFLOW model is linked to the index-overlay model to estimate the interflow potential for practical purposes. To evaluate the effect of rainfall-induced variations on the interflow, Monte Carlo simulations were used (Chuen-Fa et al., 2021). Using pyGSFLOW, integrated hydrologic model development and post-processing for the GSFLOW model is made for effective management of limited water resources. PyGSFLOW is a python package designed to create GSFLOW-integrated hydrologic models, read existing models, edit input data, run GSFLOW models, process output and visualize model data. pyGSFLOW package architecture contains GSFLOW module and 5 sub-packages such as prms, modsim, modflow, output and utils. MODFLOW package contains Flopy interface that allows users to create new MODFLOW packages to edit existing packages (Joshua et al., 2022).

HYDRUS-1D

Hydrus-1D is an open-source windows-based modeling platform for analyzing water flow and solute transport in unevenly saturated porous media. HYDRUS-1D software package contains 1D finite element model HYDRUS-1D to the sub-basin due to precipitation is determined. To perform this, wells were drilled to a depth of 20 to 50m to observe the groundwater recharge and to collect the necessary field data for the generation of numerical for simulating the movement of groundwater, heat, multiple solutes, and the saturated media. Numerical investigation of natural recharge model. Climatological data is collected from weather stations of the study area. Later the numerical model Hydrus-1D is calibrated using collected field data. Soil and aquifer characterization is performed and the aquifer recharge due to precipitation was evaluated (Tonkul et al., 2019). To estimate recharge rates re-examination of the delta aquifer was made to employ new methods and data by using HYDRUS-1D. To analyze the historic recharge and to model the soil water fluxes in the unsaturated zone, twelve 1D models were created using HYDRUS-1D software. Data measured from remote weather stations such as hydraulic conductivity, soil moisture content, soil texture distribution, and soil temperature data were prepared to run the models. Calibration and validation are made using the inverse calibration method by giving the measured moisture contents as input to calibrate the model and have checked for RMSE value. Soil texture distribution is roughly estimated across the aquifer to assess the final recharge estimate. Due to restrictions in the HYDRUS-1D model, modeling was limited to less than a year. Model start dates, snowpack heights assumptions and initial soil moisture contents were best estimated using HYDRUS - 1D software package. Finally, significant effects on the resulting groundwater recharge are estimated (Madison et al., 2022).

Table 1. Summary of Groundwater methods, Software, tools, data, and their application.

Sl No	Methods	Softwares and Tools used	Data Used	Output / Result
1	Weighted Overlay Anal	ArcGIS, QGIS, ERDAS, ENVI	Toposheets, DEM, LULC, Soil data, thematic maps, online resources	Analysis of groundwater potential zone map
2	Analytical Hierarchy Process (AHP)	Arc GIS, QGIS, LSTM	LANDSAT data, SRTM/USGS (DEM), Thematic layers, Catastrophe theory (CT), well yield data	Identification of groundwater potential zone map
3	Visual MOD-Flow Software	Visual Mod-flow Flex	LISS, SRTM/USGS (DEM), aquifer parameters	Validation of ground water model
4	SWAT-MODFLOW	QSWATMOD, SWAT And SWAT-MODFLOW	DEM, LULC, soil maps, River network, HRUs, Sub-basins, aquifer parameters	Groundwater recharge rates, scenarios and decadal trends
5	Spatial Interpolation	Arc GIS, Spatial Analyst Tool, IDW Tool, Local and Global Polynomial Interpolation, TSPLINE	Location of wells as point data, depth to water level well information	Water level fluctuations of annual, pre and postmonsoon seasons, groundwater level modelling
6	Kriging Method	Arc GIS, Ordinary Kriging, Empirical Bayesian Kriging, Simple Kriging, Universal Kriging, Density Sampling Network Tool and Priority Index	Samples of well points, its location &water levels, piezometer levels	Forecasted spatial-level differences, to predict the standard errors, estimation of groundwater potential sites

7	LISA	LISA, gradient and surface interpolation tools	Depth to water level, electrical conductivity	Availability of groundwater
8	GRACE	GRACE, CLSM, GLDAS, GTCH, EOF	Canopy water storage, soil moisture, vertical deformation of water levels, terrestrial water storage and precipitation anomalies	Mapping of groundwater storage and its variations
9	GS FLOW	GSFLOW, PRMS, MODFLOW, AHP & GSFLOW, pyGSFLOW, modified index overlay model	Percolation, evaporation, and stream flow data	Impacts of surface and subsurface water interfaces, integrated hydrologic model
10	HYDRUS-1D	HYDRUS-1D	Well information, meteorological data, soil and aquifer data	Groundwater recharge and soil water fluxes

Conclusions

To manage the groundwater resources geospatial tools and techniques act as a powerful tools to delineate the groundwater potential sites. Geospatial technology is found to be proficient to mineralize time, labor, and cost and thus enables making the speedy decision for the sustainability and management of water resources. Table 1 explains the ten commonly used geospatial methods which include data, software, and tools with their applications to analyze groundwater resources. It is observed that Weighted overlay analysis, Analytical Hierarchy Process (AHP), Visual MODFLOW, and SWAT MODFLOW are widely used in various research works. Spatial interpolation and the Kriging method are the influential tools in the ArcGIS environment to perform Groundwater analysis. Softwares such as LISA, GRACE, GSFLOW, and HYDRUS-1D need enhancement in the research areas. HYDRUS-1D can be implemented to check recent changes as the modeling is constrained to less than a year. Integration of interpolation techniques with cluster analysis, gradient analysis, and spatial data analysis is required such that we get a detailed and complete profile of the groundwater system. The system is divided into boundaries using GIS tools based on the study area and then it is subjected to various techniques and data analysis which is more advanced when compared to the analysis of these data individually without integrating them. The overlaying analysis of influencing factors helps to identify the aquifers and the potentiality in them to store water. Based on the research work to be conducted, any of the ten methods can be used to model and generate groundwater resources. This study helps the concerned decision-makers to plan and analyze groundwater zones effectively using geospatial methods and techniques. Groundwater fills the pore spaces in soils and porous/fractured rocks as precipitation infiltrates into these aquifers. However, contamination of surface water is almost instantaneous whereas groundwater contamination is a slow process (1 to 10 years). Contaminants in groundwater are harmless, if their level is below safe limits, as set by the WHO or the National Standards, but above these limits they become pollutants and water may be unfit for drinking, household, agricultural or industrial uses.

References

Abbas, S., Xuan, Y. and Bailey, R. (2018) Improving river flow simulation using a coupled surface groundwater model for integrated water resources management. EPiC Series in Engineering, v.3, pp.1-9.

Ajay Kumar,V., Mondal, N. C. and Ahmed S. (2020) Identification of groundwater potential zones using RS, GIS and AHP techniques: a case study in a part of Deccan volcanic province (DVP), Maharashtra, India. Journal of the Indian Society of Remote Sensing, v.48(3), pp.497-511.

Ali, S., Liu, D., Fu, Q., Cheema, M. J. M., Pham, Q. B., Rahaman, M. M. and Anh, D.T. (2021) Improving the resolution of grace data for spatio-temporal groundwater storage assessment. Remote Sensing, v.13(17), p.3513.

Ali, S., Wang, Q., Liu, D., Fu, Q., Rahaman, M. M., Faiz, M.A. and Cheema, M. J. M. (2022) Estimation of spatio- temporal groundwater storage variations in the Lower Transboundary Indus Basin using GRACE satellite. Journal of Hydrology, v.605, p.127315.

Anand, B., Karunanidhi, D., Subramani, T., Srinivasamoorthy, K. and Suresh, M. (2020) Long- term trend detection and spatiotemporal analysis of groundwater levels using GIS techniques in Lower Bhavani River basin, Tamil Nadu, India. Environment, Development and Sustainability, v.22(4), pp.2779-2800.

Bailey, R., Rathjens, H., Bieger, K., Chaubey, I. and Arnold, J. (2017) SWATMOD-Prep: Graphical user interface for preparing coupled SWAT-MODFLOW simulations. JAWRA Journal of the American Water Resources Association, v.53(2), pp.400-410.

Behera, A. K., Pradhan, R. M., Kumar, S., Chakrapani, G. J. and Kumar, P. (2022) Assessment of groundwater flow dynamics using MODFLOW in shallow aquifer system of Mahanadi delta (East coast), India. Water, v.14(4), p.611.

Bouhout, S., Haboubi, K., Zian, A., Elyoubi, M. S. and Elabdouni, A. (2022). Evaluation of two linear kriging methods for piezometric levels interpolation and a framework for upgrading groundwater level monitoring network in Ghiss-Nekor plain, north- eastern Morocco. Arabian Journal of Geosciences, v.15(10), pp.1-17.

Chen, C., Ahmad, S. and Kalra, A. (2018) A Conceptual Framework for Integration Development of GSFLOW Model: Concerns and Issues Identified and Addressed for Model Development Efficiency. Geoscientific Model Development Discussions, pp.1-18.

El-Meselhy, A., Abdelhalim, A. and Nabawy, B. S. (2020) Geospatial analysis in groundwater resources management as a tool for reclamation areas of New Valley (El-Oweinat), Egypt. Journal of African Earth Sciences, v.162, p.103720.

Gunaalan, K., Ranagalage, M., Gunarathna, M. H. J. P., Kumari, M. K. N., Vithanage, M., Srivaratharasan, T. and Warnasuriya, T.W.S. (2018) Application of geospatial techniques for groundwater quality and availability assessment: A case study in Jaffna Peninsula, Sri Lanka. ISPRS International Journal of Geo-Information, v.7(1), p.20.

Hariharan, V. and Shankar, M. U. (2017) A review of visual MODFLOW applications in groundwater modelling. In IOP Conference Series: Materials Science and Engineering, v,263, p.032025.

Jasrotia, A.S., Kumar, R., Taloor, A.K. and Saraf, A.K. (2019) Artificial recharge to groundwater using geospatial and groundwater modelling techniques in North Western Himalaya, India. Arabian Journal of Geosciences, v.12(24), pp.1-23.

Kanagaraj, G., Suganthi, S, Elango, L. and Magesh, N. S. (2019) Assessment of ground water potential zones in Vellore district, Tamil Nadu, India using geospatial techniques. Earth Science Informatics, v.12(2), pp.211-223.

Larsen, J. D., Alzraiee, A. and Niswonger, R. G. (2022) Integrated hydrologic model development and post processing for GSFLOW using pyGSFLOW. Journal of Open-Source Software, v.7(72), p.3852.

Li, B., Rodell, M., Kumar, S., Beaudoing, H. K., Getirana, A., Zaitchik, B. F. and Bettadpur, S. (2019) Global GRACE data assimilation for groundwater and drought monitoring: Advances and challenges. Water Resources Research, v.55(9), pp.7564-7586.

Liu, W., Park, S., Bailey, R. T., Molina-Navarro, E., Andersen, H. E., Thodsen, H. and Trolle, D. (2020) Quantifying the streamflow response to groundwater abstractions for irrigation or drinking water at catchment scale using SWAT and SWAT– MODFLOW. Environmental Sciences Europe, v.32(1), pp.1-25.

Loukika, K. N., Venkata Reddy, K., Durga Rao, K. H. V. and Singh, A. (2020) Estimation of groundwater recharge rate using SWAT MODFLOW model. In Applications of geomatics in civil engineering, pp. 143-154.

Minea, I., Boicu, D., Chelariu, O. E., Iosub, M. and Enea, A. (2022) Assessment of recharge capacity potential of groundwater using comparative multi-criteria decision analysis approaches. Journal of Geographical Sciences, v.32(4), pp.735-756.

Nasiri, S., Ansari, H. and Ziaei, A. N. (2022) Determination of water balance equation components in irrigated agricultural watersheds using SWAT and MODFLOW models: A case study of Samalqan plain in Iran. Journal of Groundwater Science and Engineering, v.10(1), pp.44-56.

Ni, C. F., Tran, Q. D., Lee, I. H., Truong, M. H. and Hsu, S. M. (2021) Mapping Interflow Potential and the Validation of Index- Overlay Weightings by Using Coupled Surface Water and Groundwater Flow Model. Water, v.13(17), p.2452.

Park, S., Nielsen, A., Bailey, R. T., Trolle, D. and Bieger, K. (2019) A QGIS-based graphical user interface for application and evaluation of SWAT-MODFLOW models. Environmental modelling & software, v.111, pp.493-497.

Rajaveni, S.P., Brindha, K. and Elango, L. (2017) Geological and geomorphological controls on groundwater occurrence in a hard rock region. Applied water science, 7(3), 1377-1389.

Raihan, A. T., Bauer, S. and Mukhopadhaya, S. (2022) An AHP based approach to forecast groundwater level at potential recharge zones of Uckermark District, Brandenburg, Germany. Scientific Reports, v.12(1), pp.1-19.

Rajasekhar, M., Sudarsana Raju, G., Imran Basha, U., Siddi Raju, R., Pradeep Kumar, B. and Ramachandra, M. (2019) Identification of suitable sites for artificial groundwater recharge structures in semi-arid region of Anantapur District: AHP approach. Hydrospatial Analysis, v.3(1), pp.1-11.

Rasel, H. M., Alam, S., Hasnat, A., Hossain, I., Hasan, M. and Ahsan, A. (2019) Geospatial analysis of groundwater level variations using Kriging Method. Jour. Eng. Appl. Sci., v.3(2), pp.21-34.

Saini, S. S. and Kaushik, S. P. (2012) Risk and vulnerability assessment of flood hazard in part of Ghaggar Basin: A case study of Guhla block, Kaithal, Haryana, India. International Journal of geomatics and Geosciences, v.3(1), p.42.

Sandoval, J. A. and Tiburan Jr, C.L. (2019) Identification of potential artificial groundwater recharge sites in Mount Makiling Forest Reserve, Philippines using GIS and Analytical Hierarchy Process. Applied geography, v.105, pp.73-85.

Saranya.T. and Saravanan S. (2020) Groundwater potential zone mapping using analytical hierarchy process (AHP) and GIS for Kancheepuram District, Tamilnadu, India. Modeling Earth Systems and Environment, v.6(2), pp.1105-1122.

Sree Laxmi Pavani, C. and Reddy, K. V. (2022) Analysis of Groundwater Level Fluctuation Near the Rejuvenated Tank Under Mission Kakatiya. In Innovative Trends in Hydrological and Environmental Systems, pp. 809-820.

Sarkar, T., Kannaujiya, S., Taloor, A. K., Ray, P. K. C. and Chauhan, P. (2020) Integrated study of GRACE data derived interannual groundwater storage variability over water stressed Indian regions. Groundwater for sustainable development, v.10, p.100376.

Stafford, M. J., Holländer, H. M. and Dow, K. (2022) Estimating groundwater recharge in the Assiniboine delta aquifer using HYDRUS-1D. Agricultural Water Management, v.267, p.107514.

Tonkul, S., Baba, A., Şimşek, C., Durukan, S., Demirkesen, A. C. and Tayfur, G. (2019) Groundwater recharge estimation using HYDRUS 1D model in Alaşehir sub-basin of Gediz Basin in Turkey. Environmental monitoring and assessment, v.191(10), pp.1-19.

Xiao, Y., Gu, X., Yin, S., Shao, J., Cui, Y., Zhang, Q. and Niu, Y. (2016) Geostatistical interpolation model selection based on ArcGIS and spatio-temporal variability analysis of groundwater level in piedmont plains, northwest China. Springer Plus, v.5(1), pp.1-15.

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