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Geospatial Technologies for Groundwater Contamination Hazard Assessment: A Review

Abstract

This paper gives a brief overview of the potential application of remote sensing in water resources. Here we discuss about developing and existing technology of GIS and RS which is widely used in almost every field like urban planning, construction, forest management, hospital, defense centers, hydrological mapping etc. groundwater is considered the major portion of the world's freshwater resources. Whereas this resources need to be sustainably developing and one of the prominent challenge towards this is better management of freshwater resources. Integrated use of remote sensing and GIS have been generally used to describe the surface water bodies and hydro-metrological variables such as precipitation, temperature, soil moisture, land surface characteristics and evapotranspiration fluxes. Today almost near real time spatial-temporal data's can be recorded frequently which is beneficial for monitoring drought, flood estimation and irrigation management. From last few decades groundwater used for domestic, industrial, commercial and various other purposes. Therefore exploitation of resource leads to contaminate it, meanwhile fluoride is one of the prominent pollution that deteriorate the groundwater second most important pollutant is nitrate. This article illuminates major pollutants and their sources in groundwater also discuss about reliable methods and tool that help in development and management of groundwater resources.

Keywords: Remote Sensing, Groundwater, Hydrology, Water Chemistry.

Introduction

Water is life, nevertheless one billion people throughout the world suffer for safe drinking water. Groundwater contaminated naturally as well as by the interference of human's including rock-water interaction, geology, climate, temperature, uses of fertilizers, septic tanks seepage, coal burning as well as many emerging industries.

Researchers investigated and studied from time to time about the types and levels of pollution in agricultural practices, chemical industries, and mining activities that affects major lineament that directly deteriorate quality of groundwater (Hejabi A.T. et al. 2009). The quality of groundwater primarily depends upon the soil and rock masses found in the pathways of saturation zone (olayinka et al. 1999 & Chidambarm et al. 2008). Most of the acute problem arises in groundwater due to geogenic and also because of some important inorganic pollutant like fluoride and arsenic. It was assessed that one third population of the world reliance on groundwater for drinking water (Nickson et al. 2005). In India more than 50% of groundwater resources are contaminated with fluoride. Remote sensing technology emerged as a useful and cost-effective tool to produce meaning full data of geology, geomorphology, slopes, lineaments and many more that make the study of groundwater more feasible (Gebrie Tesfa et al. 2018). GIS has been using by scientist of diverse field for spatial interrogations, analysis and integration from last three decades (Anbazhagan S. & Nair M. Archan, 2014). This study gives sorted idea about usage of GIS application in hydrology. Remote sensing satellite continuously endow data on comparatively large scale that permit exclusive monitoring of groundwater problem at long-term basis and it is cost-effective also. Major limitation in the practice of RS in groundwater study that it distinguish change in surface water or at shallow aquifer in earth. High resolution spectral image (HRSI) clearly illustrate minor faults, lineaments and supply intensely immaculate spatial information on product like terrain modeling, DEM, orthoimage and linear feature extraction (Poon 2007 & Dalati 2004). Main character of the landscape applied for evaluating groundwater status by using RS are: Topography, slope, vegetation, geologic landform, lake, stream, drainage, density, drainage pattern, drainage texture, lineament and spring type (Jha & Chowdary 2007 & Reddy 1999).

Remote Sensing in hydrology

Variety of satellite and sensor data available that can be used for groundwater study in one or various ways. Mainly remote sensing is the surmise of surface parameters by the dimension of emergence electromagnetic radiation from the land surface. With the support of remote sensing we can not only perceive the surface although obtain spatial variability and if observation made on regular interval temporal variability also. So due to its ability to acquire spatial variation for the hydro-metrological variables it is emerging as an active for hydrologic process and it is widely used for delineating surface water bodies and primary set of state variables: temperature, precipitation, soil moisture, surface roughness, land use/cover and vegetation cover. GIS is the science of acquiring information about any object/sources without any physical interaction by the target of investigation and these knowledge acquired by sensors to extent the EMR (electromagnetic radiation) that are emitted or reflected by the source. Broadly used bands in remote sensing are: visible (0.4-0.7 μm), infrared (0.7-1.30 μm) and microwave (0.1-100 μm). The sensor used in remote sensing are widely categorized into active and passive sensor. Passive sensor only observe the energy reflected by the target whereas active sensor also send the pulse of electromagnetic radiation. These are the few sensors that operates in VIS and IR are: Indian remote sensing (IRS) LISS-3, P6, Thematic Mapper (TM) and Enhanced Thematic Mapper. In any hydrological study different nature and dates image used for better result. In multi-spectral image water body shown in a darker tone in infrared bands and it is readily separated from the land and vegetation (J Thomas et al. 2002). Latest innovation in passive remote sensing is the use of numerous narrow constant spectral bands that is called hyper-spectral remote sensing. Normally a hyper spectral sensor accumulate more than 200 channel of electromagnetic radiation spectrum. The main obstacle in groundwater occurrence in any terrain due to its fault and fractures which is derived from lineament feature. Lineament is a direct feature of landscape of a primary geological structure like faults. It plays significant role in circulation and storage of groundwater. Water absorb energy in NIR and MIR wavelengths while vegetation and soil have greater reflectance at these wavelengths (Kumar Nagesh D. & Reshmidevi T.V. 2013). GIS application for hydrology broadly classify into three classes:

1. Simple classification of easily identified features of surface like sediments plumes, rivers, snow cover and many more.

2. Detail explanation and sorting of the remotely sensed data to obtain more minute feature like lineament, geologic features and diverse land cover type.

3. Use of digital data to assessment of hydrological condition variable founded on the correlation among spatial observation and physical observation from ground.

Mapping of water bodies require accurate spatial resolution geostatistical data to acquire very clear images of the boundaries of water surface (KD Sharma et al. 1989). Landsat TM image of 30 m resolution with the assistance of very clear resolution image such as IKONOS & SPOT comparatively 1m resolution has proven as a decent illustration for the remotely sensed data used for mapping water bodies in jodhpur district of total area 0.9 ha.

Optical remote sensing is a great achievement in the field of RS and give very clear spatial resolution but still unable to pertaining in cloud which is a great obstruction for the application to work in bad weather condition and this only happens in tropical region where weather is mostly cloudy. One more obstacle fin this tool is in flood monitoring because flood cause due to bad weather condition (B Brisco et al. 2009). Also optical remote sensing has bad experience in mapping water resources in dense vegetation cover. So use of microwave sensor proven a good achievement to overcome from this limitation.

Development of Remote Sensing in groundwater mapping

Hydrogeological mapping is the major tool for organized and precise improvement and preparation of groundwater resources. These studies and maps used by researchers, engineers, hydrologist and planners to allocate sustainable water management. Groundwater mapping shows geology, topography, hydrology, hydrogeology, graphical distribution of aquifers and hydrochemical features.

Rainfall: It is the major driving tool in hydrological cycle so it is necessary variable in measurement of rainfall. Use of Radar rainfall measurement has been proven successful particularly for combined raingauge network and in low relief area. Conventional method used for rainfall has drawback due to improper spatial coverage that is necessary for capturing spatial variation in rainfall data. Sensors that are used from space based platform serves better opportunity in capturing spatial variation in broad areas while acquiring data in mountain region.

Water Quality: Water quality is a term that define physical, chemical, biological and thermal properties of water bodies. Ancillary conventional methods used for measurement of water quality are onsite and laboratory analysis is an extravagant and time taking methods and moreover unable to provide spatial and temporal measurement which is very important for evaluation of huge area water body. In RS change detection in optical sensors measure to check the existence of contaminations. So optimum wavelength taken to measure is rest on the substance measured, its concentration and the sensor characteristics (Jasmin Ismail & Mallikarjuna P. 2011)). Based on the physical analysis, VIR & NIR part of EMR spectrum having wavelength from 0.7-0.8 μm were establish to be more competent band to monitor suspended sediment in water (Kumar Nagesh D. & Reshmidevi T.V. 2019). Optical character of water then modified into water quality indices by dealing with empirical relationship, radiative removal function or physical models. Following are empirical relation to examine chlorophyll content in Chesapeake Bay by Harding et al.

$$\text{Log10 [Chlorophyll]} = A+B\ (-\log 10\ G)$$

$$G = (R2)2/R1*R3$$

Where A & B are empirical constant derive from in situ calculation and R1, R2 & R3 are radiance at 460 nm, 490 nm & 520 nm respectively.

Remote sensing of water quality parameters in sooner days occupied clear resolution image from satellite, example- LANDSAT TM (P. Brezonik et al. 2005). Yet bad temporal coverage of the image was a prime constraint in this type of studies. Suspended sediments is one of the important pollutant together in weight and volume in surface water of fresh water system (BM Lesht et al. 2013 & DM Bjerklie et al. 2005). Present remote sensing technique have various powerful and dynamic tool to assess water quality and water resources but hindrance in spatial resolution of many sensor which limit the monitoring of water quality of large area. Newly launched satellite such as (SEWAIFS, EOS, MOS, IKONOS and many more) and some sensors also. Which provide better opportunity in spatial and spectral resolution demanded to monitor water quality from space (Schalles JF et al. 1997). Hyper-spectral data based on space platform will permit researchers to differentiate between water quality parameters to build up a better understanding of light/water/substance interaction (Schmugge J. Thomas et al. 2002).

Spatial Interpolation methods

Interpolation method used to identify the values of unsampled points and make a regular dataset to study the spatial interpolation. Basically interpolation uses to predict any unknown value for some geographic point data like elevation, noise level, rainfall, chemical concentration and so on. Inverse distance weighted is a tool uses in interpolation it is one of the common method used in interpolation method. There are many more types of interpolation methods available. Jin Li & D. Heap discussed almost 42 types of interpolation method and broadly categories it into 3 type: 1. Non-geostatiscal method, 2. geostatiscal method and 3. Combined method. In geostatic method when we are using secondary data sources then it is called Multivariate whereas when we are not using secondary data it is called univariate. It is necessary to be noted that multivariate mostly revealed more than one variable. Non-geostatistic include IDW, spline, regression models, and trend surface analysis and so on.

Inverse distance weighted is kind of a affirmatory method for multivariate interpolation with a known disseminated point. The allotted value to unknown point are considered with a weighted average of the values accessible at the well-known points.

$$[illegible] = 1/dip$$

$$\sum 1/dip$$

This is the equation for weight expression.

The main factor that the accuracy of this IDW is the value of power parameter, weight reduce as the distance upsurge when the value of power parameters increase so close sample has heavier weight and have more impact in valuation (Isaaksand Srivastava, 1989). One of the most common choice for p is 2.

Spline tool uses interpolation method that estimate values by using mathematical functions. Assessment of spline interpolation contain the weighted average values of surrounding sample point. There are two basic grouping of spatial interpolation- Deterministic and Geo-statistical. Deterministic point make surface with known point, rooted on some degree of similarity (Inverse Distance Weighted) or based on the smoothing (Radial Basis Function) whereas geostatistical interpolation method (e.g. Kriging) use statistical properties of measured point. Basheer A. Elubid et al. 2019 demonstrated that Kriging interpolation technique is most favorable.

Impact of Land use/Land Cover on groundwater quality

Land cover transformation of any area highly affect surface as well as groundwater it increase the extent the pollution potential and relating the land use with economy make it land use. Largely a huge agriculture land converted into urbanization or a barren land. Singh S.K. et al 2017 carry out a great study about the change in LU/LC pattern of Harmu River of Ranchi city this river used for domestic and irrigation purpose by local people. They compare 17 years of change in their study and remarked that this changes made due to expansion of new buildings and commercial use of lands. For explanation of LULC classes 321 RGB for IRS LISS IV camera in two different modes uses, mono and multi-spectral mode. A study of land use change on groundwater quality were taken two different period for the study of change pattern of land cover with the help of multispectral satellite image from LISS IV sensor IRS 1 D satellite. The multispectral satellite image contains 3 bands; green (0.5-0.9 μm), Red (0.6-0.7 μm) and Near Infrared (0.7-0.9 μm) with pixel size 5.8 m and land cover of this area classify on the source of possible causes of groundwater contamination (Kahn H. Harish et al. 2010). Meanwhile there is important point related to LULC is that the LULC map acquired from directed classification are not taken as final map because there are always some divergences in any automatic classification that must be resolved by using manual effort and after manual editing the map will be finalized (Ahmed Shakeel, (2010).

In hyper-spectral images the spectral reflectance values noted in the narrow adjoining bands that are used to produce spectral reflectance curves for all pixel. By using these spectral reflectance curves which support distinctive class for different classes, so now it is possible to differentiation the classes like recognize different crop types, pattern of cropping etc. land cover classification with the help of multispectral remote sensing data proven as a well-established RS tool in the field of hydrology (Rao NR, 2008). Barber et al. (1996) studied about influence of urbanization on groundwater quality related to land use change pattern by using GIS. Groundwater contamination and spatial relationship between groundwater quality, topography, geology, land use and pollution sources using geospatial technologies in Seoul,Korea, this study was carried out by Ahn & Chon (1999). A huge number of studies demonstrate the hydrologic application of the LULC maps produce from IRS LISS 3 (Sekhar KR & Rao BV, 2002 & Chowdary et al. 2009) & LANDSAT MS/TM+ imageries (Mauser W & Schadlich, 1998 & Russell GD, 2004). Having spatial resolution 23-30 m and also give clear resolution satellite image such as IKONOS & Quickbird. These days it is also presumable to produce the LULC maps of smaller than 1m spatial.

Drainage lines were readily found by using digital enhancement technique like principal component analysis (PCA), radiating and false color composting as compare to actual Landsat TM image (Astaras & Soulakellis 1992). Lineament study necessary to overview water quality of groundwater recognizance of lineament by using Landsat TM imagery were found to be hydro-logically valuable and accomplish reproducibility of 90 %(Sander et al. 1996).

Effective models for evaluating groundwater quality and its vulnerability

Though there are enormous number of model available for groundwater hazard study. DRASTIC Model arguably it is a widely used model for assessing aquifer vulnerability however there is enormous number of models available for aquifer mapping like: DRASTIC, GOD, AVI and SINTACS (Aller et al. 1987, Foster S, 1987, Stempvoort Van 1993 & Civita, M. 1994). As according to study it is estimated that DRASTIC model is most accurate for the study of groundwater vulnerability because it has property to show all the parameter of hydrology in a single map. It was first used by US Environment Protection Agency (USEAPA). Basically DRASTIC is a cipher of abbreviation of its seven parameters: depth, net recharge, aquifer, soil media, topography, impact of vadose zone, hydraulic conductivity. This model work on the equation using linear combination method given by Hopkins 1977

Pollution Potential = Dr Dw + Rr Rw + Ar Aw + Sr Sw + Tr Tw + Ir Iw + Cr Cw

Where, r is the rating and w is the weight

Ratings given according to the importance of each parametrs and vary from 1-10.

Table 1. Weight Assigned for DRASTIC Parameters

Feature	Weight	Agricultural Weight
Water Table Depth	5	5
Net Recharge	4	4
Aquifer Media	3	3
Soil	2	5
Topography	1	3
Vadose Zone	5	4
Hydraulic Conductivity	3	2

Source: Aller, et al., 1985

Generally DRASTIC Model used on the basis of data required by the model should be available and variables taken in the model should be related to groundwater vulnerability. Rundquist et al. 1991 engage ERDAS software and DRASTIC to map groundwater pollution risk in Nebraska at a scale of 1:250000 also it best suited for specific site study because it we take large area so sometime all the adequate data not available. Abdullah O. et al. 2016 taken two model for comparative study of aquifer vulnerability i.e. DRASTIC & COP (Concentration of flow, overlying layer & precipitation). A study of shallow aquifer vulnerability of a granitic terrain of southern India by using DRASTIC model and study of hydrochemistry of groundwater. According to the author 43% area are healthy having very low vulnerability and 57% area having highly polluted zone due to presence of tannery industry. They divide the area into four zones negligible, low, moderate and high on behalf of DRASTIC vulnerability index. Author Mondal N C mentioned that vulnerability assessment with the help of DRASTIC model of any hydrogeological system along with hydrochemical signatures is significant for groundwater sustainable management.

GIS and RS are demanding tool for the collection and analysis of large spatial data used in several field like urban planning, mineral and mining research, geology, hydrogeology, lithology and many more. Satellite images are acquired world-wide for the qualitative study of groundwater by using its geology, hydrogeology and lithological structures.

Conclusion

By using geospatial technique it was quite possible to describe spatial variation of groundwater quality. Remote sensing widely applied in hydrological study by using through different passive and active sensor dealing with various satellite. Inspection of the application of the passive sensor directing in visible infrared, infrared and microwave wavelengths exhibit immense possibility in improving RS data for the study of hydrology. An overview of remote sensing technology in various kind of realm of water resources illustrate the perspective of remote sensing application in water resources management.

Overall perspective of RS & GIS acknowledged universally as a wacky, highly impressive and enormously versatile application for characterization, monitoring and management of groundwater studies. Areas like rainfall calculation with the help of cloud indexing, soil moisture, snow cover mapping and surface water detection broadly used remote sensing application in operational way but in some conditions it is not applied in large areas but researchers working on this issues. The field where additional accentuation needed are: land cover, albedo, physiography, evapotranspiration, sediments loads and erosion and many more. Finally area where currently no adequate remote sensing addressed are deep soil moisture of groundwater, stream flow, chemical pollutant, infiltration so acute progresses for this field are requisite in next multiple years.

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