North Asian International Research Journal of Social Science & Humanities

IRJIF I.F. : 5.010

ISSN: 2454-9827 Vol. 7, Issue-11 November -2021

Index Copernicus Value: 57.07 DOI NUMBER: 10.6947/2454-9827.2021.00009.9 Thomson Reuters ID: S-8304-2016

A Peer Reviewed Refereed Journal

GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN GROUNDWATER: CASE STUDY ANALYSIS

***SHAURYA GUPTA**

**Department of Geography The University of Burdwan*

ABSTRACT

Geographic Information Systems (GIS) are versatile tools that have many applications across all areas of study. There are many ways that these tools can be used to monitor and track groundwater resources, and they are valuable for the development and management of groundwater resources. Three case studies were analyzed to assess their use of GIS in groundwater monitoring and sensing, and the techniques used were compared.

KEY-WORDS:- GIS, Groundwater, Geographic, Information.

INTRODUCTION

Geographic Information Systems (GIS) is a tool used to review, analyze, and map spatial and non-spatial data in many ways, and the use of this tool is highly beneficial for the monitoring, mapping, and prediction of groundwater resources. Two of the main ways that GIS is used in groundwater modeling include the development of models and the pre- or post-processing of the modeling data (Das, 2009). The GIS platform is beneficial for modeling groundwater data because of its unique way of joining data in a visual manner, allowing for unseen patterns and trends to become apparent. Some of the most beneficial uses of GIS in groundwater models is the ability to predict movement of contaminated water, monitoring and determining the volume of available groundwater in local areas, prediction of groundwater resources, vulnerability mapping of at risk aquifers, prediction of maximum pumping volumes, evaluation of well draw on resources, and planning of groundwater development (Das, 2009).

BACKGROUND

Groundwater consists of the water that is stored underground in reservoirs or aquifers and makes up 95% of the world's freshwater supplies (National Ground Water Association, n.d.). An abundant natural resource, groundwater is considered a renewable because of how it is recharged from the water that soaks into the soil from precipitation and moves down through cracks and openings in the rock and soil beds. This important water supply provides 38% of the drinking water for the U.S. and provides much of the water used in agriculture and irrigation for the U.S. (National Ground Water Association, n.d.). In most parts of the world, water removed from the ground is replaced by natural process, but in arid and semiarid regions replenishment rate is often exceeded by the rate of groundwater pumping which can cause serious issues (National Ground Water Association, n.d.).

Monitoring groundwater is an important aspect of groundwater management and provides a wealth of important information regarding the health of groundwater reservoirs. One of the primary reasons to monitor groundwater resources is to better understand the aquifer levels under static and pumping conditions, which allows a greater understanding of how development affects the aquifer levels. Additionally, consistent monitoring allows for the determination of how much water can be safely pumped without disrupting the levels of the water tables (Vaux, 2011). Excessive pumping has many negative consequences, such as the drying up of wells, reduced surface water levels, deterioration of water quality, increased expense for water pumping, and the potential to lower the water tables in groundwater reservoirs (U.S. Geological Survey, n.d.).

Environmentally, groundwater is vital for keeping surface water levels at minimum levels and maintaining flow into rivers, lakes and wetlands at levels to sustain the wildlife and plants that depend on these sources (International Groundwater Resources Assessment Centre, n.d.). Climate change impacts groundwater levels through changing weather patterns and increased duration and severity of drought. When a region is in a prolonged drought status, groundwater is stressed through increased use for drinking water supplies and irrigation needs; reduced recharge capabilities and increasing populations add greater stress to these important resources (International Groundwater Resources Assessment Centre, n.d.).

DISCUSSION

Case Study 1: GIS Based mapping of groundwater fluctuations in Bina Basin

The Bina River watershed is a major tributary to River Betwa in Madhya Pradesh, India that has been identified as a vulnerable aquifer facing alarming groundwater decline. This case study was designed to analyze groundwater fluctuations, recharge rates, irrigation practices, and to identify regions that had high potential for increased aquifer recharge (Nayak, Gupta, and Galkate, 2015). Identification of inputs and outputs to the groundwater table is essential for evaluation; inputs mainly consist of rainfall infiltration and leakage from surface water, while outputs mainly consist of withdrawal through groundwater wells and outflow from the aquifer (Nayak, Gupta, and Galkate, 2015).

The Integrated Land and Water Information System (ILWIS) was the GIS used for this study. Because it is difficult to measure groundwater levels at all points of the watershed, interpolation of fixed-point data was necessary for analysis, and the authors used the ordinary kriging technique to minimize estimation errors. The process started with a vector base map containing the watershed boundary, major roads, the drainage network, and the important settlements in the region, with a point map of the measurement well locations added (Nayak, Gupta, and Galkate, 2015). Next, the creation of point maps for the pre- and post-monsoon season groundwater levels for the years 1995, 2000, 2005, and 2010 was completed to allow for further breakdown of water table trends. After experimentation with different parameters, the spherical model was chosen as the best fit for the analysis. Kriging was used to create raster maps from the data showing reduced levels of groundwater, with contour map creation of groundwater table trends for the years selected. The MapCalc operation in ILWIS was used to calculate changes in the groundwater tables and water table fluctuation; fluctuation maps were created from these calculations (Nayak, Gupta, and Galkate, 2015).

Analysis of the groundwater fluctuation maps show that the groundwater decline became more of a problem after 2000, and that the agricultural areas within the bounds of the watershed were declining at faster rates due to over exploitation. Further analysis identified areas in the lower regions of the agricultural fields that were favorable for increased aquifer recharge during the monsoon season (Nayak, Gupta, and Galkate, 2015).

Case Study 2 – Long term monitoring and GIS based determination of groundwater drought propagation, the lower Silesia region, SW Poland

Groundwater drought typically refers to a period in which declining groundwater levels create water related issues in the surrounding region. Groundwater typically is the last resource to be impacted by drought status, unless surface waters are directly fed by the groundwater sources. The study area was in Southwestern Poland, in the region of Lower Silesia, and was chosen due to problems with water management and concerns over properly responding to drought effects. Groundwater in this region is pumped through drilled wells and is the main source of drinking water for the local communities (Gurwin, 2014).

In order to properly identify periods of time in which the region was in a groundwater drought, the authors examined long-term groundwater table measurements. Of the 288 groundwater monitoring points in the study area, 77 were used for calculating the incidence and intensity of drought on groundwater sources (Gurwin, 2014). All points utilized were chosen due to length of operation and placement in major hydrological structures in the region. While shallow aquifers are more at risk from drought status, due to the information available and monitoring stations used, this study focused on the risk of depletion on the strategic regional groundwater resources (Gurwin, 2014).

This case study used ArcGIS Spatial Analyst and Model Builder to make calculations and create the different maps used for analysis. Several thematic layers were used as input data sets to build the model. The first two layers used looked at the occurrence of droughts and the distribution of topographical zones; these layers allowed for the identification of areas with high levels of vulnerability (Gurwin, 2014). The next three layers looked at groundwater resource exploitation, groundwater resource water permits, and groundwater intake. These three layers examined human activity on groundwater supply, and when combined with the first two layers allowed for identification of areas most susceptible to groundwater shortages. The final layer used looked at drainage associated with mining activities and allowed for verification of impact from these activities (Gurwin, 2014).

The kriging method was used to convert point values for spatial examination, and outlier values were removed for a more accurate analysis. Three periods of time were identified as long-term groundwater drought; autumn 1982 to spring 1984, summer 1990 to spring 1994, and summer 2003 to spring 2007 (Gurwin, 2014). Since morphological, topographical and meteorological conditions affect susceptibility to drought, the study area was divided into geographic sections and a drought contour map was created to show the distribution of drought intensity. Reclassification allowed for the development of five drought intensity classes, from very low to high (Gurwin, 2014). GIS spatial modelling tools were used to create a weighted overlay that combined several influence factors and their parameters, with each layer given a weight factor based upon its influence on the susceptibility to hydrological drought and a final reclassification allowed for the division of four levels of drought risk on the area (Gurwin, 2014).

Barycz River was identified as highly vulnerable to groundwater drought, as was the area east of Odra River where the majority of mining occurs. The central and northern areas of the study region were found to have a moderate amount of risk to drought, while the high mountain range in the southwest has a low amount of risk (Gurwin, 2014).

Case Study 3 – Groundwater potential assessment using GIS and remote sensing: A case study of Guna tana landscape, upper blue Nile basin, Ethiopia

The combined use of remote sensing, GIS and multi-criteria decision analysis is beneficial in determining groundwater potential zones and promising areas for recharge zones, and has the potential for improving groundwater resources and management. Guna Tana landscape is in Northwestern Ethiopia and is situated on the watershed Gumara and Ribb. Groundwater in this region is primarily used for domestic purposes and to supplement irrigation in downstream areas; demand for water high and water scarcity is a concern for the local communities (Andualem, and Demeke, 2018).

Seven thematic maps were used in the development of this study, and all maps were developed from datasets using ArcGIS. The thematic maps used include geology, slope, soil type, land use, lineament density, drainage density, and geomorphology (Andualem, and Demeke, 2018). Multi-criteria decision analysis was used to assign a weight to each thematic map using factors identified through expertise and literature reviews and the analytic hierarchy process method was used to calculate the weights of the different themes and layers based upon the importance of the identified criteria. A weighted sum overlay tool was utilized to overlay the thematic maps and develop groundwater potential maps, then prospect zones were appraised according to the groundwater potential index (GWPI) and the weighted overlay analysis tool was used to create GWPI vales for the study area. Groundwater prospect zones were classified into five groups utilizing the Jenks natural break method (Andualem, and Demeke, 2018).

Results were validated through examination of the existing wells pumping test data. The groundwater prospect map identified regions downstream that had high groundwater potential due to even terrain and high permeation tendency. Maps were created that identified the distance of groundwater from the ground surface and pumping well discharge, and the use of kriging method showed that downstream and southern area of the region have very good to excellent groundwater conditions (Andualem, and Demeke, 2018). The identification of these areas for potential groundwater development could be used to increase the productivity of irrigation in the region and domestic use.

ANALYSIS

All three of the case studies analyzed for this paper used the kriging method for interpolation of data and the creation of new maps to continue their analysis of their respective groundwater concerns. This demonstrates that kriging is one of the optimal interpolation techniques for this specific topic, and that the data used in groundwater analysis operations fits within the criteria for use in kriging (GISGeography, n.d.). GIS Based Mapping of Groundwater Fluctuations in Bina Basin is the only case study that identified a specific model used in their application of GIS, which was the spherical model. Additionally, this was the only case study that did not used thematic layers for map building or any type of weighted overlay; instead they used a vector base map and the kriging method to create additional raster and contour maps for their area of study (Nayak, Gupta, and Galkate, 2015).

Both Long-term monitoring and GIS based determination of groundwater drought propagation and Groundwater potential assessment using GIS and remote sensing used several thematic maps as a base for their analysis, and both used a weighted overlay for suitability modeling. While Long-term monitoring used a weighted overlay based on influence on drought vulnerability, only Groundwater potential assessment used multi-criteria decision analysis to assign weights and classifications to the thematic layers, and then used the weighted overlay tool on those layers (Andualem, and Demeke, 2018; Gurwin, 2014). The use of both the multi-criteria decision analysis and the weighted overlay tool has the potential to be more accurate than tool alone, since it considers more factors that impact conditions of groundwater. However, Long-term monitoring was the only study to divide their study area into sections based on geographic factors, and this step was done before utilizing the weighted overlay tool which may have assisted in the assignment of weights to the thematic layers used (Gurwin, 2014).

CONCLUSION

GIS Based Mapping of Groundwater Fluctuations in Bina Basin looked at groundwater fluctuations in the vulnerable Bina River aquifer to identify areas within the watershed that had the fastest decline and to also identify regions that would be most favorable for recharge. This case study used the Integrated Land and Water Information System GIS platform to integrate the data, perform analysis and create maps of the watershed. The kriging method was used for analysis of the fixed-point data for groundwater level measurement and was added to the vector base map of the region. This study used the spherical model during this process, and the kriging method was used again to create raster maps of groundwater levels and contour maps of the groundwater table. The MapCalc operation was used to calculate changes in the groundwater table and water table fluctuations, and fluctuation maps were created from this data. The fluctuation maps showed that the agricultural areas showed the fastest rates of groundwater decline and identified an area within the agricultural zone for increased aquifer recharge (Nayak, Gupta, and Galkate, 2015).

Long-term monitoring and GIS based determination of groundwater drought propagation examined historical groundwater table data to identify periods of groundwater drought in the Odra River basin in Poland. This case study used ArcGIS spatial analyst and model builder tools to make calculations with the data collected from the monitoring points used for analysis. Six thematic maps were used as input data to create a base map that allowed for identification of areas most vulnerable to groundwater shortages. The kriging method was used for converting data for spatial examination, and the area was divided into geographic sections based on geographic conditions. A drought contour map was created from this data, and reclassification allowed for the creation of five drought intensity classes. The creation of a weighted overlay based on factors that influence drought susceptibility allowed for a final reclassification that allowed for division into four levels of drought impact on the study area. One river and the region that contained mining activity were identified as most susceptible to groundwater drought (Gurwin, 2014).

Groundwater potential assessment using GIS and remote sensing used the combination of remote sensing, GIS, and multi-criteria decision analysis to determine groundwater potential zones in Ethiopia, where demand for water is high and water scarcity is a concern. Seven thematic maps were used for development, and multi-criteria decision analysis was used to assign a weight to each thematic map. Analytic hierarchy process was then used to calculate the weights of different themes and layers based on identified importance of the criteria, and the weighted sum overlay tool was used to develop a groundwater potential map from these thematic layers. Prospective groundwater zones were appraised according to the groundwater potential index, the use of the weighted overlay analysis tool created groundwater potential index values for the area and groundwater prospect maps identified regions downstream with high groundwater potential. Additional maps were created to identify the distance of groundwater resources from ground surface and to identify pumping well discharge zones. Kriging method was used to identify zones that have very good to excellent groundwater conditions for future development (Andualem, and Demeke, 2018).

Two of the case studies reviewed in this paper used a combination of several thematic maps to build their map foundation, while one of them used a vector map. Thematic maps traditionally only show data for a single topic, or theme, such as soil type or population density. These types of maps are designed to emphasize the spatial patterns of geographic attributes and the relationships between places and are more focused on the mapping of data in these locations than about the geographic features of the locations (Bolstad, 2016). In contrast, vector maps are more general maps that are designed to show geographic features in relation to each other, and emphasize the mapping of places and location of spatial phenomena such as rivers, roads, and cities; these are the types of maps that most people interact with on a daily basis (Bolstad, 2016).

All three of the case studies used kriging interpolation for the creation of visual data from fixed point data. Interpolation is a type of mathematical estimation that is used to predict unknown values at other locations, and kriging is a popular interpolation technique that relies on the use of semi-variogram to assist in the prediction and reduce errors in the output data (Esri, n.d.). Kriging is widely used to generate estimated surfaces from data points because of how the statistical model uses the information to reflect a spatial relationship between the measured points. There are three main criteria data must meet to effectively use the kriging method: your data must have a normal distribution, must be stationary in nature, and cannot have any trends (GISGeography, n.d.).

The utilization of the weighted overlay tool in two of the studies shows the importance of knowing how different factors may influence groundwater trends and giving them weight according to their impact. This tool is used in overlay analysis to help solve multi-criteria problems, with each input assigned a different preference rating that implies the importance or significance of that input to the criteria identified (Esri, n.d). This allows for a more accurate analysis of the area because it gives a more realistic view of the conditions that effect the movement and condition of groundwater resources.

Only one of the case studies used remote sensing and multi-criteria decision analysis in combination with GIS to map potential groundwater resources, but the combination of these technologies was highly beneficial for the region of study due to struggles with water scarcity. Utilizing these techniques to identify potential groundwater resources in arid or semi-arid regions could prove helpful for the populace in these regions.

GIS has many applications in groundwater resources, and the case studies reviewed only showcased five of these applications: identifying water fluctuations and patterns, detecting aquifer recharge zones, looking at historical data to classify periods of hydrological drought, identification of drought vulnerable aquifers, and mapping of groundwater potential zones (Andualem, and Demeke, 2018; Gurwin, 2014; Nayak, Gupta, and Galkate, 2015). As water resources continue to come under increased stress, the utilization of GIS in monitoring, identifying, and mapping will become more valuable to the global community.

REFERENCES

1. Andualem, Tesfa Gebrie, and Demeke, Girum Getachew. 2018. "Groundwater potential assessment using GIS and remote sensing: A case study of Guna Tana landscape, upper blue Nile Basin, Ethiopia." Journal of Hydrology: Regional Studies 24 (August): 1-13. https://doi.org/10.1016/j.ejrh.2019.100610
2. Bolstad, Paul. 2016. GIS Fundamentals: A First Text on Geographic Information Systems, fifth edition. White Bear Lake: Elder Press.
3. Das, D. 2009. "GIS application in hydrological studies." Last modified September 1, 2009. https://www.geospatialworld.net/article/gis-appliaction-in-hydrological-studies
4. Esri. n.d. "How Weighted Overlay works." Accessed December 10, 2019. https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-weighted-overlay-works.htm
5. n.d. "How Kriging works." Accessed December 10, 2019. https://desktop.arcgis.com/en/arcmap/10.3/tools/3d-analyst-toolbox/how-kriging-works.htm
6. GISGeography. n.d. "Kriging Interpolation – The Prediction is Strong in this One." Accessed December 7, 2019. https://gisgeography.com/kriging-interpolation-prediction/
7. Gurwin, Jacek. 2014. "Long-term monitoring and GIS-based determination of groundwater drought propagation, the Lower Silesia region, SW Poland." Episodes 37, no. 3 (September): 172-182.
8. International Groundwater Resources Assessment Centre. n.d. "Groundwater & Climate Change." Accessed November 19, 2019. https://www.un-igrac.org/areas-expertise/groundwater-climate-change
9. National Ground Water Association. n.d. "Groundwater Fundamentals." Accessed November 19, 2019. https://www.ngwa.org/what-is-groundwater/About-groundwater
10. Nayak, T.R., Gupta, S.K., and Galkate, R. 2015. "GIS Based Mapping of Groundwater Fluctuations in Bina Basin." Aquatic Procedia 4: 1469-1476.
11. U.S. Geological Survey. n.d. "Groundwater Decline and Depletion." Accessed November 19, 2019. https://www.usgs.gov/special-topic/water-science-school/science/groundwater-decline-and-depletion?qt-science_center_objects=0#qt-science_center_objects
12. Vaux, Henry. 2011. "Groundwater under stress: the importance of management." Environmental Earth Science 62 (January): 19-23.