A GIS BASED DRASTIC MODEL FOR THE ASSESSMENT OF GROUNDWATER VULNERABILITY TO POLLUTION IN GOGHAT - I AND II, HOOGHLI, WEST BENGAL

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled "**A GIS based DRASTIC Model for the Assessment of Groundwater Vulnerability to Pollution in Goghat - I and II, Hooghli, West Bengal"** is bona fide work carried out by **ARITRO BHATTACHARYA** under our supervision and guidance for partial fulfilment of the requirement for the Master of Engineering degree in Water Resources & Hydraulic Engineering in the School of Water Resources Engineering, Jadavpur University during the academic session 2020-2022.

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed, or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of my Master of Engineering in Water Resources & Hydraulic Engineering degree during academic session 2020-2022. All information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by this rules and conduct, I have fully cited and referred all material and results that are not original to this work.

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ABSTRACT

Although it is challenging to contaminate groundwater, it is also challenging to clean up after contamination. Utilizing several aquifer vulnerability assessment techniques is essential to achieving this objective. All of these tactics rely on statistical or overlay index approaches as well as process model frameworks. Due to dwindling groundwater levels and increasing contamination, which pose a serious threat to the environment and water sources, groundwater vulnerability is a hot issue of discussion. Extensive research has been done using all the methodologies based on various characteristics and indices in order to detect the risk and estimate the vulnerability. One of the most significant and reliable overlay and index methods for determining groundwater vulnerability is the DRASTIC method. In Goghat I and II, Hooghly District, West Bengal, this research project examines the DRASTIC Model's applicability. In particular in agricultural, arid, semi-arid, and basaltic zones, this study found that integrating GIS with DRASTIC is the most efficient and accurate technique to determine groundwater vulnerability. The Goghat -II block has a significant groundwater vulnerability, according to the research, which suggests that the situation there is urgent. Due to excessive use for irrigation, the depth of groundwater has already significantly decreased. This study thus creates a new avenue for investigation into groundwater law and how organised regulation can optimise the use of this resource. The study suggests that this can be an effective tool for local authorities responsible for managing groundwater resources.

Keywords: Groundwater Pollution, ArcGIS Software, Drastic Model, Groundwater Vulnerability Zones, Raster Calculator, Weighted Sum Analysis

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CHAPTER 1

INTRODUCTION

1.1 General Background

Groundwater, unlike many other natural resources, is a renewable resource. However, it is a limited resource (Chatterjee and Purohit, 2009). Aquifers, which are underground formations that contain groundwater, can be a key hydrological component of watersheds and basins. The three-dimensional character of aquifers is poorly understood, and it is rarely taken into account in management modelling. The hydrologic cycle, as well as anthropogenic alterations to the hydrologic cycle, define the status and characteristics of a certain aquifer (Burke, 1998). The amount of water stored in an aquifer over time can be determined by accounting for inflows and outflows using the following formula: Change in storage = recharge – depletion

Groundwater abstraction has been expanding swiftly and steadily over the world, and excessive groundwater abstraction has resulted in catastrophic groundwater level decreases in several locations (Ward and Robinson, 1990). Groundwater levels are dropping, which has a lot of negative consequences for the ecosystem. Groundwater level drop is a direct indicator of groundwater depletion, which poses a threat to aquifer sustainability. The globe is rapidly running out of fresh water, our demand for this "blue gold" is expanding at an alarming rate, and countless more people are being forced to live in a water-stressed environment.

According to a report by India's Central Water Commission, groundwater is widely utilised in agricultural sectors, with groundwater accounting for half of all irrigated land. "Central Water Commission, Ministry of Jal Shakti, Department of Water Resources, River Development, and Ganga Rejuvenation, Government of India," 2000. In India, groundwater well irrigation accounts for 60% of irrigated food output. At slightly over 260 cubic kilometres per year, India uses 25% of all groundwater taken worldwide, putting it ahead of the United States and China. In India, groundwater supplied 70% of the water used in agricultural sectors. For years to come, India's water supply will be a lifeline. The majority of water difficulties in India are related to groundwater, which is found beneath the earth's surface.

It's because we use the most groundwater in the world and are hence extremely reliant on it. Groundwater exploitation and contamination has become a global issue. Groundwater resources are under threat due to overexploitation and pollution concentrations, according to environmental and hydrogeology professionals. Groundwater overexploitation happens in a scenario where groundwater has transformed from a "reserve resource" exploited in times of scarcity to a "resource now systematically extracted in an uncontrolled or unregulated way." The area's inappropriate groundwater management and vulnerability model have resulted in the depletion of potential natural resources and continual deterioration of their quality. The term "vulnerability" relates to a shifting situation in which there is a danger of harm to a society or any prospect of harm.

The DRASTIC model is being used to assess the research areas' groundwater risk index. It can be a useful technique for identifying contaminated groundwater supplies by employing basic hydro-geologic and hydro-geomorphological characteristics that are thought to influence contaminant transmission from surface sources to groundwater. The first effort incorporating the partial automation of DRASTIC utilising GIS concepts was completed at the University of Kansas by applying a commercially available Erdas Imagine software package to data compiled for Harvey Country. For Nassau and Suffolk, Kansas created a GIS geared at groundwater management. The research of water supply affected by naturally existing radon contamination in dolomite aquifers with a high potential of groundwater pollution by surface activity was conducted using GIS technology in the counties of Long Island, New York. The first of them is the designation of mappable hydro-geologic parameters, which is the initial component of DRASTIC. For mapping groundwater resources, remote sensing and geographic information system (RSGIS) technologies have become indispensable. Geology, topography, climate conditions, soil, land use, land cover, and other factors all influence groundwater availability in a given area. To deal with the water scarcity problem in the drought-prone region, accurate modelling is required to delineate groundwater potential zones. Only a few research on water issues are being conducted in the district.

1.2 The Current Scenario of Groundwater as a Natural Resource

Groundwater is a very critical natural resource. A growing number of aquifers are being used to unsustainable levels. According to a World Bank reports, Deep Wells and Prudence, over 60% of India's aquifers will be in critical condition in 20 years if current patterns continue. This will have major consequences for agriculture's long-term viability, food security, livelihoods, and economic growth. Over a fourth of the country's harvest is expected to be jeopardised. There is a pressing need to alter the current situation.

1.2.1 Global Scenario

The main distinction between groundwater and other mineral resources is that it is renewable as part of the whole water cycle. According to estimations based on the global model Water GAP-2, the average perennial quantity of groundwater recharge for land is around 14,000 km3/year, or roughly 36% of river runoff is formed by groundwater. As of April 2015, the country's water resource potential, or annual water availability, in terms of natural runoff (flow) in rivers, was at 1,869 billion cubic metres (BCM) per year. However, the country's useable water resources have been assessed to be 1,123 BCM/year. It is difficult to extract the total possible 1,869 BCM/year due to terrain limits and uneven distribution of assistance in several river basins. Surface water and groundwater share 690 BCM/year and 433 BCM/year, respectively, of the 1,123 BCM/year total. With 35 BCM set aside for natural discharge, the country's net annual groundwater availability is 398 BCM.

1.2.2 National Scenario

In India, rainfall is the primary source of groundwater recharge, with recharge from canals, irrigated fields, and surface water bodies supplementing it. The upper unconfined aquifers, which are also active recharge zones and hold the replenishable groundwater supply, account for a large portion of groundwater removal. The Central Ground Water Board, in collaboration with the respective State Government authorities, analysed the replenishable groundwater resource in the active recharge zone of the country. The evaluation was conducted using the Block/Mandal/Taluka/Watershed as the unit and following the Ground Water Estimation Committee (GEC)-1997 recommendations. The annual replenishable groundwater supply in this zone has been assessed at 432 billion cubic metres, according to the most recent evaluation (BCM). After keeping 34 BCM for natural discharge during the non-monsoon period to maintain flows in springs, rivers, and streams, 399 BCM is deemed available for development for diverse applications (Central Ground Water Board, 2006).

1.2.3 Regional Scenario (West Bengal)

West Bengal, a state with historically rich groundwater, is currently experiencing water scarcity during dry seasons. On the basis of groundwater development, some groundwater management regions have been moved from "safe blocks" to "semi-critical" or "critical blocks" due to uncontrolled agricultural growth (Central Ground Water Board 2014). The government groundwater board has designated the Goghat-I and II blocks in Hugli district, West Bengal, as semi-critical and critical blocks (Central Ground Water Board 2017). In this location, there is severe water scarcity, which has a significant impact on society. The goal of this research is to determine the sensitivity of groundwater resources and to identify susceptible zones in a water-stressed region of Goghat-I and II.

1.2.3.1 Groundwater Extraction and Use

India is rapidly approaching a groundwater contamination and usage issue. Overuse or overexploitation of groundwater is described as a condition in which the average extraction rate from aquifers exceeds the average recharge rate over time. Surface water availability is more important in India than groundwater availability. Groundwater, on the other hand, is widely accessible due to its dispersed availability and accounts for the majority of India's agriculture and drinking water supply. Groundwater for irrigation uses 89 percent of the extracted groundwater, making it the greatest category user in the country, followed by groundwater for household use, which uses 9% of the extracted groundwater. Groundwater provides 2% of industrial water, 50% of urban water demand, and 85% of rural home water requirements.

The water extracted for irrigation is the most major component of groundwater consumption. Canals, tanks, and wells, including tube wells, are the country's principal irrigation systems. Groundwater accounts for the lion's share of all of these sources. Wells, which include dug wells, shallow tube wells, and deep tube wells, produce 61.6 percent of irrigation water, while canals provide 24.5 percent. The use of surface water for irrigation has decreased through time, while the use of groundwater for irrigation has increased. The number of tube wells has expanded rapidly, indicating that farmers are using more groundwater for irrigation. The Green Revolution, which relied on the extensive use of inputs such as water and fertilisers to promote farm production, increased irrigation's reliance on groundwater. Low electricity prices have resulted in excessive water consumption, resulting in a significant drop in water tables.

1.2.3.2 Groundwater Contamination

The presence of some chemicals in groundwater that exceed the limitations set for drinking water is known as groundwater pollution. Arsenic, fluoride, nitrate, and iron are examples of geogenic pollutants that are regularly found. Bacteria, phosphates, and heavy metals are among the other pollutants produced by human activities such as home waste, agricultural practises, and industrial effluents. Landfill pollution, septic tanks, leaky underground gas tanks, and the overuse of fertilisers and pesticides are all sources of contamination. It is stated that over 60% of districts in the country have concerns with groundwater availability, quality, or both.

TABLE 1.1: COMPARATIVE STATUS OF GROUNDWATER DEVELOPMENT IN INDIA (20 YEARS)

Geogenic Contaminants	Number of Affected States	Number of Affected Districts
Arsenic	10	68
Fluoride	20	276
Nitrate	21	387
Iron	24	297

Source: (Central Ground Water Board, 2006)

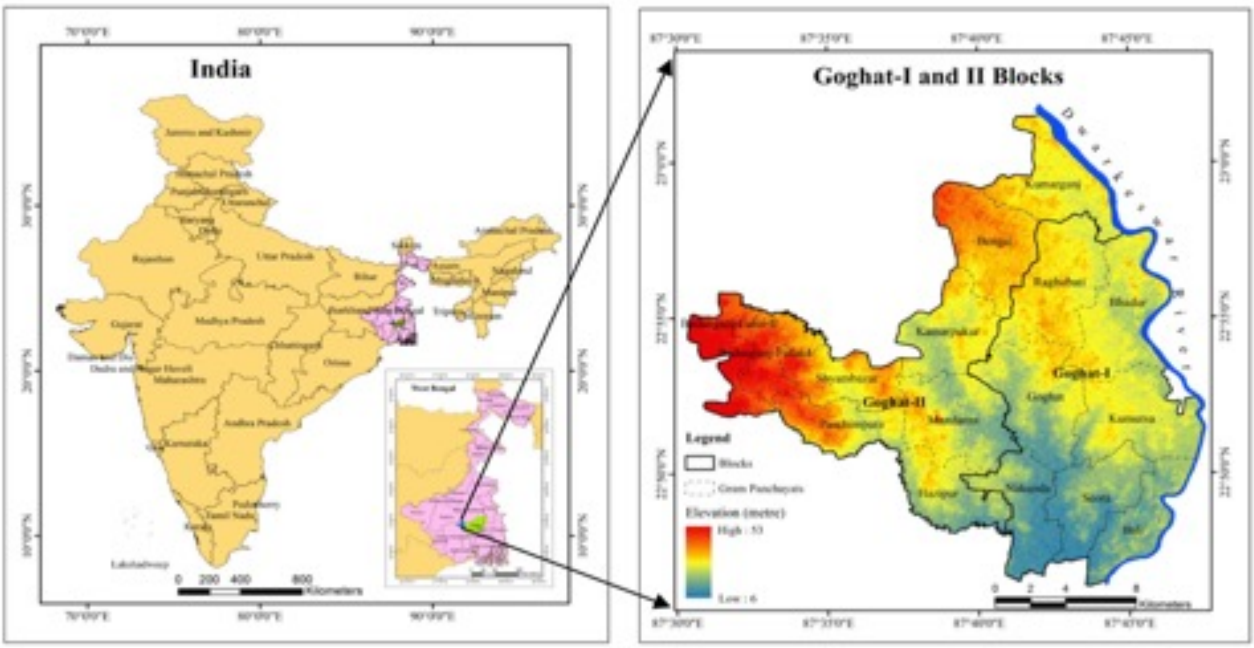
The Committee on Estimates 2014-15, as indicated in Table 1.1, examined the occurrence of high arsenic content in groundwater and found that high arsenic pollution in groundwater affects 68 districts in ten states. Haryana, Punjab, Uttar Pradesh, Bihar, Jharkhand, Chhattisgarh, West Bengal, Assam, Manipur, and Karnataka are the states in question.

Water, being one of the most important resources, is critical for all types of growth. Water resource management in semi-arid hard rock locations like Goghat is currently a big concern due to variables such as restricted water reservoirs, water availability, global water demand, regional inequities, and climate change. Even after 72 years of independence, the people of this region still lack basic necessities such as food and drinking water. They will have to work hard to meet these basic needs in their daily life. As a result, water resource management in such areas necessitates careful planning and engagement from all stakeholders in order to preserve this valuable resource. With increasing demand, groundwater is used for drinking and agricultural purposes in Goghat I and II.

The Environmental Protection Agency (EPA) of the United States has created a DRASTIC model to classify the contamination potential of aquifers (Aller et al. 1987) and has integrated it into ArcGIS 10.5 software to analyse groundwater vulnerability. Raster Analysis and Weighed Sum Analysis were used in this research work to attempt to map the groundwater sensitivity zones in the study area.

1.3 Study Area

Goghat-I and II blocks (22° 46′ 21″ N–23° 01′ 31″ N and 87° 30′ 22″–87° 47′ 27″ E) are situated in the western part of Hugli district of West Bengal, India. Goghat-I consists of 7 gram panchayats (administrative units' com- prising a group of villages) with a total area of 186.34 km2. Goghat-II contains 9 gram panchayats that cover an area of 190.05 Km2 (Census of India 2011). The Dwarkeswar river in the eastern part of the area separates these two blocks from the rest of the district. Goghat-I and II blocks are immediately underlain by a sequence of alluvial sediments known as the older alluvium. These consist of sand, silt and silty clay (Geo- logical Survey of India 2006). The region has a tropical monsoon climate (Aw in the Köppen–Geiger classification system), characterised by a cool, dry winter and a warm, humid summer. The mean annual rainfall is about 1500 mm, most of which falls during the period of June–September each year. The economy of this region is primarily dependent upon agriculture. Most of the area is under cultivated land, which has resulted in high cropping intensity.



Map. 1.1: Location of study, Goghat- I and Goghat-II in Hooghly, West Bengal

1.3.1 Scope of the Study

Despite risks from contaminating activities, groundwater is frequently remarkably robust, and water quality is often good across huge portions of the globe. This is partly due to the fact that many aquifer systems have a natural potential to absorb pollution and so ameliorate it. Though groundwater is not easily contaminated, once it is, remediation is tough. A failing local aquifer's replacement cost is typically considerable, and its loss may put a strain on other water supplies used as substitutes. As a result, it's critical to figure out which aquifer systems and environments are the most prone to degradation. The vulnerability studies allow for a better understanding of the severity of the likely impacts of pollution loading. A timely assessment of the vulnerability of groundwater resources prevents qualitative degradation, deterioration, or pollution. To assist groundwater resource protection and quality conservation planning, policy, and strategy, groundwater vulnerability assessment must be interconnected with and integrated into master plans.

1.3.2 Research Objective

The main objective of this research study is to determine the feasibility of the DRASTIC model for assessment of aquifer vulnerability in agricultural areas of Hooghly district by verifying the model output in Goghat – I and II of Hooghly District, West Bengal.

Some other objectives of this study include:

- Understanding various other hydrogeological conditions of the study area.
- Understanding land use and land cover of the study area.

1.3.3 The Methodology Adopted for the Research

The total research approach can be broken down into five parts: Review of the literature to determine the purpose and objective Primary and secondary surveys are used to gather information about the current situation. Data Presentation and Data Analysis Organisation Development of a system for assessing groundwater risk zones in the research region, as well as output and analysis for identifying solutions for scientific and sustainable groundwater resource management. According to scientific studies, the study location chosen is chronically water scarce. The vulnerability of the area was mapped using hydro geological parameters. To identify the probable pollution zones in my study area, Arc-GIS software was used to map soil media, aquifer media, topography, recharge, Vadose zone, ground water depth, and hydraulic conductivity. The Chaturvedi Equation was used to calculate the study area's net recharge.

1.3.4 The Proposed Outcome of the Research Study

The following outcome would possibly have emerged through this research study:

- A map of the study area's groundwater potential pollution zones, which are divided into three categories: high, moderate, and low groundwater potential zones.
- It is feasible to identify regions that are more likely to be contaminated by groundwater than others based on their proximity.
- An understanding of the state of the groundwater resource, which will aid in the planning of future artificial recharge projects in the study region to assure long-term groundwater use.

1.4 Thesis Layout

This dissertation contains eight chapters. In chapter 2, a Literature Review on the groundwater vulnerability mapping and the available techniques in order to evaluate vulnerability is presented. Chapter 3 is the Description of Study Area. Chapter 4 provides an insight into the theory and concepts governing groundwater vulnerability. Chapter 5 is the Methodology used in this study, followed by Chapter 6 which provides the calculations of DRASTIC index. Results and Discussion are provided in Chapter 7. A summary of the conclusions and the suggested future work is discussed in Chapter 8.

CHAPTER - 2

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LITERATURE REVIEW

2.1 Review of International and National Research on Groundwater Vulnerability Assessment

Priyank Patel et al., (2022) - Industrial and municipal wastes, agricultural contamination owing to pesticides and chemical hazards, seawater intrusion in coastal areas, and other factors damage groundwater. In several towns and industrial clusters across India, is becoming a rising subject of concern. Groundwater is difficult to contaminate, but once contaminated, it is difficult to clean up. It is critical to attain this goal using a variety of aquifer vulnerability assessment approaches. All of these strategies rely on process models as well as statistical or overlay index methodologies. Groundwater vulnerability is a major topic of discussion due to declining groundwater levels and rising contamination, posing a serious threat to the environment and water sources. To identify the risk and to assess the vulnerability extensive research has carried out among them all the methods are worked based on the different parameters and different indexes. DRASTIC method is one of the most important and accurate method of overlay and index method for the assessment of groundwater vulnerability. This research study is a systematic analysis of the available research articles on the applications of DRASTIC and Modified DRASTIC (DRASTIC-L) performance management process on Geographical Information Systems (GIS). This research also reveals research gaps in the various groundwater vulnerability assessment approaches, as well as their limits and hypotheses. This study discovered that integrating GIS with DRASTIC is the most effective and accurate way for determining groundwater vulnerability. In the agricultural, arid, semi-arid, and basaltic zones, the modified DRASTIC model also outperforms the traditional DRASTIC model.

Amit Bera et al. (2021) - Nangasai basin is a semi-arid watershed where agriculture is the main source of the economy, much like the area in my study. In the present day, increasing population demands increase in food productivity which leads to increased use of fertilisers and chemical pesticides in agriculture. These fertilisers on the other hand mix up with the groundwater and increase the pollution, which affects human health adversely. So, for controlling the groundwater contamination risk proper water resource management and assessment of groundwater vulnerability is extremely important. Total 7 hydrogeological parameters have been considered for this study, and the final groundwater vulnerability map has been prepared by an overlay weighted method with the help of DRASTIC index, which is classified into 5 vulnerable classes (very high, high, moderate, low, and very low). In the south and south-eastern regions of the basin namely Deghi, Bankada, Baram, Macha, Katin, Tilabani high groundwater contamination is observed. For validating the model, the water quality parameters-nitrate and TDS have been used with the accuracy of 89% and 86% respectively. Using effective as well as scientifically approved methods, the anthropogenic and agricultural contamination can be controlled and managed which will lower the risk of contamination. This paper has provided me with a clear pathway towards understanding how the lifecycle of contaminants are in the vadose and phreatic zones respectively.

Yongxiang Zhang et al., (2021) - Groundwater vulnerability assessment is a basic work for groundwater exploitation and protection. The Chaoyang district of Beijing was selected and investigated in this study. The Groundwater vulnerability index system in Chaoyang district was constructed based on hydrogeological settings of the local region, the human influence and the DRASTIC model. The comprehensive vulnerability assessment was carried out with weights of 0.4 and 0.6 for the intrinsic vulnerability and the specific vulnerability, respectively. In this study, total 9 hydrogeological parameters were considered, and the diagram of groundwater vulnerability assessment results in Chaoyang District was obtained by using DRASTIC index and overlay weighted method. The groundwater quality is poor in the southwest of Chaoyang District. The correlation analysis between total hardness, total dissolved solids and vulnerability results was carried out, and the correlation results were 06 and 0.7, respectively. The area with high groundwater vulnerability is also the regions with serious groundwater pollution, indicating that the assessment results are objective and reasonable, which can provide prevention and control of groundwater reference for the management department in the future, so as to reduce the risk of pollution.

Santanu Mallik et al., (2021) - This research is aimed to develop a modified DRASTIC model to demarcate groundwater vulnerability zones based on experimental analysis of field samples to make the model more feasible at local scale. The rapid increase in demand and consumption of groundwater in the past few decades has imposed colossal pressure on the stakeholders responsible for groundwater management. Assessment of groundwater vulnerability and knowledge about hydrogeological settings are crucial for a particular region, especially at a local scale, to manage groundwater resources effectively. Four techniques were implemented in this study to determine groundwater vulnerability zones: (a) DRASTIC; (b) DRASTIC–AHP (analytic hierarchy process); (c) Modified DRASTIC; (d) Modified DRASTIC–AHP. The best groundwater vulnerability model was determined based on validation results with groundwater nitrate concentration. The comparative assessment showed that the Modified DRASTIC–AHP outperformed the other models. More than 50% of the study area was classified as 'high' (33.06%) and 'very high' (21.31%) groundwater vulnerability zones. The vulnerability map shows that high vulnerable zones dominate in the northwestern part and in some portions of the floodplain near the central part of the study area. The results of this study envision that inclusion of experimentally derived parameters can be used to modify the conventional DRASTIC model and obtain better results at local scale and is therefore very suitable for the chosen location of study.

Biswajit Das, Subodh Chandra Pal, (2020) - This study tries to show the vulnerability of dynamic groundwater resources in water scarce Goghat-I and II blocks of West Bengal. Central Ground Water Board (CGWB) of India has classified Goghat-I as a semi-critical and Goghat-II as the only critical block of West Bengal. Abstraction rate of annual rechargeable groundwater is a matter of concern in these blocks. Different methods like MCDA, AHP, Fuzzy logic and ensemble have been used to find out the spatial vulnerability of renewable groundwater resources. Annual groundwater recharge has been measured by the WLF method, whereas abstraction for irrigation and domestic use has been measured through field survey. These are essential to show the use of the water resource, which reveals the level of vulnerability of this precious natural and dynamic resource. In both the blocks, over 80% of renewable resources are used; and the trend of groundwater level is continuously decreasing over the years. Sustainability of groundwater is a concern for both the blocks. Various controlling factors of groundwater vulnerability have been used to show the micro-level variation of vulnerability over this region. Results of all the methods reveal that very low and low vulnerability is present in north-eastern and southern parts to a small extent. High and very high vulnerability is found in the entire western, north-western and south-eastern parts; and it is present over an extensive area. Rest of the area represents moderate vulnerable areas. ROC curve is used to validate the results; AUC value of more than 0.8 for all the methods shows that the applied methods are suitable for this study. This paper provides an insight on my chosen location of study through other vulnerability assessment techniques.

Srimanti Duttagupta et al., (2020) - This study is the first attempt to evaluate the groundwater vulnerability to pesticide pollution due to anthropogenic activities across the Western Bengal basin. The groundwater of the Western Bengal basin is found to be polluted by various non-point source contaminants. A significant increase in anthropogenic activities subsequently affects water quality. Pesticide concentration of 141 wells for three consecutive years (2012 - 2014) was collected and data were acquired from West Bengal Pollution Control Board (WBPCB). Based on seven hydrogeological parameters groundwater specific vulnerability was assessed. The vulnerability to pesticide pollution across the Western Bengal basin was again validated with analysed pesticide concentration for 235 wells for 2014–2016. The agricultural prone region of the study area is highly susceptible to pesticide pollution. The spatiotemporal trend of different pesticides suggests the basin is more vulnerable to insecticides such as malathion than that of herbicides. The application of pesticides influences mostly the spatiotemporal variability of pesticide concentration in groundwater of shallow aquifers across Western Bengal basin; however, the natural hydrogeological setting of this area is one of the most influential parameters which impact the pesticide infiltration into the aquifer. Depth to the water table is the most sensitive parameter which showed a significant impact on pesticide concentration in groundwater. This paper gives a definitive insight on the current impact on the usage of fertilisers and pesticides in agriculture dependent blocks of West Bengal and how as a researcher it is imperative to incorporate contaminant and area specific norms to the model to optimise it.

Gebremedhin Berhe Zenebe et al., (2020) - This study was aimed to analyse the spatial vulnerability to contamination and human activities impact on the groundwater of Elalla-Aynalem Catchment, using depth to water table, net recharge, aquifer type, soil media, topography, impact of vadose zone, hydraulic conductivity and land use/cover. DRASTIC index gives three different groundwater vulnerability zones, namely: high (6.7%), moderate (32%) and low (61.3%), and the modified DRASTIC (Human activity impact) index map gives four vulnerability zones as low, medium, high and very high with area coverage of 18.5%, 29.1%, 32.6% and 19.8% of the study area, respectively. The depth to water table and vadose media are the most significant hydrogeological factors determining the DRASTIC vulnerability resulting from sensitivity analyses. The groundwater vulnerability map with measured NO3 data shows 70.69% and 84.48% agreement for DRASTIC model and modified DRASTIC model, respectively, indicating that the role of LuLc is important.

Solid waste disposal, sewerage, gases from industries, municipal wastes, garages, fuel stations, health centres and agricultural activities are some of the possible pollutants that could continuously deteriorate the quality of groundwater in the catchment. This study provides an integrated platform and compressive data set of hydrogeological factors for spatial analysis to fill spatial data gaps, and it can be effectively utilised in the application of a similar model in Hooghly.

Sahajpreet Kaur Garewal et al., (2020) - Groundwater vulnerability assessment is an essential tool for identification, classification and analysis of factors affecting groundwater and thus to take necessary steps for reduction of adverse environmental consequences. DRASTIC is a widespread approach for assessment of groundwater vulnerability. It is a region-specific method, and a major challenge is to manage its intrinsic subjectivity for evaluating the approximate parameters and assigning rates and weight to the parameters, depending on the regional factors affecting groundwater. In order to minimise the subjectivity of DRASTIC, in the present study DRASTIC methodology was optimised by addition of Land use (Lu) parameters and rebuilding the parameters rates and weight. The criteria for the optimisation of rates were mean nitrate concentration and weight of the parameters was Analytical Hierarchy Process (AHP). The modified DRASTIC-Lu model formed by optimising the conventional DRASTIC by applying various modifications shows good correlation with field quality parameters. These optimisations make local models more accurate and effective.

Aditi Mukherji, (2020) - This paper provides a perspective on how in order to put forth sustainable groundwater withdrawal and management policies, one has to consider the food, energy and water nexus. India is an agriculture dependent country, and in 2009, NASA's GRACE model showed areas in Haryana, Punjab and Rajasthan showed extensive groundwater depletion. It has already been established that major groundwater depletion is because of the agricultural sector. So it was understandable that places like Punjab and Haryana, which are completely agriculture dependent, have such stressed conditions after the 1960s-1970s after the manifestation of the Green Revolution in India. Many policies that were introduced then owing to increased production of water intensive crops like paddy and wheat, introduction of MSP, introduction of mechanised processes in irrigation, and policies allowing more groundwater withdrawal has led to groundwater depletion to a great extent. These policies have not changed much since the 1970s and as a result does not cater to the current stressed condition. The paper then talks about amendment in these policies, introduction of less water intensive crops, usage of innovative techniques in irrigation like micro irrigation techniques, laser levellers etc to troubleshoot the groundwater depletion. The paper also talks about groundwater policy amendments in consideration to this nexus

Ahsen Maqsoom et al, (2020) - Land use types and anthropogenic activities represent considerable threats to groundwater pollution. To effectively monitor the groundwater quality, it is vital to measure pollution levels before they become severe. In this research, located in Gilgit Baltistan in northern Pakistan, groundwater supplies are diminishing due to urban sprawl. A GIS-based DRASTIC model (Depth to water, Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, Hydraulic conductivity) has been used here to analyse the area's hydrological attributes to assess the groundwater susceptibility to pollution. Considering the importance of anthropogenic activities, this research primarily utilises an adjusted DRASTIC model called DRASTICA, which incorporates anthropogenic impact as a parameter in the model. The resulting map, which depicts vulnerability to groundwater contamination, reveals that 19% of the study area is classed as having high vulnerability, 42% has moderate vulnerability, 37% has low vulnerability, and 2% has very low vulnerability to groundwater contamination. The adopted validation process (nitrate parameter of water quality) revealed that the suggested DRASTICA model achieved better results than the established DRASTIC model in a built-up environment. Nitrate concentration has been used in groundwater to verify the formulated results, and the single parameter sensitivity analysis and map removal sensitivity analysis to analyse the model sensitivity. The sensitivity analysis indicated that the groundwater vulnerability to pollution is largely influenced by anthropogenic impact and depth to the water table, thereby suggesting that anthropogenic impact must be explicitly tackled in such studies. The groundwater zones exposed to anthropogenic pollution can be better classified with the help of the proposed DRASTICA model, particularly in and around built-up environments. This paper provides an insight on the diversity of land-use oriented modifications that can be incorporated into the DRASTIC model that is suitable based on the research objectives.

G. Venkatesan et al., (2019) - In this paper, the DRASTIC model is applied to find out and generate a small-scale map of groundwater vulnerability to assess the contamination in the upper Palar river basin, Tamil Nadu, India. A number of tanneries are located along the banks of the river basin. The quality of groundwater in and around the river basin area has been affected very much due to the untreated effluent of the tanneries discharged directly to the river. The DRASTIC model consists of seven hydrogeological parameters including depth to water table, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity; each factor is assigned by weight and rating which depends upon the influence of the seven hydrological layers of the river basin area. The ArcGIS 10.3 software was used to create the groundwater vulnerability map by overlaying the seven layers, which is intended to show potential areas of groundwater contamination. The results of the study shows that 50% of the study area falls under a very high pollution potential zone, 20% under high pollution potential, 15% under moderate pollution potential, 10% under low pollution potential, and the remaining 5% of the area has no risk. The very high vulnerability class which is covered by the alluvium along the river course is most likely to cause pollution due to the very lower slope terrains in the direction of the central part, which allows better percolation of contaminants into the groundwater. The low vulnerability class lies in the area covered by the hard rock and clay loam soil in the upper reach of the Palar River which contains mountains and hard rock terrain. These were the key learnings from the paper.

Soumya S. Singha et al., (2019) - Intensive use of fertilisers in the agricultural lands and a swift flying of coal and allied industries in Korba district, India in an unprecedented manner has led to groundwater contamination. Accordingly, an integrated modified DRASTIC and risk index model combined with other statistical techniques are applied to evaluate groundwater susceptibility and pollution risk in the region. The ArcGIS based spatial distribution map of the DRASTIC vulnerability index (DVI) reveals that the high (63%) and very high (23.61%) vulnerable zones identified in DVI map are reduced to that of 57.86% and 17.74%, respectively, when compared with pollution risk map. Results of sensitivity analysis, i.e., map removal sensitivity analysis and single parameter sensitivity analysis confirms that amongst seven DRASTIC parameters the net recharge parameter is the most influencing parameter in view of groundwater contamination. The linear correlation coefficient (r = 0.89) obtained between risk index values and NO3 concentrations alongside nearly 75% of the study area comprises of agricultural lands and forest/tree clad area corresponds to high to very high risk contamination zones reveal the model validation in the light of the influence of anthropogenic contamination factor in these zones. Furthermore, elevated iron concentration also supports the certain influence of geogenic contamination within the study area. In essence, this study can be effectively utilised in the planning and management of precious groundwater resources in high to very high vulnerable and risk zones of the study area, for its overall sustainable development.

Aamir Shakoor et al., (2018) - The aim of this research work was to find out the groundwater vulnerability potential zones in Faisalabad and its nearby areas, which is the fastest growing city of Pakistan The demand of groundwater has significantly increased during the past two decades to meet the food and fibre requirements due to constrained surface irrigation water. The groundwater has a major share to grow agriculture in Punjab-Pakistan, which produces more than 90% gains of the country. Beside the importance of groundwater, a major concern in recent years is the contamination of groundwater. The consecutive monitoring and mapping of aquifer water quality in large areas is a hectic job and not even economically feasible. Thus groundwater vulnerability maps are becoming more in demand to represent regional aquifer contamination potential.. For this purpose, GIS based DRASTIC model was used to measure vulnerability related to agriculture in Faisalabad district. The inputs of the model are based on seven different layers. The results of the model were compared with groundwater samples. It was found that the DRASTIC model accurately identified the vulnerability of Faisalabad District with prediction efficiency of about 73%. The results revealed that more than 30% of the study area was under high vulnerability potential. The areas under high vulnerable pollution are located in the middle and upper part of Faisalabad District. The high vulnerable pollution in the surrounding of Salarwala, Chak Jhumra and Khurrianwala cities was due to shallow groundwater table, high recharge, gradual slope, sandy aquifer media and soil media consisting of medium sand. The high vulnerable pollution in the surrounding of Dijkot city was due to shallow groundwater table, gradual slope, vadose zone consisting of coarse sand and high hydraulic conductivity. It is therefore recommended that Rainwater harvesting and ASR (Aquifer Storage and Recovery Wells) should be adopted in medium and high vulnerability areas to reduce water salinity. This provides useful recommendations for water stressed blocks in the Hooghly district like Goghat I & II.

Aboubacar Modibo Sidibe, Lin Xueyu, (2018) - The study area is located in the south of Mali and is the most populous part of the country with intense agricultural activities that use a huge amount of mineral fertilisers and pesticides. Mining is another booming industry within the area which is dominated by the proliferation of traditional gold panning where the use of certain heavy metals is inevitable hence resulting in the degradation of the groundwater quality. Groundwater is becoming increasingly vulnerable to pollution from the gold-panning activities. Assessment of the vulnerability of groundwater has become a useful tool for decision support in monitoring the pollution.

This study uses vulnerability mapping as a basic tool for monitoring groundwater resources from pollution. It is based on the DRASTIC model for estimating the vulnerability of groundwater pollution in the Upper Niger and Bani Basins. The use of GIS in the model makes it possible to assess the vulnerability of groundwater by superimposing different spatially referenced hydrogeological parameters that affect groundwater contamination. The study focuses on the hydrogeological, hydrodynamic and physicochemical characteristics of over three thousand boreholes. Thirty samples from mining sites only were analysed to determine presences of heavy metals in the groundwater. Vulnerability analysis makes it possible to understand the role played by heavy metals and nitrates in monitoring the pollution. The results obtained show that 6.43% of the surface has a very high vulnerability; 52.12% are of high vulnerability; 36.89% are of moderate vulnerability; 4.57% are of low vulnerability, and 0.004% are of very low vulnerability. The large variation of the vulnerability index is observed in the elimination of depth layers (mean variation index = 3.09%), the lower the depth, the greater the vulnerability. The vadose zone with an average index changes of 0.52% has the least effect on the overall change in the vulnerability index. Validation of the vulnerability map is done using the nitrate map indicating that maximum concentrations of 92.65 mg/l is observed in the very high vulnerability class. The concentrations of heavy metals such as cyanide, cadmium, arsenic, lead, and chromium are also used in the validation. Levels of lead (0.702 mg/l), chromium (0.0588 mg/l) and arsenic (0.54 mg/l) are above the global standard whereas cadmium (0.0013 mg/l) and cyanide (0.006 mg/l) are below international standards. The presence of these metals in very small amounts in groundwater samples indicates contamination. The use of GIS allows interpolation from the data with Geostatistical methods and extraction of zonal statistics for a better interpretation of the results. This learning will be key towards the application of DRASTIC in the vulnerability assessment of my location of study.

Deepesh Machiwal et al., (2018) - Increasing groundwater contamination across the globe triggered the concept of “aquifer vulnerability”, which has been extensively used worldwide during the past three to four decades by researchers and policy makers for protecting groundwater from pollution. However, only a few recent studies have focused on the performance evaluation of two or more vulnerability assessment methods. Some of these studies have resulted in contrasting findings. Given this fact and considering the growing threat of groundwater contamination due to increasing human activities across the globe, it is necessary to critically review existing methods, understand current research trends, and identify major challenges associated with the assessment of aquifer vulnerability.

Hence, the aim of this study was to present a comprehensive review of the methods and approaches used for the evaluation of aquifer vulnerability for ‘resource’ and ‘source’ protection. First, I developed an understanding of the concept and types of aquifer vulnerability along with the definitions evolved over the years, and then learnt about the methods for assessing aquifer vulnerability classification. Second, the concept of vulnerability assessment for ‘source’ protection is something that I also learnt about, and also about the evolution of groundwater vulnerability evaluation methods. Third, I studied current research trends and critiques on past studies. Fourth, I reviewed the major challenges of vulnerability assessment and a future prospectus. It is concluded that the progress of vulnerability evaluation methods has not kept pace with the advancement of knowledge and tools/techniques. There is an urgent need for developing a scientifically robust and somewhat versatile methodology for the evaluation of ‘intrinsic’ and ‘specific’ groundwater vulnerability for ‘resource’ and ‘source’ protection under varying hydrogeologic and hydro-climatic conditions.

I Machdar et al., (2018) - This present study assessed the groundwater vulnerability to protect aquifers in part of Banda Aceh City (the sub-district of Banda Raya and Lueng Bata), Indonesia. The study area covers 1,164 Ha and the total population was estimated around 50,000 inhabitants. A DRASTIC model in a GIS (Geographic Information System) environment was used in this study to generate vulnerability maps. The vulnerability map provides five categories of vulnerability, i.e. less, low, medium, high, and very high. It was found that the village areas, labelled with the high groundwater pollution potential, are mainly in the area of Lamlagang and the part of Geuce Kaye Jatoe and Geuce Komplek (Banda Raya sub-district) and the part of Batoh and Suka Damai (Lueng Bata sub-district) This study prompts that the DRASTIC approach is helpful and efficient instrument for assessing groundwater vulnerability. The generated map can be an effective tool for local administrators in groundwater management as well. This research paper provides good insight on the advantages of using the DRASTIC model in assessing groundwater vulnerability.

Shaofei Li et al., (2018) - Assessment of groundwater vulnerability to contamination is the basement approach for preserving the quality of groundwater. Based on the DRASTIC model containing seven hydrogeological parameters and GIS techniques, groundwater vulnerability assessment was carried out in the plain area of Tianjin City, China. The results indicate that the studied area can be divided into five zones: low, slightly lower, middle, slightly higher, and high groundwater vulnerability zones, with coverage area of 1.8%, 24.8%, 53%, 19.6% and 0.8%, respectively. Low vulnerability zone is located downtown, where the ground is covered by an impervious surface. High and slightly higher vulnerability zones mainly located in the groundwater recharge areas and the suburban areas surrounding downtown. Medium vulnerability zone covers most parts of the plain areas in the south of the Baodi fraction. The result is consistent with the actual situation.

Balal Oroji, Zainab Fallah Karimi, (2018) - In recent years, the DRASTIC method has been used to map groundwater vulnerability to pollution in many areas. As this method is used in different places without any evolution, it cannot bring up the effects of pollution type and characteristics. Hence, the method needs to be calibrated and reformed for a specific aquifer and pollution. In the present research, the rates of DRASTIC parameters have been reformed so that the vulnerability potential to pollution can be determined more exactly. The new rates were calculated using the relationships between each parameter and the nitrate concentration in the groundwater. The suggested methodology was applied to the Asadabad aquifer located in western of Iran. The measured nitrate condensation values were used to correlate the pollution potential in the aquifer to DRASTIC index. The results showed that the modified DRASTIC is better than the original method for non-point source pollutants in agricultural zones. Application of the new rates, a new DRASTIC map was expanded that shows that 2.1 percent of the area fall in high vulnerability class. This percentage was 2.5 before the modification. The assessed area was 34.2% and 58.19% for moderate class and, for low vulnerability class, 63.7% and 31.39% respectively, before and after use of the new rates. This gives a clear indication towards the requirement of modification of the DRASTIC model based on various aspects of the location, whether it’s the presence of excess nitrates due to fertiliser usage in agricultural practice or the land use pattern.

Izrar Ahmed et al., (2018) - Through this study, I learnt about the management of groundwater resources of an important agriculture track of north-western part of Saudi Arabia. Considering my area of focus is the agricultural tracks of West Bengal, I opted for this particular focus area. Due to strategic importance of the area efforts have been made to estimate aquifer proneness to attenuate contamination. This includes determining hydrodynamic behaviour of the groundwater system. I learnt about various parameters of any vulnerability model: geological formations in the region, depth to water levels, soil, rainfall, topography, vadose zone, the drainage network and hydraulic conductivity, land use, hydro-chemical data, water discharge, etc. All these parameters have greater control and help determine response of groundwater systems to a possible contaminant threat. A widely used DRASTIC model helps integrate these data layers to estimate vulnerability indices using the GIS environment. DRASTIC parameters were assigned appropriate ratings depending upon existing data range and a constant weight factor. Further, the researchers have integrated a land-use pattern map of the study area with a vulnerability map to produce a pollution risk map. Model validation was done with NO3, SO4 and Cl concentrations. These maps help to assess the zones of potential risk of contamination to the groundwater resources.

Mohammad Ali Baghapour et al., (2016) - Extensive human activities and unplanned land uses have put groundwater resources of Shiraz plain at a high risk of nitrate pollution, causing several environmental and human health issues. To address these issues, water resources managers utilise groundwater vulnerability assessment and determination of protection. This study aimed to prepare the vulnerability maps of Shiraz aquifer by using Composite DRASTIC index, Nitrate Vulnerability index, and artificial neural network and also to compare their efficiency. The parameters of the indexes that were employed in this study are: depth to water table, net recharge, aquifer media, soil media, topography, impact of the vadose zone, hydraulic conductivity, and land use. These parameters were rated, weighted, and integrated using GIS, and then, used to develop the risk maps of Shiraz aquifer. The results indicated that the southeastern part of the aquifer was at the highest potential risk. Given the distribution of groundwater nitrate concentrations from the wells in the underlying aquifer, the artificial neural network model offered greater accuracy compared to the other two indexes. The study concluded that the artificial neural network model is an effective model to improve the DRASTIC index and provides a confident estimate of the pollution risk. As intensive agricultural activities are the dominant land use and water table is shallow in the vulnerable zones, optimised irrigation techniques and a lower rate of fertilisers are suggested. The findings of our study could be used as a scientific basis in future for sustainable groundwater management in Shiraz plain.

Dipankar Saha, Fakhre Alam, (2014) - Delineating areas susceptible to contamination from anthropogenic sources form an important component of sustainable management of groundwater resources. This research aims at estimating vulnerability of groundwater by application of DRASTIC and Pesticide DRASTIC models in the southern part of the Gangetic plains in the state of Bihar. The DRASTIC and Pesticide DRASTIC models have considered seven parameters viz. depth to water level, net recharge, aquifer material, soil material, topography, impact of vadose zone and hydraulic conductivity. A third model, Pesticide DRASTIC LU has been adopted by adding land use as an additional parameter, to assess its impact on vulnerability zonation. The DRASTIC model indicated two vulnerable categories, moderate and high, while the Pesticide DRASTIC model revealed moderate, high and very high vulnerable categories. Out of the parameters used, depth to water level affected the vulnerability most. The parameter causing least impact was topography in DRASTIC, while in case of Pesticide DRASTIC and Pesticide DRASTIC LU models, the parameter was hydraulic conductivity. A linear regression between groundwater NO3 concentrations and the vulnerability zonation revealed better correlation for Pesticide DRASTIC model, emphasising the effectiveness of the model in assessing groundwater vulnerability in the study region. Considering all three models, the most vulnerable areas were found to be concentrated mainly in two zones, firstly in the south-western part along Ekangarsarai-Islampur patch and second around Biharsharif-Nagarnausa area in the central part. Both zones were characterised by intensive vegetable cultivation with urban areas in between. The area of study in this paper is very similar to my chosen location of study and as a result has proven to be very effective in getting a better understanding of application of both the DRASTIC and Pesticide-DRASTIC models.

Shyamal Dutta, (2013) - Irrigation is the most important input required for successful cultivation of new seeds. Adoption of High Yielding Varieties (HYV) and intensification of agriculture in a country like India without the availability of irrigation is not possible. Indian agriculture is a gamble in the hands of monsoon since groundwater utilisation may be considered as one of the important sources of irrigation throughout the year to supply water for proper seed germination in agricultural fields in India in general and every state in particular. This article is an integrated draft to focus on the present day situation of the correspondence between groundwater utilisation and cropping pattern on block level in the Hugli district in West Bengal, India. After applying different methods and techniques (Pearson’s product moment correlation coefficient, Residual analysis etc.) it has been concluded the aforesaid area has a positive but low correspondence between these two variables. Therefore the upward increase of cropping intensity in various blocks is not governed by the groundwater utilisation alone. So, there are other physical, socio-economic as well as institutional factors too. This paper will help in the correlation of cropping pattern with the increase in the vulnerability in the vadose and phreatic zones due to increase in percentage of contaminants.

Aminreza Neshat et al., (2013) - Groundwater contamination from intensive fertiliser application affects conservation areas in a plain. The DRASTIC model can be applied in the evaluation of groundwater vulnerability to such pollution. The main purpose of using the DRASTIC model is to map groundwater susceptibility to pollution in different areas. However, this method has been used in various areas without modification, thereby disregarding the effects of pollution types and their characteristics. Thus, this technique must be standardised and be approved for applications in aquifers and particular types of pollution. In this study, the potential for the more accurate assessment of vulnerability to pollution is achieved by correcting the rates of the DRASTIC parameters. The new rates were calculated by identifying the relationships among the parameters with respect to the nitrate concentration in groundwater. The methodology was implemented in the Kerman plain in the southeastern region of Iran. The nitrate concentration in water from underground wells was tested and analysed in 27 different locations. The measured nitrate concentrations were used to associate and correlate the pollution in the aquifer to the DRASTIC index. I learnt about the Wilcoxon rank-sum nonparametric statistical test, which was applied to determine the relationship between the index and the measured pollution in Kerman plain. Also, the weights of the DRASTIC parameters were modified through the sensitivity analysis. The results of this study revealed that the modified DRASTIC model performs more efficiently than the traditional method for nonpoint source pollution, particularly in agricultural areas. The regression coefficients showed that the relationship between the vulnerability index and the nitrate concentration was 82 % after modification and 44 % before modification. This comparison indicated that the results of the modified DRASTIC of this region are better than those of the original method.

Dhundi Raj Pathak et al., (2008) - In this paper, groundwater aquifer vulnerability map has been developed by incorporating the major geological and hydro-geological factors that affect and control the groundwater contamination using GIS based DRASTIC model. This work demonstrates the potential of GIS to derive a map by overlying various spatially referenced digital data layers that portrays cumulative aquifer sensitivity ratings across the Kathmandu Valley, Nepal, providing a relative indication of groundwater vulnerability to contamination. In fact, groundwater is the major natural resource in Kathmandu for drinking purposes. The decline in groundwater levels due to the over exploitation and thus extracted water from shallow aquifers has been contaminated by the infiltration of pollutants from polluted river and land surface is continuous and serious.

This study has provided me with a good understanding of how the model can be used with a major change in the topography and impact of vadose zone. As the demand for water for human and industrial use has escalated and at the same time, the engineering and environmental costs are much higher for new water supplies than maintaining the existing sources already in use. Management of groundwater source and protecting its quality is therefore essential to increase efficient use of existing water supplies. Aquifer vulnerability maps developed in this study are valuable tools for environmental planning and predictive groundwater management. This paper has been very essential for me to get an understanding of how dynamic the Drastic model can be.

Manik Chandra Kundu et al., (2007) - We made an inventory of nitrate (NO3-N) enrichment in surface and groundwater systems in the Hooghly district of India owing to intensive farming with high fertiliser doses as a function of quantity of fertilisers use, soil characteristics, types of crop grown, depth of groundwater sampling and also N-load in soil profiles. Water samples were collected from different sources at 412 odd sites spread over in 17 blocks of the district along with representative soil profiles. On average, the study area had high clay and NO3-N in soil profiles with increasing and decreasing trends along depth, respectively. The content decreased with increasing depth of wells ($r = -0.39^{**}$) and clay content of soil profiles ($r = -0.31^{**}$). It, however, increased with increasing rate of fertiliser application ($r = 0.72^{**}$), NO3-N load in soil profiles ($r = 0.85^{**}$) and was higher in areas where shallow- rather than deep-rooted crops are grown. Results indicated even under fairly high quantities of fertiliser use, groundwater of the study area is safe for drinking purposes.

Linda Aller et al., (1987) - DRASTIC is a methodology which allows the pollution potential of any area to be systematically evaluated. The system optimises the use of existing data and has two major portions: the designation of mappable units, termed hydrogeologic settings, and the superposition of a relative ranking system called DRASTIC. Hydrogeologic settings incorporate the major hydrogeologic factors which are used to infer the potential for entering groundwater. These factors form the acronym DRASTIC and include depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone and hydraulic conductivity of the aquifer. The relative ranking scheme uses a combination of weights and ratings to produce a numerical value, called the DRASTIC Index which helps prioritise areas with respect to pollution potential.

CHAPTER - 3

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DESCRIPTION OF STUDY AREA

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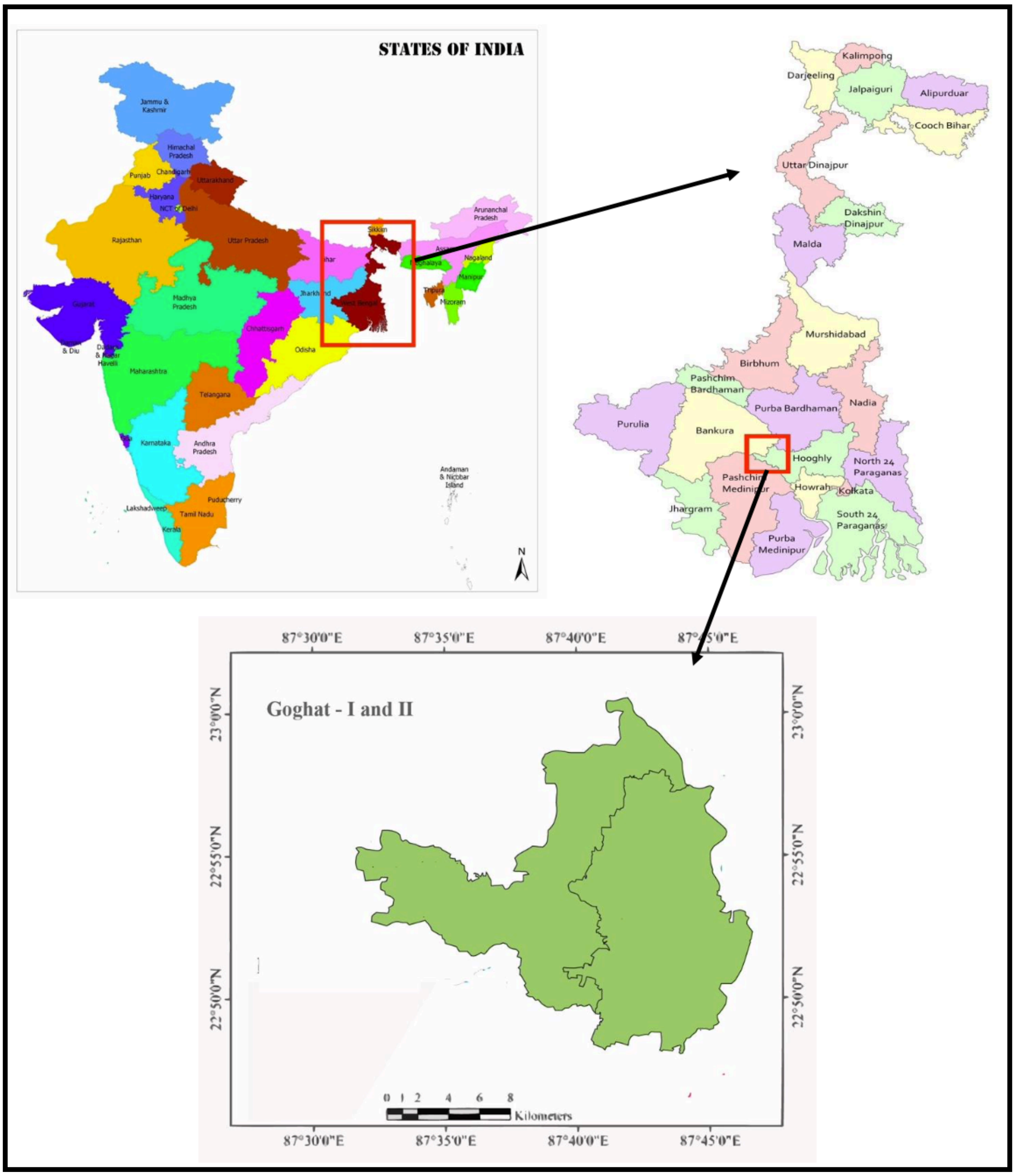
3.1 Location of Study Area



Map 3.1: Map of Hoogli District with Study Area

Goghat is located at 22°52′31″N 87°42′13″E. Goghat I CD Block is bounded by Raina II CD Block, in Bardhaman district, in the north, Arambagh CD Block in the east, Chandrakona I and Ghatal CD Blocks, in Paschim Medinipur district, in the south, and Goghat II CD Block in the west. Goghat I CD Block has an area of 186.32 km2. It has 1 panchayat samity, 7 gram panchayats, 107 gram sansads (village councils), 99 mouzas and 97 inhabited villages. Goghat police station serves this block. Headquarters of this CD Block is at Goghat. Gram panchayats of Goghat I block/ panchayat samiti are: Bali, Bhadur, Goghat, Kumursha, Nakunda, Raghubati and Saora. As per the 2011 Census of India, Goghat I CD Block had a total population of 140,030, all of which were rural. There were 71,804 (51%) males and 68,226 (49%) females. The population below 6 years was 14,581. Scheduled Castes numbered 54,321 (38.79%) and Scheduled Tribes numbered 8,415 (6.01%).

Goghat-II is a Community Development Block that forms an administrative division in Arambagh Sub-Division of Hooghly District in the Indian state of West Bengal. Goghat-II CD Block is bounded by Raina-II CD Block, in Purba Bardhaman District, in the North, Goghat-I in the East, Chandrakona-I and Garhbeta-II CD Blocks, in Paschim Medinipur District in the South and Kotulpur CD Block, in Bankura District, in the West. It has 9 (Nine) Gram Panchayats, 121 Gram Sansads (Village Councils), 112 Mouzas. Goghat Police Station serves this block. The headquarters of this CD Block is at Kamarpukur.

RLI Centre – 14, DTC Centre – 12.

TABLE 3.1: CHARACTERISTICS OF STUDY AREA

PARAMETER	DATA
Main Crops	Paddy, Sesame, Wheat, Mustard, Lentil, Ground Nut, other fruits.
Total Cultivated Area	12661 Hectare
Irrigated Area	10763 Ha
Non- Irrigated Area	1898 Ha
Marginal Farmers	670 (<0.4 Ha.)
Small Farmers	2030 (>0.4 to <0.8 Ha)
Semi Medium Farmers	7950 (>0.8 to <1.6 Ha.)

Medium Farmers	2806 (>1.6 to <4 Ha.)
Large Farmers	184 (> 4 Ha)

3.2 Population of Study Area

As per the 2011 Census of India, Goghat I CD Block had a total population of 140,030, all of which were rural. There were 71,804 (51%) males and 68,226 (49%) females. Population below 6 years was 14,581. Scheduled Castes numbered 54,321 (38.79%) and Scheduled Tribes numbered 8,415 (6.01%). As per the 2011 Census of India, Goghat II CD Block had a total population of 160,585, all of which were rural. There were 82,262 (51%) males and 78,323 (49%) females. Population below 6 years was 17,056. Scheduled Castes numbered 58,052 (36.15%) and Scheduled Tribes numbered 7,587 (4.72%).

TABLE 3.2: POPULATION OF RESPECTIVE VILLAGES IN GOGHAT- I (CENSUS 2011)

#	Villages	Administrative Division	Population
1	Adra	Goghat - I	481
2	Amadpur	Goghat - I	1,001
3	Amdoba	Goghat - I	1,224
4	Anandapur	Goghat - I	2,873
5	Arazi Surjyapur	Goghat - I	439
6	Badla	Goghat - I	833
7	Bajua	Goghat - I	2,949
8	Bali	Goghat - I	4,063

9	Ballabhbati	Goghat - I	927
10	Bamunia	Goghat - I	501
11	Bara Kumursa	Goghat - I	224
12	Barama	Goghat - I	916
13	Barul	Goghat - I	302
14	Belekusuma	Goghat - I	2,103
15	Beli	Goghat - I	495
16	Belibela	Goghat - I	1,751
17	Bhabadighi	Goghat - I	887
18	Bhadur	Goghat - I	2,898
19	Bhanjapara	Goghat - I	518
20	Bijalkona	Goghat - I	1,702
21	Birampur	Goghat - I	850
22	Brahmangram	Goghat - I	402
23	Buintya	Goghat - I	486
24	Chak Hari	Goghat - I	1,251
25	Chak Mamrej	Goghat - I	364
26	Chak Netara	Goghat - I	280

27	Chatra	Goghat - I	1,408
28	Dahiakanda	Goghat - I	1,800
29	Dakshin Balarampur	Goghat - I	702
30	Damodarpur	Goghat - I	3,154
31	Darinakunda	Goghat - I	2,041
32	Dewan Chak	Goghat - I	147
33	Dhulepur	Goghat - I	1,487
34	Dighara	Goghat - I	2,246
35	Dumurpara	Goghat - I	320
36	Ganeshbati	Goghat - I	1,094
37	Goalpara	Goghat - I	1,152
38	Gobindapur	Goghat - I	2,977
39	Goghat	Goghat - I	5,495
40	Gohalisanra	Goghat - I	759
41	Gohalpota	Goghat - I	580
42	Golpur	Goghat - I	1,846
43	Gopalbati	Goghat - I	1,202
44	Hariharpur	Goghat - I	1,115

45	Harischandrapur	Goghat - I	847
46	Jagatpur	Goghat - I	1,204
47	Jaykrishnapur	Goghat - I	2,738
48	Jot Mahabat	Goghat - I	245
49	Kalagachhia	Goghat - I	812
50	Kamche	Goghat - I	2,396
51	Kanaipur	Goghat - I	911
52	Kantali	Goghat - I	695
53	Khanati	Goghat - I	1,370
54	Khatgram	Goghat - I	1,038
55	Khilgram	Goghat - I	464
56	Khorda Kanpur	Goghat - I	1,524
57	Kota	Goghat - I	2,753
58	Kulia	Goghat - I	1,632
59	Kumursa	Goghat - I	4,449
60	Kurmana	Goghat - I	1,382
61	Lakshmipur	Goghat - I	915
62	Madanmohanpur	Goghat - I	1,186

63	Madina	Goghat - I	1,877
64	Mandalghanti	Goghat - I	1,627
65	Mathura	Goghat - I	1,493
66	Methul	Goghat - I	2,704
67	Mirga	Goghat - I	1,026
68	Mirzzapur	Goghat - I	681
69	Mohanpur	Goghat - I	1,466
70	Muktarpur	Goghat - I	1,049
71	Nabasan	Goghat - I	1,797
72	Nakunda	Goghat - I	4,228
73	Palpukur	Goghat - I	128
74	Patulsara	Goghat - I	2,076
75	Penchera	Goghat - I	641
76	Pirmallik	Goghat - I	264
77	Purbba Amarpur	Goghat - I	1,027
78	Pyarinagar	Goghat - I	430
79	Radhaballabhpur	Goghat - I	1,860
80	Raghubati	Goghat - I	1,785

81	Rajgram	Goghat - I	1,027
82	Ratanpur	Goghat - I	1,643
83	Rautara	Goghat - I	380
84	Santa	Goghat - I	1,390
85	Santoshpur	Goghat - I	1,337
86	Saora	Goghat - I	4,290
87	Sekati	Goghat - I	768
88	Shancha	Goghat - I	841
89	Shyambati	Goghat - I	1,107
90	Sitanagar	Goghat - I	1,078
91	Sulut	Goghat - I	666
92	Sunia	Goghat - I	2,329
93	Surjyapur	Goghat - I	336
94	Syamballabpur	Goghat - I	4,985
95	Teligram	Goghat - I	980
96	Udayrajpur	Goghat - I	1,517
97	Uttar Balarampur	Goghat - I	2,391

TABLE 3.3: POPULATION OF RESPECTIVE VILLAGES IN GOGHAT- II (CENSUS 2011)

#	Villages	Administrative Division	Population
1	Agai	Goghat - II	2,090
2	Ambaula	Goghat - II	484
3	Andua	Goghat - II	911
4	Anupnagar	Goghat - II	1,721
5	Anur	Goghat - II	3,320
6	Arazi Kirttibaspur	Goghat - II	77
7	Ashpur	Goghat - II	1,548
8	Baburampur	Goghat - II	807
9	Badanganj	Goghat - II	3,865
10	Bahagal	Goghat - II	1,135
11	Balitakunda	Goghat - II	34
12	Bara Salabeltala	Goghat - II	661
13	Beldiha	Goghat - II	2,185
14	Belepara	Goghat - II	740
15	Belun	Goghat - II	344
16	Bengai	Goghat - II	4,674

17	Betbani	Goghat - II	549
18	Betra	Goghat - II	3,262
19	Bhagabanpur	Goghat - II	1,149
20	Bhurkunda	Goghat - II	2,361
21	Chakran	Goghat - II	438
22	Chandpur	Goghat - II	1,177
23	Dakshin Arjungaria	Goghat - II	454
24	Dakshin Sainte	Goghat - II	594
25	Dariahar	Goghat - II	287
26	Dashghara	Goghat - II	1,458
27	Datpur	Goghat - II	1,332
28	Daulatbati	Goghat - II	509
29	Debkhanda	Goghat - II	2,510
30	Dharmmapur	Goghat - II	239
31	Durgapur	Goghat - II	1,111
32	Dwariapur	Goghat - II	310
33	Dwaripara	Goghat - II	490
34	Fului	Goghat - II	5,984

35	Gar Mandaran	Goghat - II	6,264
36	Gauripur	Goghat - II	459
37	Gotai	Goghat - II	771
38	Gurulia Bhatsala	Goghat - II	2,064
39	Harihar	Goghat - II	1,666
40	Harisabha	Goghat - II	1,757
41	Hazipur	Goghat - II	3,643
42	Idalbati	Goghat - II	1,980
43	Indira	Goghat - II	471
44	Jharia	Goghat - II	947
45	Jharikhanda	Goghat - II	439
46	Jitarpur	Goghat - II	131
47	Jotchandi	Goghat - II	1,505
48	Kajla	Goghat - II	192
49	Kamala	Goghat - II	505
50	Kamarpukur	Goghat - II	3,121
51	Kantagarya	Goghat - II	1,049
52	Kapsit	Goghat - II	197

53	Karnapur	Goghat - II	344
54	Kayapat	Goghat - II	3,351
55	Kayrakhali	Goghat - II	556
56	Khatul	Goghat - II	2,643
57	Khejurbandi	Goghat - II	535
58	Kokandi	Goghat - II	1,112
59	Kotai	Goghat - II	1,185
60	Krishnaganj	Goghat - II	2,321
61	Krittibaspur	Goghat - II	371
62	Kuchedahari	Goghat - II	288
63	Kultala	Goghat - II	556
64	Kumarganj	Goghat - II	1,171
65	Kurchigaria	Goghat - II	696
66	Laluka	Goghat - II	2,497
67	Laskarpukur	Goghat - II	1,059
68	Madhubati	Goghat - II	1,991
69	Mamudpur	Goghat - II	2,109
70	Mandala	Goghat - II	316

71	Masidbera	Goghat - II	467
72	Maynadanga	Goghat - II	412
73	Meherbanpur	Goghat - II	198
74	Mulluk	Goghat - II	737
75	Naldubi	Goghat - II	656
76	Naraharbati	Goghat - II	190
77	Narasinbati	Goghat - II	1,157
78	Paba	Goghat - II	2,100
79	Pandugram	Goghat - II	2,290
80	Paschim Amarpur	Goghat - II	1,106
81	Paschim Chakla	Goghat - II	594
82	Paschim Para	Goghat - II	2,975
83	Pukhuria	Goghat - II	1,446
84	Pundahit	Goghat - II	1,317
85	Punia	Goghat - II	789
86	Purba Chakla	Goghat - II	357
87	Raghunathpur	Goghat - II	370
88	Rangamati	Goghat - II	551

89	Rayan	Goghat - II	713
90	Ria	Goghat - II	851
91	Samantakhanda	Goghat - II	2,973
92	Satberia	Goghat - II	1,378
93	Selampur	Goghat - II	4,471
94	Senai	Goghat - II	1,195
95	Shalikona	Goghat - II	1,194
96	Shaljhar	Goghat - II	2,079
97	Shantipur	Goghat - II	3,768
98	Shripur	Goghat - II	4,727
99	Shyambazar	Goghat - II	6,293
100	Shyampur	Goghat - II	379
101	Sikil Beldiha	Goghat - II	275
102	Sinrapur	Goghat - II	1,629
103	Subir Chak	Goghat - II	1,079
104	Sundarpur	Goghat - II	2,505
105	Tarahat	Goghat - II	3,501
106	Tarui	Goghat - II	640

107	Tehure	Goghat - II	672
108	Tilari	Goghat - II	1,444
109	Tilati	Goghat - II	568
110	Uttar Sainte	Goghat - II	1,467

3.3 Agricultural / Irrigation Data

This is a rich agricultural area with several cold storages. The main occupation is Agriculture. Though rice is the prime crop of the district, the agricultural economy largely depends on potato, jute, vegetables, and orchard products. Though potato is cultivated in all the blocks of this district Dhaniakhali, Arambagh, Goghat, Pursurah, Haripal, Polba-Dadpur, Tarakeswar, Pandua and Singur contributed much of its production to this district.

Some of the primary and other hats or markets in the Goghat I and Goghat II CD Blocks are: Amar hat, Baddangang hat, Bengali market, Ballihat, Goghat market, Hazipur hat, Khatul hat, Kamarpukur, Madina market, Shyambazar hat, Shyamballabhpur market, Badanganj hat and Dewagang hat.

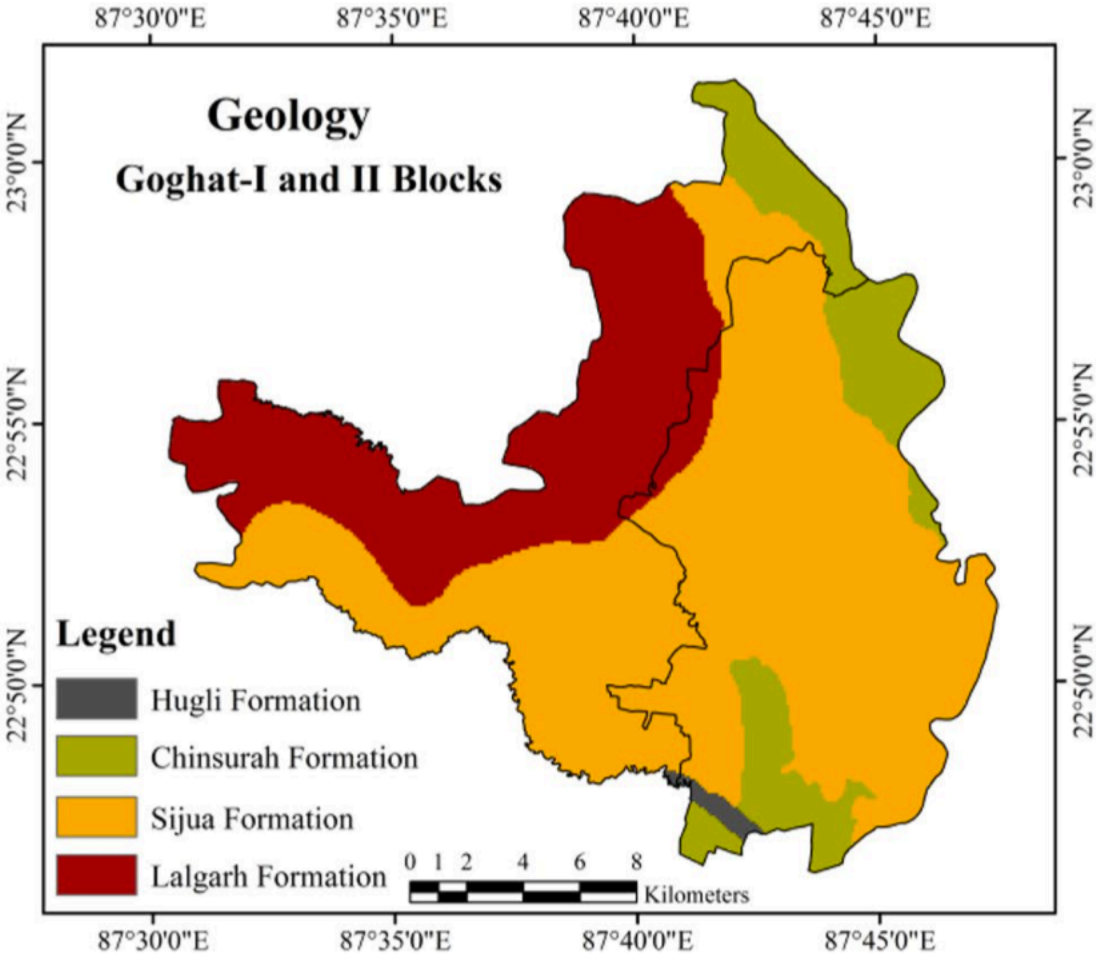
The Tebhaga movement launched in 1946, in 24 Parganas district, aimed at securing for the sharecroppers a better position within the existing land relation structure. Although the subsequent Bargadari Act of 1950 recognised the rights of bargadars to a higher share of crops from the land that they tilled, it was not implemented fully. Large tracts, beyond the prescribed limit of land ceiling, remained with the rich landlords. From 1977 onwards major land reforms took place in West Bengal. Land in excess of the land ceiling was acquired and distributed amongst the peasants. Following land reforms, land ownership pattern has undergone transformation. In 2013-14, persons engaged in agriculture in Goghat II CD Block could be classified as follows: bargadars 10.38%, patta (document) holders 17.80%, small farmers (possessing land between 1 and 2 hectares) 3.70%, marginal farmers (possessing land up to 1 hectare) 28.23% and agricultural labourers 39.90%.

Goghat II CD Block had 85 fertiliser depots, 8 seed stores and 43 fair price shops in 2013-14.

In 2013-14, Goghat II CD Block produced 95,203 tonnes of Aman paddy, the main winter crop from 32,498 hectares, 13,351 tonnes of Boro paddy (spring crop) from 4,271 hectares, 1,346 tonnes of Aus paddy (summer crop) from 550 hectares and 40,723 tonnes of potatoes from 3,350 hectares. It also produced oilseeds and some wheat. In 2013-14, the total area irrigated in Goghat I and Goghat II CD Blocks was 27,605 hectares, out of which 10,300 hectares were irrigated by canal water, 4,270 hectares by tank water, 870 hectares by river lift irrigation, 840 hectares by deep tube wells and 11,325 hectares by shallow tube wells.

3.4 Geology

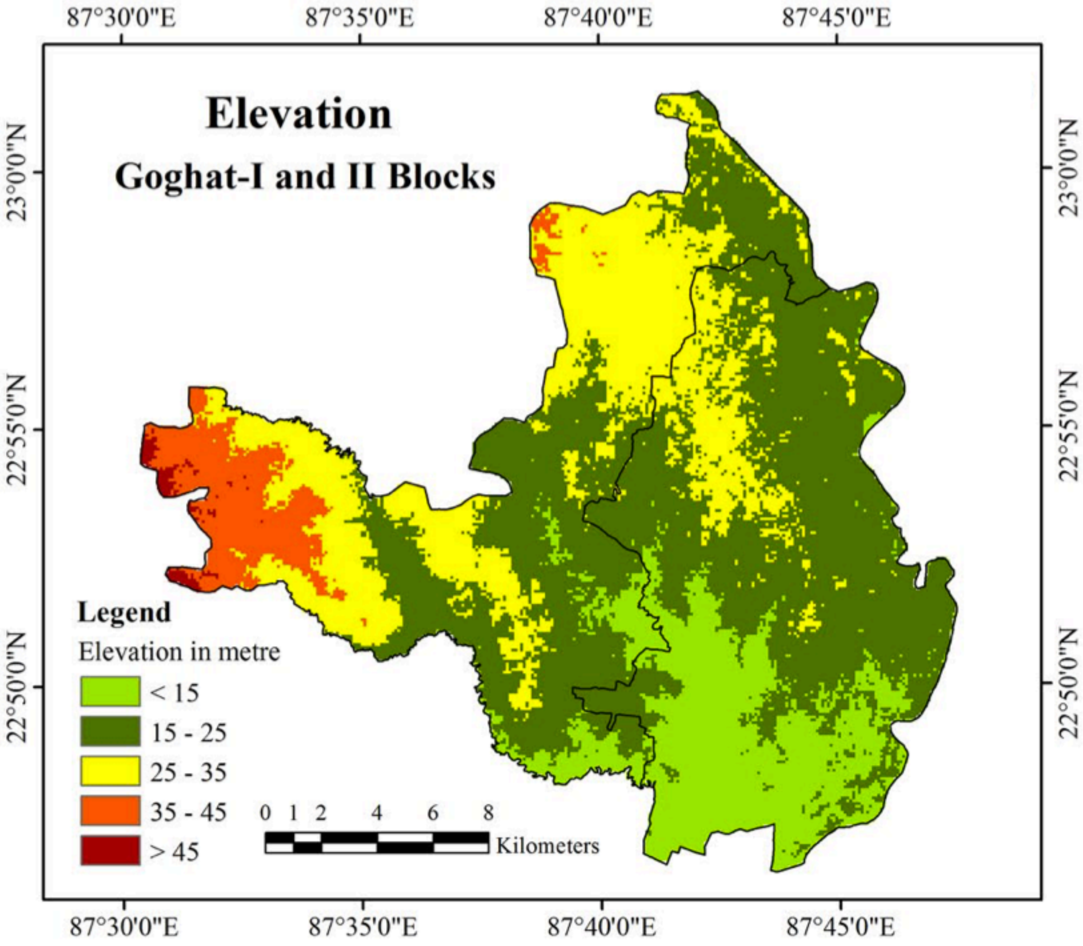
The two blocks are underlain by the Lalgarh formation, which consists of secondary laterite, lateritised grits and con- glomerates of lower Pleistocene age, which cover the western part of this region. Much of the study area is underlain by the Sijua formation of middle Pleistocene to Holocene age, which consists of sandy loam, silt and silty clays, whereas Chinsurah and Hugli formations of upper Holocene age are present in small parts of the area. These formations consist of unconsolidated sands, silts and clays of alluvial origin (Geological Survey of India 2006). There is only limited groundwater in the Lalgarh formation due to the low permeability of the laterite. The older sediments in the Sijua formation are more permeable than those of the Lalgarh formation and have a higher potential to contain significant amounts of groundwater. The Chinsurah and Hugli formations are quite favourable for the occurrences of groundwater.



Map 3.2 - Geology Map of Study Area

3.5 Elevation

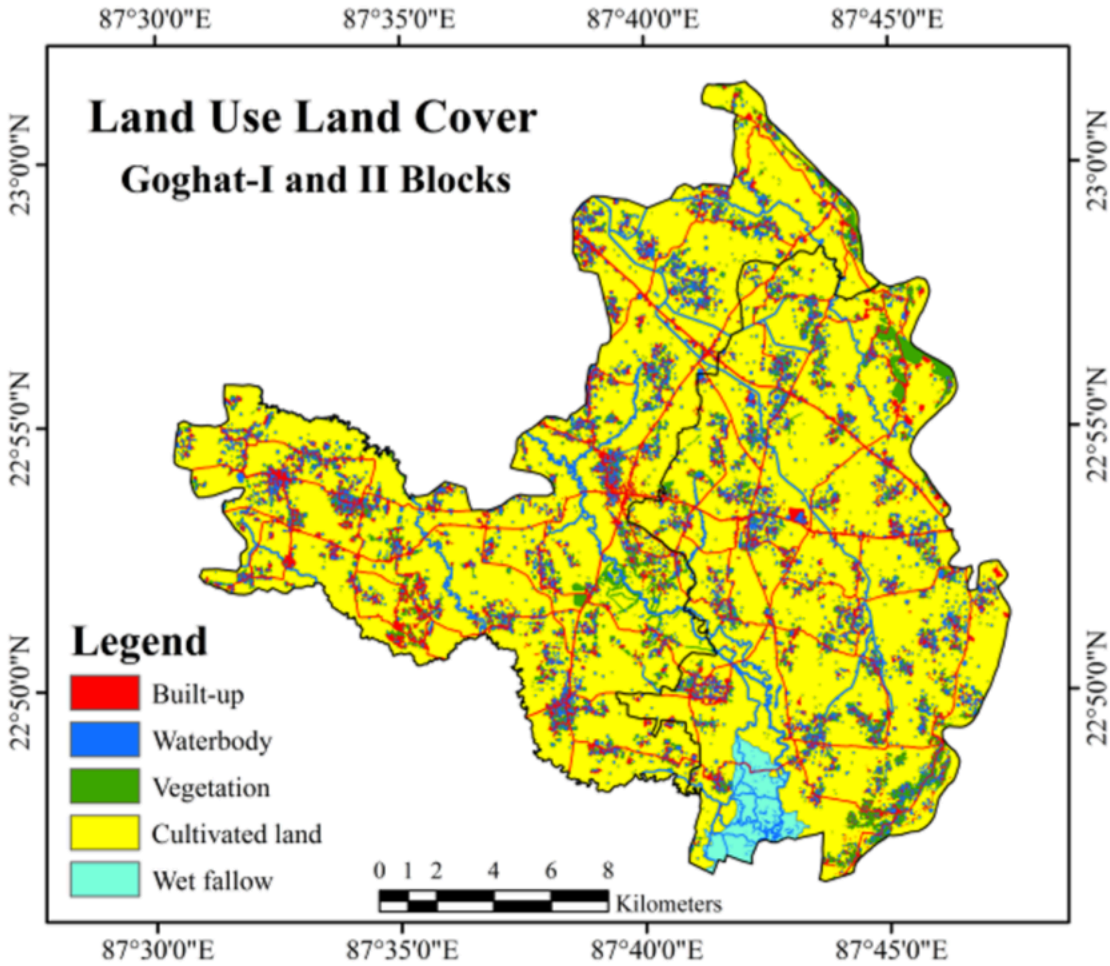
The study area is characterised by upland plains coupled with undulating topography. The elevation of the area ranges from 10–50 m above mean sea level (Fig. 1.4). Plains in the eastern and southern parts of the study area generally have a lower elevation than in the western part of the area. Elevated upland is underlain by hard laterite, which limits ground- water recharge; whereas lower elevated plain land is typically underlain by newer alluvium sediments that are more favourable for recharge. Groundwater considered to be more vulnerable to over-exploitation in upland areas than areas with a lower elevation. Consequently, different weights were allocated to different elevations.



Map 3.3 - Elevation Map of Study Area

3.6 Land use land cover

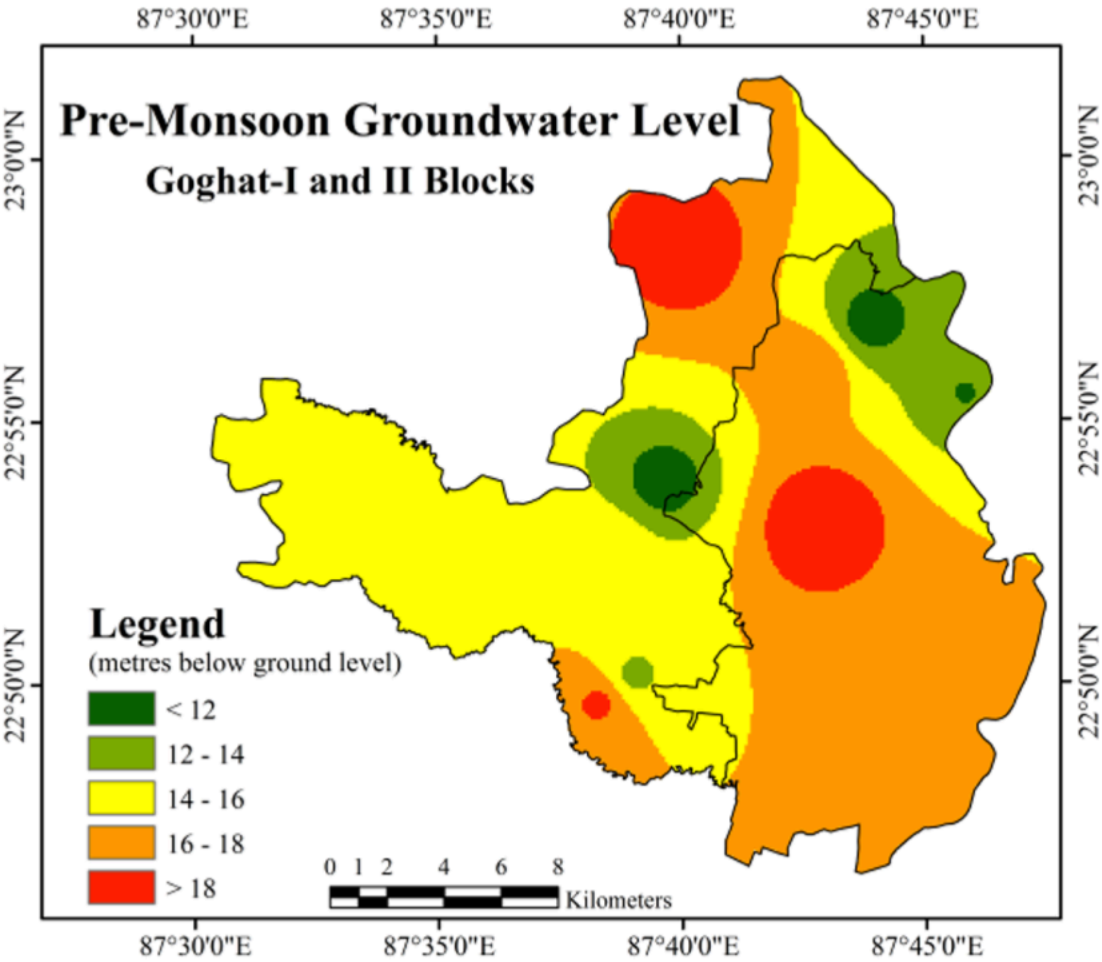
The vulnerability of groundwater too excessive abstraction is influenced by the land use land cover of a region. This is because land use land cover directly controls the recharge capacity of an area. Cultivated land is the most dominant land use type within the study area (Fig. 1.5). Groundwater is heavily used for agricultural purposes. Overuse of groundwater for irrigation purposes is increasing the vulnerability of replenishable groundwater resources. Although the region is rural in nature and the degree to which the land surface is covered with paved surfaces is comparatively low, the recharge is generally low in the urbanised areas. In this study, the maximum weightage has been given to cultivated land due to excessive water use in the agricultural land.



Map 3.4 - LULC Map of Study Area

3.7 Pre-monsoon groundwater levels

Groundwater level of a region indicates the hydrological condition of an aquifer and the degree to which it has been affected by abstraction. Measured groundwater levels have their lowest values in the pre-monsoon season and are an indicator of the vulnerability of the system to excessive groundwater use. Although groundwater levels in the pre- monsoon season decline due to natural reasons, the rate of declination has increased in last few decades due to overuse of groundwater for Boro rice cultivation, which is creating extra stress on the aquifer. Water levels in most of the study area remain 14 m below ground level during the pre-monsoon season. Pre-monsoon groundwater level of more than 18 m below ground level has been given maximum weight as this region is already in a vulnerable condition.



Map 3.5 - Pre-monsoon GWL Map of Study Area

3.8 Water Resource Problem of Study Area

The two blocks are underlain by the Lalgarh formation, which consists secondary laterite, lateritised grits and con- glomerates of lower Pleistocene age, which cover the western part of this region (Fig. 3a). Much of the study area is underlain by the Sijua formation of middle Pleistocene to Holocene age, which consists of sandy loam, silt and silty clays, whereas Chinsurah and Hugli formations of upper Holocene age are present in small parts of the area. These formations consist of unconsolidated sands, silts and clays of alluvial origin (Geological Survey of India 2006). There is only limited groundwater in the Lalgarh formation due to the low permeability of the laterite. The usage of fertilisers in agriculture in this area is also very high owing to the same being the key source of livelihood for these blocks. As a result the soil contains amounts of Nitrate and other contaminants. Because of the known health and economic impacts associated with groundwater contamination, steps to assess the vulnerability of groundwater must be taken for sustainable groundwater protection and management planning. Vulnerability of groundwater refers to the intrinsic characteristics that determine the sensitivity of the water to being adversely affected by an imposed contaminant load. The DRASTIC method (Aller et al., 1987), developed by the U.S. Environmental Protection Agency, is the most widely used method for identifying the areas where groundwater supplies are most susceptible to contamination. It is a relatively quick and simple to use process for assessing susceptibility to a large extent. Vulnerability to contamination is a dimensionless index function of hydrogeological factors, anthropogenic influences, and sources of contamination in any given area (Plymale and Angle 2002). The index consists of seven parameters with different weighting factors. The DRASTIC parameters are weighted from one to five according to their relative importance in contributing to the contamination potential (Aller et al., 1987). The resulting index is a comparable measure of vulnerability to contamination; higher index values are more vulnerable than those with a lower index.

CHAPTER - 4

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CONCEPTUALISATION OF GROUNDWATER VULNERABILITY

4.1 Groundwater Vulnerability Assessment

Groundwater geochemistry is the science that explores the processes controlling the chemical composition of groundwater, the groundwater quality. The groundwater quality influences the use of this resource. Groundwater may contain hazardous substances that affect health when consumed or which deteriorate the environment when the water is thoughtlessly spilled at the surface. The groundwater quality may change during the exploitation, or it may be affected by human activities of which the impact is not always immediately evident.

The interest of society in groundwater geochemistry is mainly to ensure good quality drinking water. Although drinking water can be manufactured, for example by desalination, this still is a costly affair, and to surrender to this option is in conflict with our desire to utilise groundwater as a sustainable resource, refreshingly and cleanly flowing from a well. Preservation of good groundwater therefore has a high priority for environmental authorities.

Groundwater contamination has always been a big concern for such activities and has aroused curiosity among the researchers, government agencies, and environmental organisations in recent years. The long term exposure of toxic contaminants present in groundwater has adverse effects on human health in the form of various grievous diseases like skin lesion, skin cancer, neurological effect, hypertension, cardiovascular diseases, pulmonary diseases, and diabetes mellitus (Smith et al. 1992, 2000; Saha et al. 1999; Tseng et al. 2003; Kile and Christiani 2008; Hendryx, 2009). Groundwater contaminants are naturally occurring inorganic pollutants such as arsenic, aluminium, lead, mercury, fluoride, iron, nitrate, etc. and manmade organic pollutants such as pesticides, plasticisers, chlorinated, solvents, etc. (Ghosh and Singh 2009; US Geological Survey 2014) which are widely spread in air, water, soil, rocks, plants, and animals in different ratios. Inorganic contaminants are released in the environment via chemical and physical breakdown of rocks and subsequent leaching and runoff, volcanoes, microorganisms, and human activities such as mining and excavation.

Organic contaminants are released into the environment through various agricultural activities. These contaminants get into groundwater and finally enter human bodies through the food chain. Groundwater is relatively less vulnerable to contamination in comparison to surface water. However, urbanisation and industrialisation have caused a serious threat to the water resources because the natural purification rate has been subdued by the rate of waste/industrial effluent discharge into the environment. Also, the panoptic use of tube wells has caused serious groundwater intoxication over the years. Many government agencies have come up with their reports on groundwater quality assessment models. In order to monitor and assess the quality of water from the regions where the primary source of drinking water is groundwater wells, several groundwater vulnerability and risk mapping models have been developed. These models estimate the sensitivity of groundwater to contamination, and it is expressed in the form of vulnerability map. The vulnerability map segregates the particular region into several hydrogeological subregions with different levels of severity from contamination point of view. There are mainly three kinds of techniques used in the creation of vulnerability assessment maps, viz. statistical techniques, process-based simulation techniques and index-based techniques. Statistical techniques find the mapping between the spatial variables and the presence of contaminants in the groundwater. Statistical techniques are not generic in nature as they are mostly used in the assessment of groundwater where similar contaminants are present. Process-based techniques employ simulation models to forecast pollutant movement in groundwater. However, they have shortcomings in the form of unavailability of adequate data, but they are more elaborated than simple index-based techniques. Index-based techniques have the advantages over the rest of two as it resolves their limitations. Index-based techniques are not encumbered by computational complexities and data shortage. This is the reason that index-based techniques are the most preferred for the groundwater vulnerability assessment.

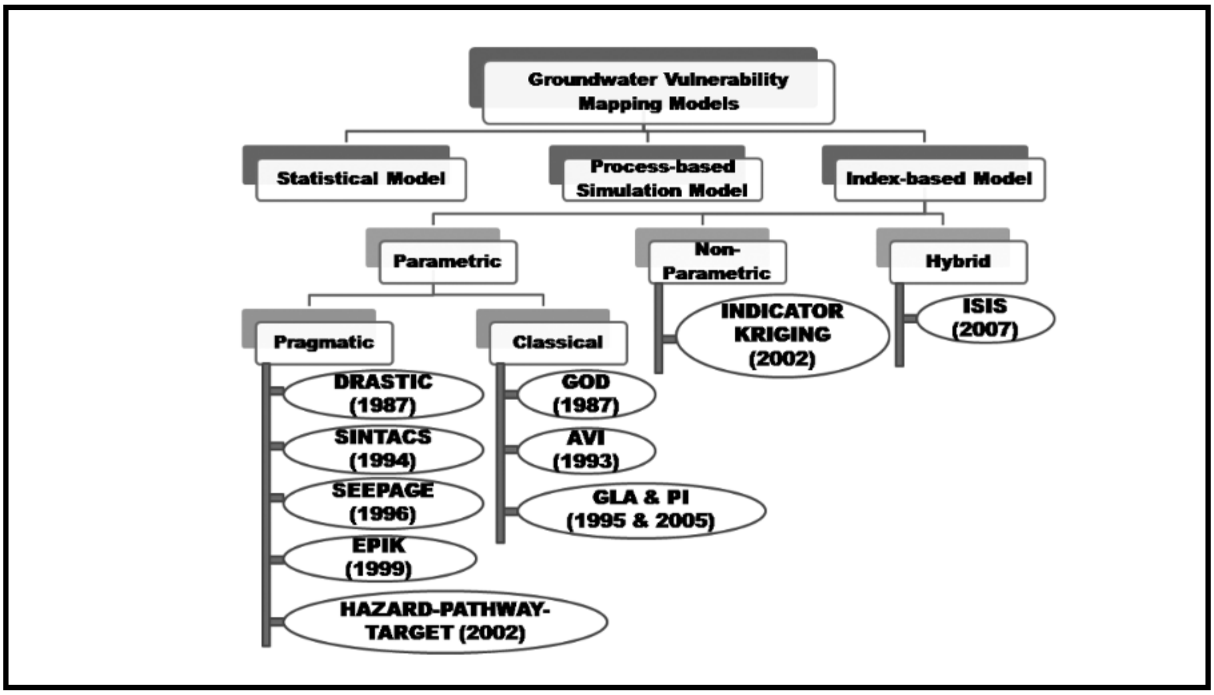

Fig. 4.1 - Index-based groundwater vulnerability mapping models.

4.1.1 Index-Based Vulnerability Mapping Models

Aquifer vulnerability has been modelled in many ways. Of all the techniques developed so far, index-based techniques remain the most widely used techniques because of its large scale aquifer sensitivity and simple implementation. Index-based models can be divided into three categories, namely, parametric, non-parametric, and hybrid models as shown in the figure above. Vulnerability mapping is a valuable tool for environmental planning and decision making using indexing methods coupled with GIS-based spatial analysis commonly relied upon to ascertain aquifer vulnerability. It divides a region to several hydrogeological areas with various levels of sensitivity from contamination point of view. Groundwater vulnerability can be categorised into intrinsic vulnerability and specific vulnerability.

Intrinsic vulnerability is independent of particular contaminants and assesses sensitivity of aquifers to human activities or nature, while the latter considers vulnerability to one or more contaminants. Intrinsic vulnerability parameters, such as soil media, depth to water and net recharge have been changed extensively due to anthropogenic activities.

On the other hand, specific vulnerability is used to define groundwater vulnerability to a specific contaminant by taking into account the contaminants' physio-chemical properties and their relationships. Basically, there are three available techniques for creating vulnerability maps: overlay and index based techniques; process based simulation techniques; and statistical techniques. Although, with respect to particular factors and under specific circumstances they have strengths and weaknesses.

4.1.1.1 Overlay and index methods

The overlay and index methods are the most widespread techniques in vulnerability map- ping due to low requirement on field data. These methods include a set of subjective ratings and weights which consider different physical and hydrogeological factors to control movement of pollutants through the unsaturated zone till they reach the water-table and spread. Overlay and index methods are often preferred because of availability of the required data and relatively simple procedures. Actually, these methods include important parameters in groundwater vulnerability evaluation without attempting to fully describe the processes that lead to contamination. Despite simplicity and convenience, there are some disadvantages in vulnerability mapping using overlay and index methods. Firstly, this system assumes a linear relationship between vulnerability and parameters while some studies have shown non-linear superposition. Secondly, all weights and rates are subject to expert judgement which introduce a subjective effect into the result. Thirdly, the value for ratings are discretised that could introduce additional error. There are many index systems for groundwater vulnerability mapping, including SINTACS, GOD, AVI, PI, GLA and DRASTIC which is the most widely used technique for vulnerability mapping.

4.1.1.2 Process based simulation model methods

Process-based methods predict contaminant flow and transport using simulation models and the required data for this method must be obtained by indirect techniques. These methods may use the advective-dispersive solute transport approach along with different chemical reaction models that can describe the dynamics a pollutant may undergo. Process-based simulation models require analytical or numerical solutions to mathematical equations that present coupled processes affecting contaminant transport. Methods in this class range from indices based on simple transport models to analytical solutions for one-dimensional transport of contaminants through the unsaturated zone to coupled, unsaturated-saturated, multiple-phase, two- or three-dimensional models. These approaches are different from others in that many of them attempt to predict contaminant transport in both space and time. Meeks and Dean (1990) used a one-dimensional advection-dispersion transport model to develop a leaching potential index, which simulates vertical movement through a soil to the water-table. Soutter and Pannatier (1996) expressed groundwater vulnerability as the ratio between the cumulative pesticide flux reaching mean water-table depth and the total quantity of pesticide applied.

Process-based models such as Visual ModFlow provide excellent tools to predict water flow and pollutant transport under specific hydrogeologic conditions in the unsaturated zone, in particular those that are highly layered (heterogeneous), and for chemical processes that undergo multiple chemical processes or chemical reactions. The most important disadvantage of this method is that they need a large volume of input data with considerable calculation power and difficulties in the calibration process.

4.1.1.3 Statistical Methods

Statistical methods using different degrees of complexities in statistics, identify parameters which are affecting groundwater contamination and they are suitable for specific regions. They produce a correlation between explanatory parameters and contaminant concentration. These methods have been used in the evaluation of vulnerability using probability models and results are expressed as probabilities. In general, these models include multiple independent variables and use a contaminant concentration or a probability of contamination as the dependent variable. Teso (1996) proposed a logistic regression model containing independent variables related to the soil texture. The dependent variable was defined as the contamination status of soil sections (uncontaminated vs. contaminated) and groundwater vulnerability was thus assessed through the estimation of a section's probability of containing a contaminated well. Worrall and Kolpin (2004) introduced a logistic regression model of groundwater contamination that brings together variation in chemical properties with land use, soil and aquifer characteristics.

Undoubtedly, simulation and statistical techniques provide more accurate information for water resource managers by relying on professional judgments, hence, they are preferred over the overlay index methods in the event required input data are available. More or less, all vulnerability models consider similar factors for predicting contamination, the only difference is the type of approach they apply for integration.

4.2 The DRASTIC Model

The most widely used groundwater assessment parametric model is DRASTIC. This model was first developed by Aller et al. (1987) at National Water Well Association Dublin, Ohio, in collaboration with U.S. Environmental Protection Agency Ada, Oklahoma, to evaluate groundwater pollution potential using hydrogeological parameters. DRASTIC model assumes following points while modelling the vulnerability of groundwater contamination:

- The contaminants are released at the earth's surface (use of fertilisers, burning of coal, and leaching of metals from coal-ash tailings)
- The contaminant flushes into the groundwater through precipitation
- The contaminant moves with the velocity of water
- The concerned area should be large enough.

There are two important aspects of this model: hydrogeological parameters and relative ranking system. The model uses seven hydrogeological parameters to assess the groundwater vulnerability, namely, depth to groundwater table (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I), and hydraulic conductivity (C) of the aquifer. These parameters are the most important parameters for groundwater as these are the parameters which regulate the movement of groundwater in a particular study area. These parameters are assigned weights and relative ratings according to their phylogenetic relations to the contaminants. The range of assigned weights is from 1 (least important) to 5 (most important) and relative ratings range from 1 (least important) to 10 (most important) (Aller et al. 1987; Babiker et al. 2005; Chakraborty et al. 2007). The weights to various parameters are fixed in the implementation of DRASTIC (Aller et al. 1987) as given in the table below. The relative ratings assignment is totally subjective in nature and is based on Delphi consensus (Aller et al. 1987). DRASTIC model uses a vulnerability index value in order to classify a particular region into different units of potential contamination. The governing equation for the computation of vulnerability index value is given in Equation (1.1).

$$\text{Vulnerability index} = \sum_{i=1}^{7} W_i \times R_i, \quad \text{.......(4.1)}$$

where Wi and Ri represent weight factor and relative rating assigned to the ith parameter of DRASTIC vulnerability index empirical formula. The original DRASTIC index (DI) was calculated by applying a linear combination of all parameters as demonstrated by the equation below:

DI = DW.DR + RW.RR + AW.AR + SW.SR + TW.TR + IW.IR + CW.CR …….(4.2)

where DI is the DRASTIC index, D, R, A, S, T, I, and C are the seven parameters; factors with W subscripts show the weight and parameters with R subscripts are the rate of the parameters. The vulnerability index is a dimensionless index and relative measure of susceptibility to pollution; regions with a higher DRASTIC index value are more vulnerable than those with a lower index. The range of index can be from 70 to greater than 200. Also, in this method, the parameters are weighted from 1 to 5 and the rates are from 1 to 10, based on the relative contribution to potential contamination. DRASTIC parameters have been explained briefly in the following sections.

Depth to Water (D)

Depth to water is one of the most important parameters in DRASTIC technique which describes the distance that contaminants must travel from the surface to reach groundwater table. In another word, it is the vertical distance from ground surface to water table, top of saturated zone, in the aquifer. It could be determined using topography and groundwater level contour maps. By subtracting elevations from groundwater level, depth to water would be calculated. In general, potential for contamination decreases with increasing D, as deeper water-table implies less chance for contamination to occur.

Net Recharge (R)

Net groundwater recharge is the main driving force for transferring contaminants to an aquifer. The total amount of water that reaches the water-table has been indicated as net recharge. Net recharge might be estimated from the rainfall infiltration, irrigation return flow, evapotranspiration and absorption wells in the study area. The more recharge shows more vulnerability to contamination. The main source of recharge could be either river leakage or rainfall. The groundwater recharge map could also be prepared using isotope studies.

Aquifer Media (A)

Aller (1987) defined an aquifer as a rock formation which yields a sufficient amount of water for use. Aquifer media refers to consolidated and unconsolidated rocks (such as sand, gravel or limestone) which serves as an aquifer. This parameter is essential to control the route, path length and movement of contaminants. In general terms, large sediment size, higher permeability and lower attenuation capacity can result in more vulnerability to pollution. Aquifer media maps could be prepared using geological information.

Soil Media (S)

The soil media represents the top weathered portion of an unsaturated zone with significant biological activities. It is the top part of the vadose zone, and its characteristics are important in potential pollution while by increasing the depth of soil, infiltration will be decreased. Generally, soil map can represent infiltration rates of pollutants. There are some effective factors that determine the potential pollution of soil comprising the type of clay, the grain size and shrink potential of clay. Indeed, less amount of clay, less shrinkage potential and smaller grain size indicate lower vulnerability of aquifer.

Topography (T)

Topography refers to the slope of the land surface and it controls the runoff of contaminants. This factor indicates the probability that contaminant runoff or remain on the ground to infiltrate. Therefore, steep slopes increase runoff which contains contaminants and lower the chance of infiltration. Digital Elevation Model could be used to prepare topography maps and slope is calculated by GIS tools.

Impact of Vadose Zone (I)

The vadose zone, also termed unsaturated zone, extends from the top of the ground surface to the water-table at which groundwater is at atmospheric pressure. Vertical movement of water in the vadose zone is important for pollution transport. The characteristic of an unsaturated zone can determine attenuation properties of the media above the water-table. A vadose zone map is also prepared using subsurface geology and lithology characteristics of drilling logs.

Hydraulic Conductivity (C)

The ability of an aquifer to transmit water and contaminants is defined as hydraulic conductivity. The results of the pumping test and lithology are used for creating a hydraulic conductivity distribution map. Regions with higher hydraulic conductivity indicate more contaminant transmission and distribution. It is also controlled by pore spaces and fractures within aquifers. The equation k=T/b might be used to calculate hydraulic conductivity of aquifer where the hydraulic conductivity of the aquifer is denoted by k (m/d), transmissivity is denoted by T (m2/d) and the thickness of the aquifer is denoted by b (m). The implementation of DRASTIC model has been done in association with Geographic information system (GIS) to study several meteorological conditions (Bhaskaran et al. 2001; Chakraborty et al. 2007; Afonso et al. 2008; Dong et al. 2009; Boughriba et al. 2010; Jin et al. 2011; Peter and Sreedevi 2012; Sener and Davraz 2013). It helps in ranking regions of potential vulnerability with respect to various contaminants (Napolitano 1995). The seven parameters of the DRASTIC model are shown in figure below and are defined in the table above with their assigned weights and relative ratings according to Aller et al. (1987).

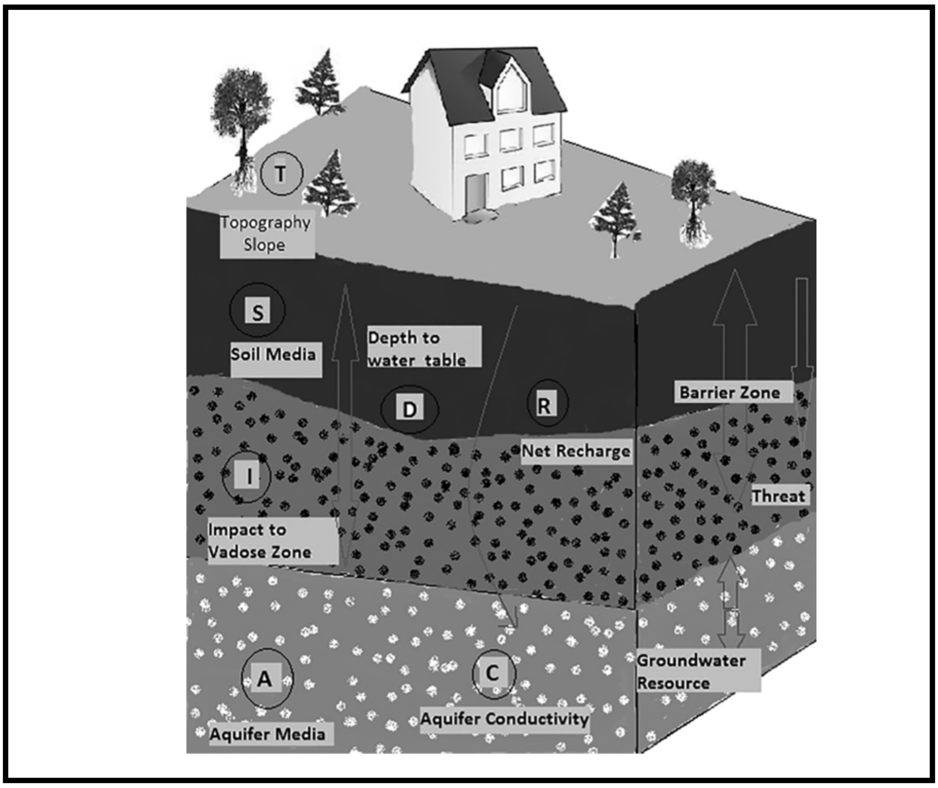

Fig. 4.2: Definition of DRASTIC parameters.

CHAPTER - 5

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METHODOLOGY

The blocks are suffering from acute water shortages for a long time, and water scarcity is a significant issue for the socio-economic development of Goghat- I and II. In the present day, aquifer depth has gotten even lower than in previous years. Along with this, the lowest rainfall and over-exploitation of groundwater has made the condition even worse.

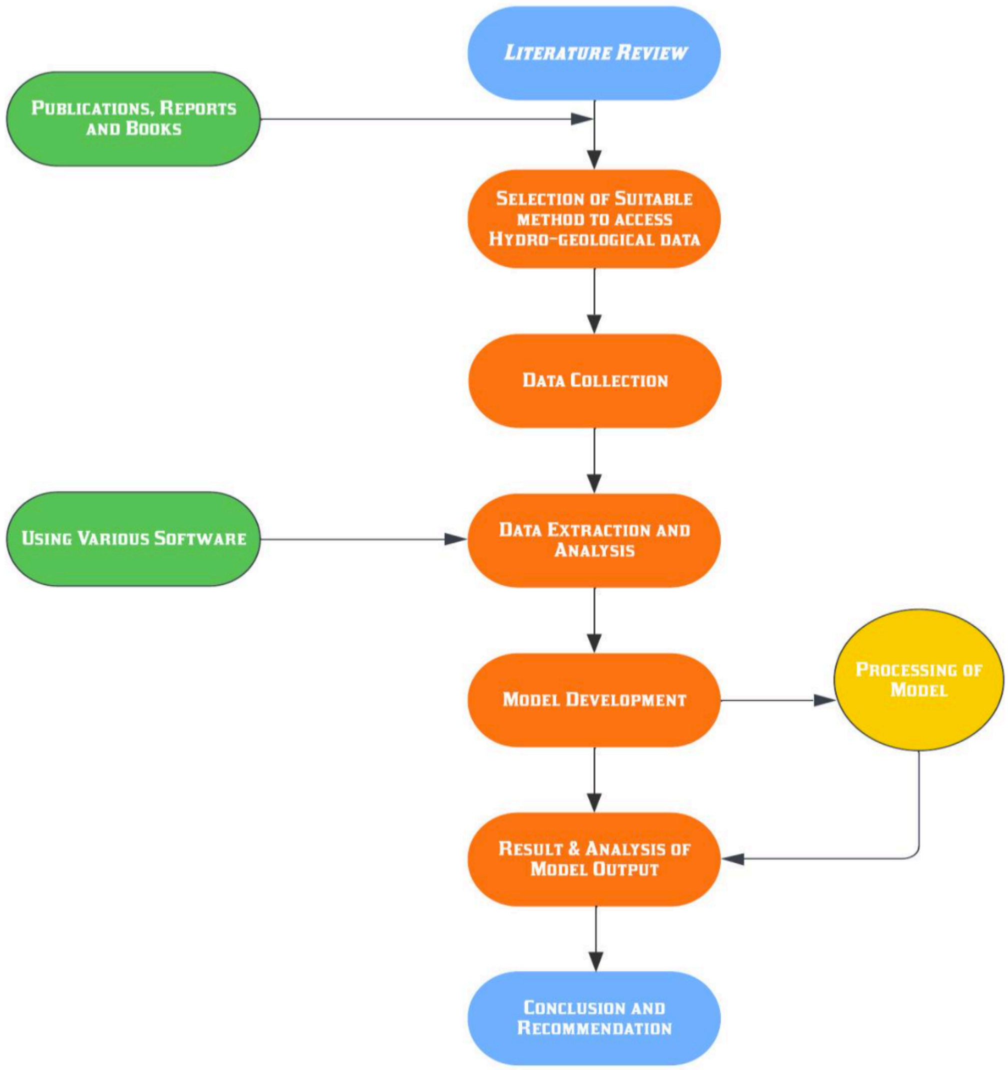

Fig. 5.1: Conceptualisation of Methodology

Most of the block of Hooghli District is affected by fluoride contamination. Surface water bodies dry up every year during the summer season. People depend on groundwater for domestic, irrigation, and other various purposes during this time, but excessive use of groundwater has worsened the situation. Therefore, proper evaluation, planning, and management of groundwater are essential for this region.

5.1 Literature Review

A literature review was carried out to select the method for mapping groundwater vulnerability. Based on the literature review, scientific and secondary data were collected for better knowledge of the survey field. Many of the reviewed studies were organised worldwide. These reviewed studies have helped to estimate groundwater pollution potential zones of the aquifer in different zones of the world. These studies were helpful by providing a general outline of how to map different groundwater zones and widen the disciplines of the research and analysis.

5.2 Data Collection

The data relating to the depth of water were collected from the Central Ground Water Board Ministry of Water Resources Government of India (2018-19), and rainfall data were collected from IMS- Pune, from which net recharge is calculated by Chaturvedi method. The map relating to aquifer media and soil media has been collected from the Geological Survey of India, Kolkata, and National Bureau of Soil Survey and Land Use Planning, 2010. Hydraulic conductivity data were collected from the (PHED Hooghli Division, Govt. of West Bengal). The topography of the study area was prepared based on processing both SRTM 90 DEM and ASTER DEM data. The impact of the vadose zone was prepared based on the map collected from the Geological Survey of India, Kolkata. Satellite Image (Landsat-8 OLI) download from USGS website. Topo-sheet of Hooghli district, scale 1:50000 collected from Survey of India (SOI). Soil map of Hooghli district collected from (NBSS). Geology map of Hooghli district collected from (GSI). DEM (Digital Elevation Model) downloads from Bhuvan (http://bhuvan.nrsc.gov.in/). The LULC map for the study area has been extracted using the Extraction tool of the ArcGIS Spatial Analyst module.

5.3 Data Analysis

The data collected were converted into digital format to insert into the Geographical Information System (GIS) environment.

The ArcGIS 10.5 was used to manipulate the data, and the weightage of each parameter was assigned as per Aller et al. (1987). The technique of “inverse distance weighted” (IDW) interpolation in GIS was used to prepare. The DRASTIC formula was used in the ArcGIS raster calculator to find out the vulnerability of groundwater. The 100 metres’ spatial pixel resolution (raster Grid) raster layer was used for all raster manipulations.

5.3.1 Model Concept

ArcGIS is a geographic information system (GIS) for working with maps and geographic information maintained by the Environmental Systems Research Institute (ESRI). It is used for creating and using maps, compiling geographic data, analysing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database. The system provides an infrastructure for making maps and geographic information available throughout an organisation, community, and openly on the Web. In the study, ArcMap, ArcCatalog, and Arc Toolbox applications of ArcGIS 10.5 have been used. ArcMap is the application used to view, edit and query geospatial data, and create maps. The ArcMap interface has two main sections, including a table of contents on the left and the data frames which display the map. Items in the table of contents correspond with layers on the map. ArcCatalog is a data management application used to browse datasets and files on one's computer, database, or other sources. In addition to showing what data is available, ArcCatalog also allows users to preview the data on a map. ArcCatalog also provides the ability to view and manage metadata for spatial datasets. Arc Toolbox contains geoprocessing, data conversion, and analysis tools, along with much of the functionality in Arc Info.

5.4 DRASTIC Model for Mapping Vulnerability

The DRASTIC method has been most commonly used for mapping vulnerability in porous aquifers (Aller et al.,1987). The objective of this study was to determine the aquifer vulnerability by integrating the DRASTIC Model into ArcGIS. The purpose of this project is to create a methodology that will permit the groundwater pollution potential of any hydrogeologic setting to be systematically evaluated with existing information.

The most critical capable factors that control the groundwater pollution potential were determined to be:

D—Depth to water

R—(Net) Recharge

A—Aquifer Media

S–Soil Media

T—Topography (Slope)

I —Impact of the Vadose Zone

C–Conductivity (Hydraulic) of the Aquifer

A numerical ranking system to assess groundwater pollution potential in hydrogeologic settings has been devised using the DRASTIC factors. The system contains three significant parts: weights, ranges, and ratings.

(1) Weights–Each DRASTIC factor has been assigned a relative weight ranging from 1 to 5. The most significant factors have weights of 5; the least significant, a weight of 1.
(2) Ranges—Each DRASTIC factor has been divided into either ranges or significant media types which have an impact on pollution potential.
(3) Ratings—Each range for each DRASTIC factor has been evaluated with respect to the others to determine the relative significance of each range with respect to pollution potential. Based on the graphs, the range for each DRASTIC factor has been assigned a rating that varies between 1 and 10.

The factors of D, R, S, T, and C have been assigned one value per range. “A” and “I” have been assigned a "typical" rating and a variable rating. The variable rating allows the user to choose either a typical value or to adjust the value based on more specific knowledge. The equation for determining the DRASTIC Index is:

D.I =DrDw + RrRw + ArAw + SrSw + TrTw+ IrIw+ CrCw ……(5.1)

Where, D = Depth to water, R = Net recharge, A = Aquifer media, S = Soil media, T = Topography (Slope), I = Impact of the vadose zone, C = hydraulic Conductivity, r = rating, w = weight
Once a DRASTIC Index has been computed, it is possible to identify areas that are more likely to be susceptible to groundwater contamination relative to one another. The higher the DRASTIC Index, the greater the groundwater pollution potential.

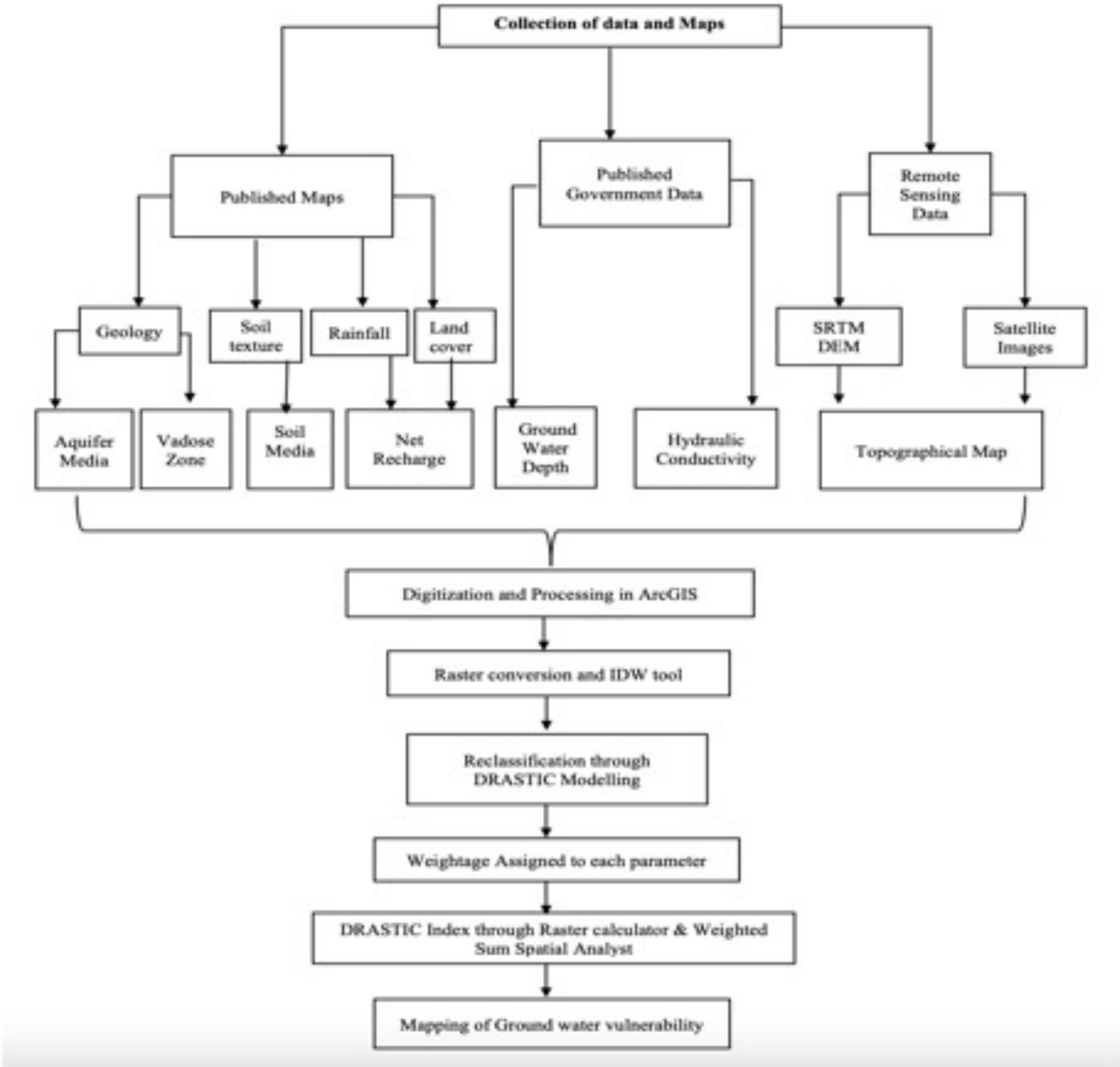

Fig. 5.2 - Flow diagram of Research Methodology

5.4.1 Assigned Weights Ranges and Ratings for DRASTIC Feature

TABLE 5.1 : WEIGHTS FOR DRASTIC FEATURES (ALLER ET AL.,1987).

PARAMETER	DEFINITION	ASSIGNED WEIGHTS	PARAMETER VALUE/ TYPES	RELATIVE RATINGS
DEPTH TO WATER	It is the actual depth from the earth surface to the water table. It works as a resistive force for the contaminant to sneak through to the groundwater	5	0–1.5 (m) 1.5-3.0 (m) 4.5-9.1 (m) 9.1-15.2 (m) 15.2-22.86 (m) 22.86-30.48 (m) 30.48 + (m)	10 9 7 5 3 2 1
NET RECHARGE	It is the amount of water per unit area of land which penetrates the ground surface and reaches the aquifer	4	0-50.8 (mm) 50.8-101.6 (mm) 101.6-177.8 (mm) 177.8-254 (mm) 254+ (mm)	1 3 6 8 9
AQUIFER MEDIA	It is the porous rock below the earth surface which holds underground water. The type of rock significantly affects the flow of contaminant in the groundwater	3	Massive Shale Metamorphic/Igneous Weathered Metamorphic / Igneous/ Thin Bedded Sandstone, Limestone Shale Sequences Massive Sandstone Massive Limestone Sand and Gravel Basalt Karst Limestone	1–3 2–5 3–5 5–9 4–9 4–9 4–9 2–10 9–10
SOIL MEDIA	It is the layer of earth rocks lying between the earth surface and the uppermost bedrock. The percolation of contaminant is highly affected by this layer	2	Thin or Absent Gravel Sand Peat Shrinking or Aggregated Clay Sandy Loam Loam Silty Loam Clay Loam Muck Non-Shrinking or Non-Aggregated Clay	10 10 9 8 7 6 5 4 3 2 1
TOPOGRAPHY	It is the gradient of the earth surface and water table follows the similar gradient in the form of conformation line	1	0–2 (percent slope) 2–6 (percent slope) 6–12 (percent slope) 12–18 (percent slope) >18 (percent slope)	10 9 5 3 1

IMPACT OF VADOSE ZONE	It is the upper portion of the water table in the form of surface soil as well as bedrock layer used for accommodating water. Its impact is measured in terms of porosity, thickness, and permeability	5	Silt/Clay Shale Limestone Sandstone Bedded Limestone, Sandstone, Shale Sand and Gravel with significant silt and clay Metamorphic/Igneous Sand and Gravel Basalt Karst Limestone	1-2 2-5 2-7 4-8 4-8 4-8 2-8 6-9 2-10 6-10
HYDRAULIC CONDUCTIVITY	It is the rate at which water is transmitted by the bedrock layers. The more the rates are, the higher is the contamination	3	1–100 (m/day) 100–300 (m/day) 300–700 (m/day) 700–1000 (m/day) 1000–2000 (m/day) >2000 (m/day)	1 2 4 6 8 10

5.5 Overlay/Index Analysis by Arc GIS Software

Overlay/Index analysis is a multi-criteria analysis wherein analysis can be carried out with complex things to find out specific themes with the help of the assignment of rank to the individual class of feature and then assign weightage to the particular feature considering its influence over theme. All the thematic maps were converted into raster format and superimposed by the weighted method, which consists of rank and weightage wise thematic maps and integration of them through GIS. Integration of thematic maps for carrying out multi-criteria or overlay analysis in a GIS environment was done using ArcGIS software.

5.5.1 Inverse distance weighted (IDW) (Spatial Analyst)

Interpolates a raster surface from points using an inverse distance weighted (IDW) technique. It determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. The surface being interpolated should be that of a locational dependent variable. This method assumes that the variable being mapped decreases in influence with space from its sampled location. For example, when interpolating a surface of consumer purchasing power for retail site analysis, the purchasing power of a more distant place will have less influence because people are more likely to shop closer to home.

How (IDW) (Spatial Analyst) works :-

- The input point features containing the z-values to be interpolated into a surface raster
- The field holds a height or magnitude value for each point.
- This can be a numeric field or the Shape field if the input point features contain z-values
- The output interpolated surface raster. It is always a floating-point raster.
- The cell size at which the output raster can be created.

5.5.2 Reclassify (Spatial Analyst)

The reclassification tools reclassify or change cell values to alternative values using a variety of methods. You can reclass one weight at a time or groups of values at once using alternative fields; based on a criterion, such as specified intervals (for example, group the values into 10 intervals); or by area (for example, group the values into 10 groups containing the same number of cells). The tools are designed to allow you to easily change many values on an input raster too desired, specified, or alternative values. All reclassification methods are applied to each cell within a zone. That is, when using an alternative value to a current value, all the reclassification methods apply the alternative value to each cell of the original zone. No reclassification method applies alternative values to only a portion of an input zone.

How to Reclassify (Spatial Analyst) works:

- Input datasets. Decide which datasets you need as inputs.
- Derive datasets. When applicable, create the datasets that you can derive from your base input datasets— for example, slope and aspect can be derived from the elevation raster. Create data from existing data to gain new information.
- Reclassify or rescale datasets. Reclassify each dataset to a common scale (for example, 1 to 10), giving higher values to more suitable attributes.
- Weight and combine datasets. Weight datasets that should have more influence in the suitability model if necessary, then combine them to find suitable locations.

5.5.3 Raster Calculator

Builds and executes a single Map Algebra expression using Python syntax in a calculator-like interface. The Raster Calculator tool allows you to create and manage a Map Algebra expression

§ Calculator and operator buttons

The calculator buttons allow you to enter numeric values into the expression. The operator buttons will enable you to enter mathematically (addition, division, and so on) and logical (more significant than, equal to, and so forth) operators into the expression. By clicking any of these buttons, that number or operator will be entered into the terminal where the pointer is currently positioned.

§ Tools

The tool list is a convenient selection of tools that can be used in the Map Algebra expression. By clicking a tool in the list, the tool name and open and close parentheses [()] will be placed in the expression where the pointer is currently positioned. The remaining input required by the tool must then be entered. There are four main areas in the tool dialog box that are used to create a Map Algebra expression:

§ Layers and variables

The input Layers and variables list identifies the input that can be used in the Map Algebra expression. When the tool is used in Model Builder, the list will contain the layers in the table of contents, outputs created in the Model, and other model variables.

§ Expression

The expression is the Map Algebra expression to be executed. The expression must be entered with valid syntax.

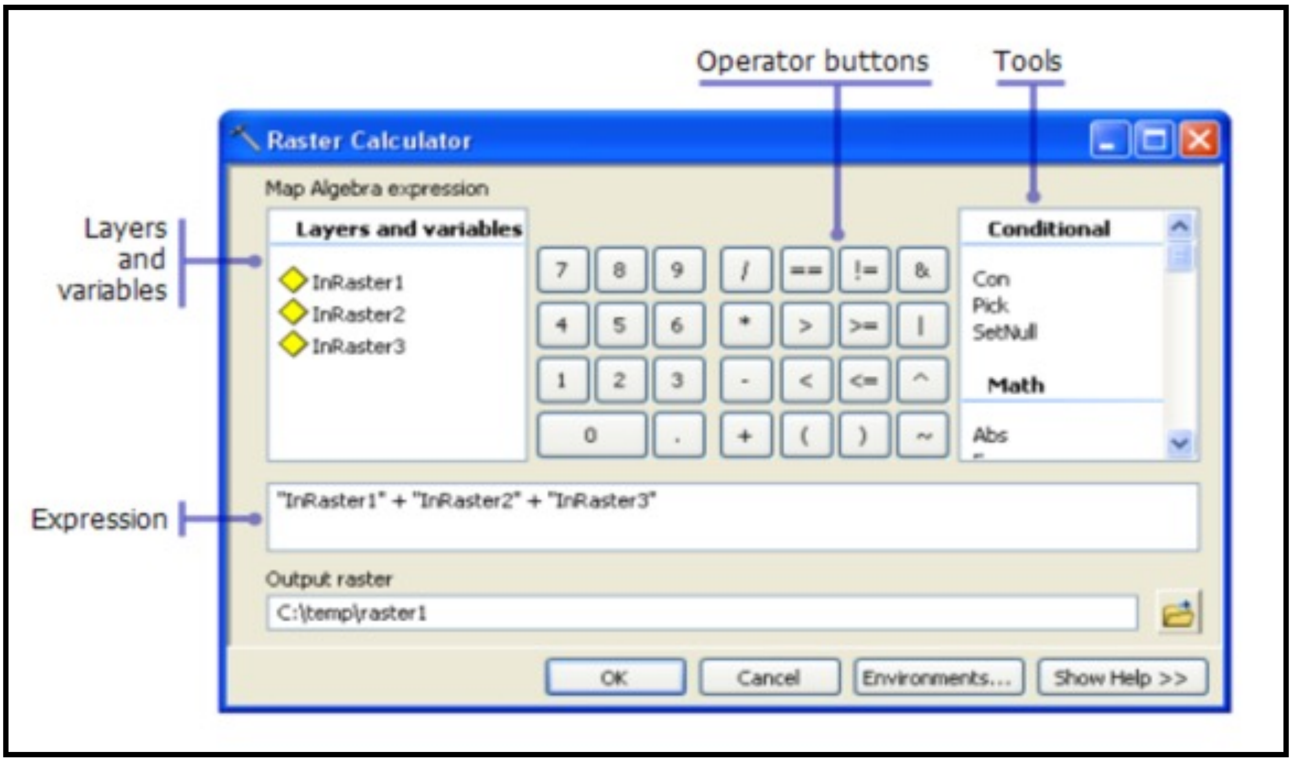

Fig. 5.3 - Raster Calculator Toolbox

5.6 Steps for Mapping Vulnerability Maps in Arc GIS 10.5 Software

- Open ArcGIS 10.5 and add data x, y coordinates to the data point exported from the excel file.
- Open the attribute table by right-clicking on the layer file in the table of content.
- Select joint and relate tool by right-clicking in layer file to export the data in the attribute table.
- Open tool arc box and select IDW analysis tool to interpolate the point data by selecting the table of content file and layer file.
- Classifying the label of the IDW map by left-clicking on properties.
- Classify the data by Reclassify analysis tool in tool arc box according to the rating given in the Drastic table.
- Open the raster calculator analysis to add weight rating from the drastic table and generate the index.
- Select the weighted sum spatial analysis tool from the tool arc box and generate the vulnerability map

CHAPTER - 6

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DESIGN CALCULATIONS FOR PREPARATION OF DRASTIC MODEL

The DRASTIC index or vulnerability rating present numerical ranking collective description of all the primary hydrological and geological considerations that influence groundwater flow through the vertical profiles of an area. In this approach, spatial collective data on depth to groundwater (D), recharge (R), aquifer type (A), soil properties (S), topography (T), impact of the vadose zone (I), and the hydraulic conductivity (C) are collected. For a defined area being investigated, each criterion is assigned a typical range and a rating relative value scale (r) from 1 to 10. In this scale, the higher values represent more sensitive area for contamination. These index criteria further are combined in an additive equation. Moreover, each criterion is decided a weight factor (w), from 1 to 5, reveal the relative importance of each factor.

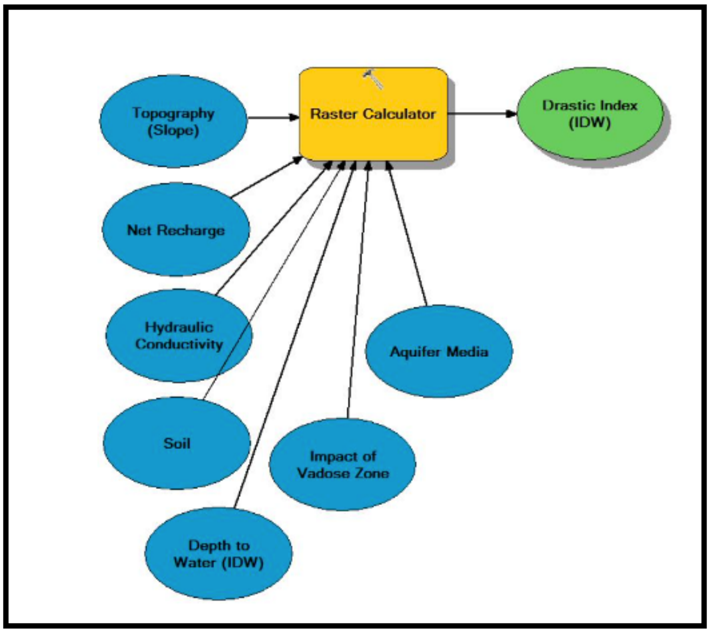


Fig. 6.1 - GIS model to calculate DRASTIC Index (based on IDW interpolation)

Fig. 6.1 presents a GIS model to compute vulnerability index that were created in Model Builder of ArcGIS.

In the end, the linear equation of the total impact criterion score as the DRASTIC index or vulnerability rating has the following formula:

DRASTIC index = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw. …….(6.1)

where w is weight and r is rank.

In this formula, it applies four assumptions, i.e.

I. the contaminant is introducing at the ground surface.

II. the contaminant is leached into the groundwater by precipitation.

III. the contaminant is soluble; and

IV. the evaluated area is 40 ha or larger.

Obtained data is simplified by a GIS model interface. The GIS software was used in this study (ArcGIS) to prepare seven maps represent the seven criteria of DRASTIC. Individual map was classified and designated ratings and weighted according to DRASTIC standards rewritten as follows:

DRASTIC index = 5Dr+ 4Rr + 3Ar + 2Sr + TrTw + 5Ir + 3Cr ……(6.2)

6.1 Depth to Water (Dr)

The depths to water-table were measured at 7 wells in the study area by Department Of Water Resources, River Development & Ganga Rejuvenation, CGWB. The Geostatistical Analyst extension in ArcGIS was used to interpolate the points and create the raster map with a pixel size of 50 m. The two ranges are : 9-16 m and 16- 23 m. The Drastic values assigned for 9-16m is 5 and 16-25 m is 3. So 5Dr = 5 x 5 = 25; 3Dr = 5x3 = 15

6.2 Net Recharge (Rr)

Net recharge criterion of this study is the sum of precipitation without taking in account of surface runoff and evapotranspiration. The source of recharge is the annual rainfall data taken from India Meteorological Department for a 50-year period. The annual rainfall in the district varies from 1083.2 mm at Arambagh to 1950.2 mm at Serampore. Since Goghat - I and II are located in Arambagh, the Recharge is taken as 1083.2 mm for our study area.

TABLE 6.1: PRE-MONSOON AND POST-MONSOON GROUNDWATER LEVELS

CGWB well no.	Groundwater level in 2014 (metres below ground level)		Increase of ground-water level in 2014 (m)
	Pre-Monsoon	**Post-Monsoon**	
WBHG12	11.93	10.24	1.69
WBHG32	10.53	7.60	2.93
WBHG34	21.27	17.35	3.92
WBHG61	15.42	12.00	3.42
WBHG62	17.05	15.16	1.89
WBHG63	16.69	14.14	2.55
WBHG70	13.43	9.00	4.43
WBHG75	10.73	6.85	3.88
WBHG76	19.73	16.54	3.19
WBHG85	18.46	15.77	2.69
WBHG91	17.95	14.36	3.59

We use the The Chaturvedi formula for finding the net recharge of our study area –

$$\mathbf{R = 1.35\ (P - 14)^{0.5}.} \qquad \text{.......(6.3)}$$

Where, P = Annual avg. rainfall = 1083.2 mm= 42.6 inches

Therefore, calculating R

= 1.35 x (42.6 - 14)0.5

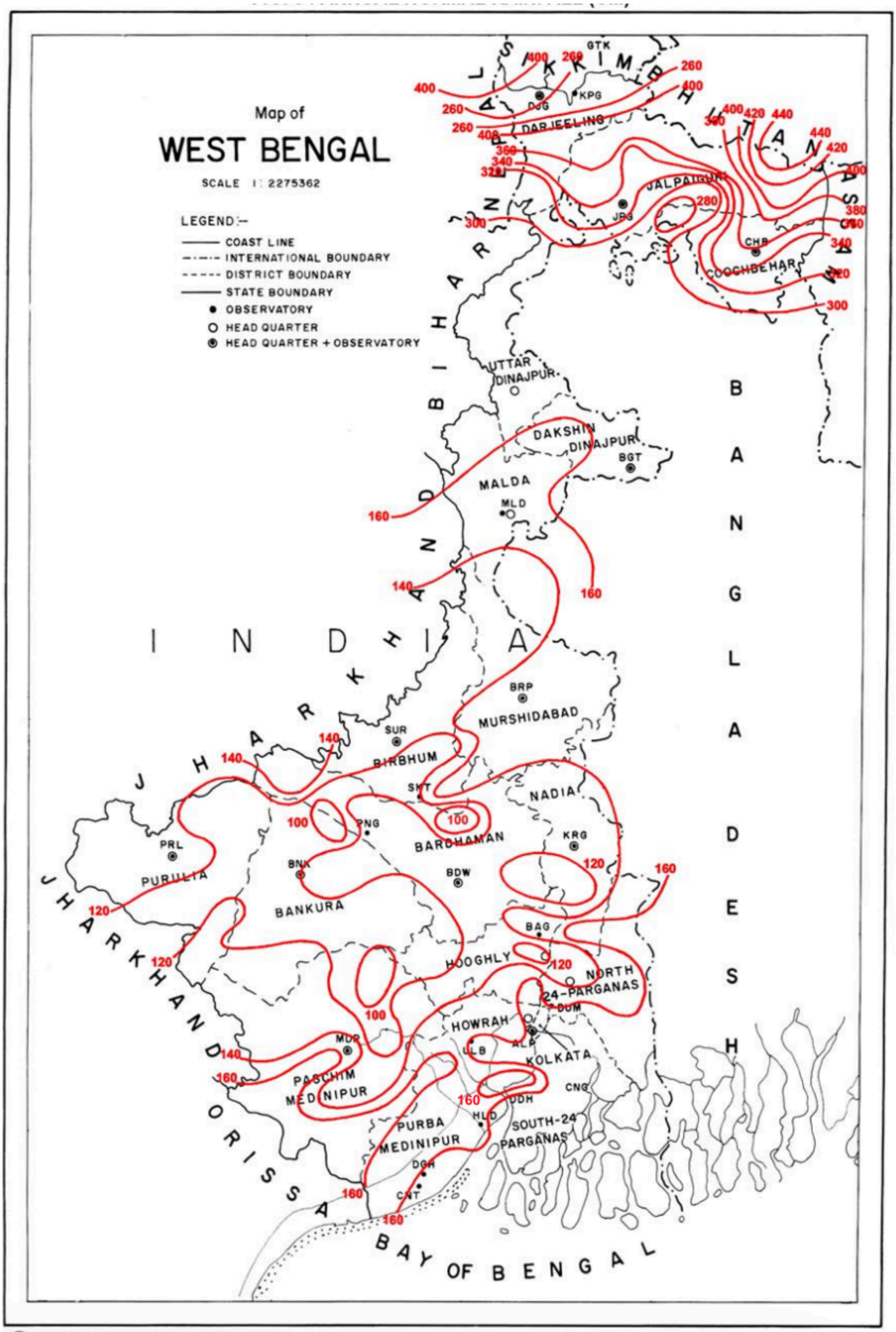
= 1.35 x (28.6)0.5

= 1.35 x 5.34

= 7.209 inches = 182 mm

Assuming the run-off coif. as 0.40, the rainfall is estimated as to be lying in the range of 101.6 to 177.8, for which the DRASTIC value is taken as 6.

So, 4Rr = 4 x 6 = 24



Map 6.1 – Rainfall Map of West Bengal (IMD Pune)

6.3 Aquifer Media (Ar)

An aquifer media map was prepared from the Geological Survey of India, Kolkata, and lithology data from India Water Resources Information System India. Goghat- II has extensive laterite formations which states it is a type of weathered Basalt. The rest of the study area is taken as Sand. The Drastic rating for Basalt is 8 and for Sand is 5. So 3Ar = 3 x 8 = 24; 3Ar= 3 x 5 = 15.

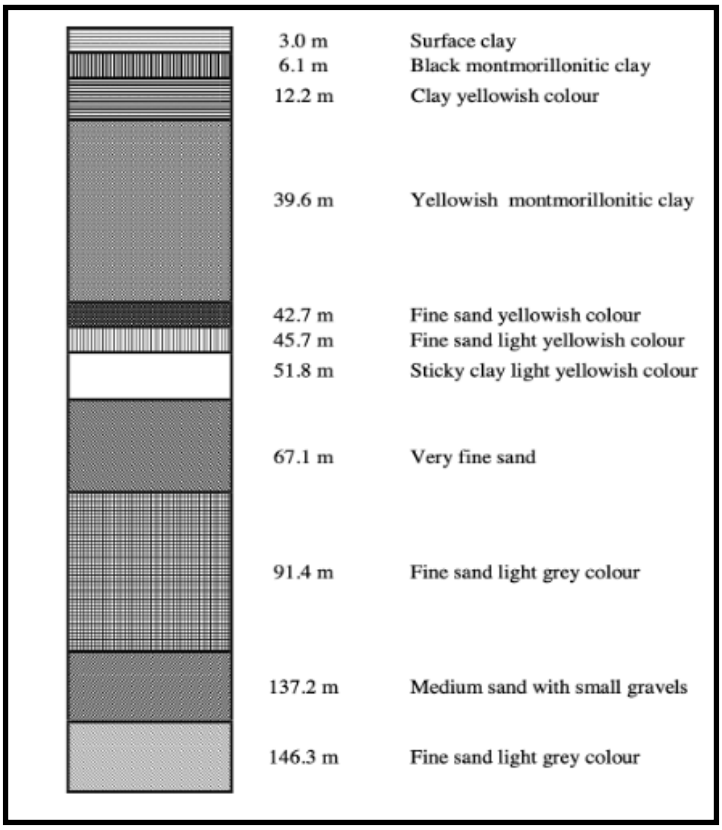


Fig. 6.2 - Soil Lithology of Hooghli District

6.4 Soil Media (Sr)

There are four main types of soils in the study area namely Loam, Silty Clay, Clay Loam and Sandy Loam. Each of these soil types have a DRASTIC rating which has been assigned to the types.

Loam = 5

Silty Clay = 2

Clay Loam = 3

Sandy Loam = 6

The DRASTIC rating ranges from 2 to 6.

So 2 Sr is evaluated as 10, 4, 6, 12 respectively.

6.5 Topography (Tr)

The topography map and contour were prepared in the ArcGIS software using the SRTM DEM and divided into two classes - 0 to 2 and 2 to 6. The DRASTIC ratings are assigned for these two classes as 10 and 9 respectively. The weightage for Topography is 1 and is therefore evaluated as 1 Tr = 9 and 10.

6.6 Impact of Vadose Zone (Ir)

The data for impact of vadose zone was retrieved from identification and classification of the sub-surface geology map. The vadose zone were assigned rating value from 4 to 8 and affected by a weight of 5. 5 Ir is calculated accordingly.

6.7 Hydraulic Conductivity (Cr)

The most reliable means to obtain hydraulic conductivity is through aquifer pumping tests. At sites at which the aquifers are low in yield, slug tests are conducted. When these data are not available, hydraulic conductivity is estimated based on grain size or a published range of values for common geological media (Freeze and Cherry, 1979). From the soil map, it has been found that the four soil classifications in the study area are - Sandy Loam, Silty Clay, Clay Loam, Loam. Since pumping test data is not available for our study area, 'K' value has been assumed based in the type of soil.

TABLE 6.2 : HYDRAULIC CONDUCTIVITY BASED ON SOIL TYPES.

SOIL TYPE	HYDRAULIC CONDUCTIVITY (m/s)
Sandy Loam	3.45E-04
Silty Clay	1.02E-06
Clay Loam	2.45E-06
Loam	1.56E-04

Based on the table above, the ranges for K is assumed as 100-300 m/day, for which the DRASTIC rating is 2. So, the value of 3Cr is 6.

6.8 Assessment of Groundwater Vulnerability

All seven required layers for DRASTIC vulnerability evaluation were created using ArcGIS; each layer was classified and rated using the rating scales based on standard DRASTIC rating system. Among DRASTIC parameters, the depth to water is one of the most important parameters with the weight equal to 5. In order to investigate about the effect of interpolation method used to create this map on the results of vulnerability assessment, two different interpolation methods; Inverse Distance Weighting (IDW) was used to interpolate the depth to water. DRASTIC map was constructed using both interpolated water depth maps and other six parameters. DRASTIC (IDW) refers to DRASTIC map obtained from interpolated water depth points using IDW and other six parameters. Then, DRASTIC index, which is a dimensionless index, was determined by multiplying the rated rasters with the weight factor. The parameters vary from 1 to 10, with the higher values describing higher pollution potential. The groundwater vulnerability map was mapped and analysed that the Goghat-I and II blocks of Hooghli district fall under three main categories of ratings namely- Low, Medium and High with their respective values. The Lalgarh formation has high groundwater vulnerability owing to various aspects ranging from climatic conditions, aquifer media characteristics, lithology, hydrogeology and other aspects.

This analysis suggests that this can be used for the prioritisation of vulnerable areas in order to prevent further pollution and groundwater withdrawal to already more polluted areas. There should be detailed and frequent monitoring in high and very highly vulnerable zones to monitor the changing level of pollutants. The intrinsic vulnerability index and the corresponding area percentages for IDW class is presented.

TABLE 6.3: RANKING AND WEIGHTAGE ASSIGNED TO VARIOUS PARAMETERS OF THE STUDY AREA

PARAMETER	WEIGHTAGE	RANGE	RATING
Depth to Water	5	9 - 16 16 - 23	5 3
Net Recharge	4	101.6-177.8	6
Aquifer Media	3	Sand Basalt (Laterite)	5 8

Soil Media	2	Loam Silty Clay Clay Loam Sandy Loam	5 2 3 6
Topography	1	0-2 2-6	10 9
Impact of Vadose Zone	5	Sand with silt and clay Sand Basalt	4 5 8
Hydraulic Conductivity	3	100 - 300	2

DRASTIC Index Calculation for Map :

The DRASTIC Index range is evaluated by taking each value separately and checking their respective ratings with weights. Then the weights and ratings are multiplied for each parameter and then added to get the final DI value.

Minimum possible Drastic Index

D.I = (5 x 3) + (4 x 6) + (3 x 5) + (2 x 2) + (1 x 9) + (5 x 4) + (3 x 2)

D.I = 15 + 24 + 15 + 4 + 9 + 20 + 6

D.I (min) = 93

Maximum possible Drastic Index

D.I = (5 x 5) + (4 x 6) + (3 x 8) + (2 x 6) + (1 x 10) + (5 x 8) + (3 x 2)

D.I = 25 + 24 + 24 + 12 + 10 + 40 + 6

D.I (max) = 141

The value of DRASTIC Index ranges from 93 to 141.

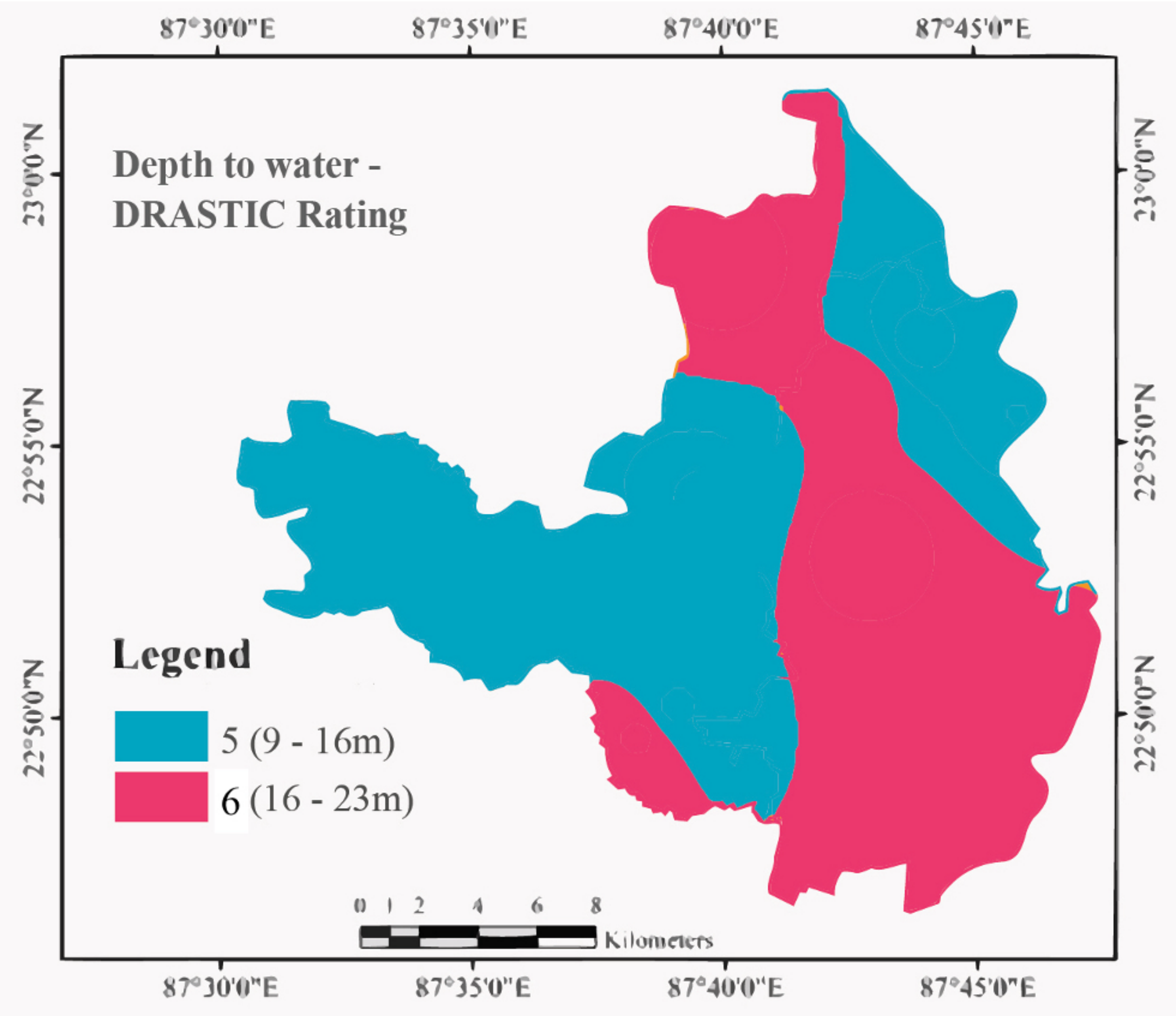
CHAPTER - 7

RESULTS AND DISCUSSION

The present study helped determine groundwater's vulnerability to contamination in the Goghat- I and II blocks by employing the DRASTIC Model in the GIS platform. Vulnerability of groundwater refers to the intrinsic characteristics that determine the sensitivity of the water to being adversely affected by an imposed contaminant load. It is a relatively quick and simple to use method for assessing the susceptibility of a large area.

7.1 Depth to Water

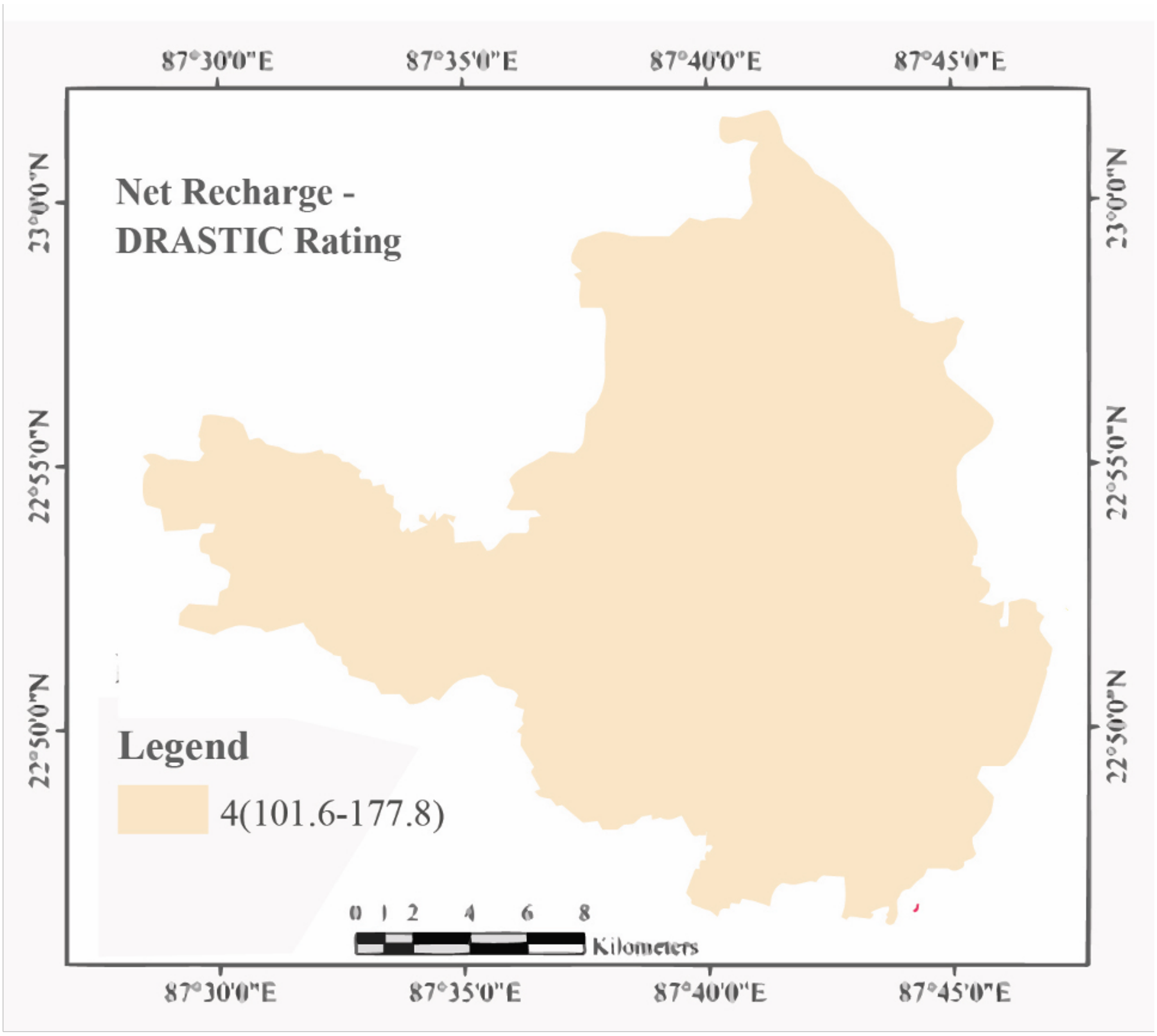
The depths to water-table were measured at 7 wells in the study area by Department of Water Resources, River Development & Ganga Rejuvenation, CGWB. The Geostatistical Analyst extension in ArcGIS was used to interpolate the points and create the raster map with a pixel size of 50 m. Due to lack of enough measured points, Kriging method was not applied as an interpolation method. Thus, Inverse Distance Weighting (IDW) was used to interpolate depth to water points and the impact of interpolation method was investigated on vulnerability index in DRASTIC approach. Based on the rating system recommended in the original DRASTIC model, maps were rated and divided into different classes.



Map 7.1 - Depth to Water

7.2 Net Recharge

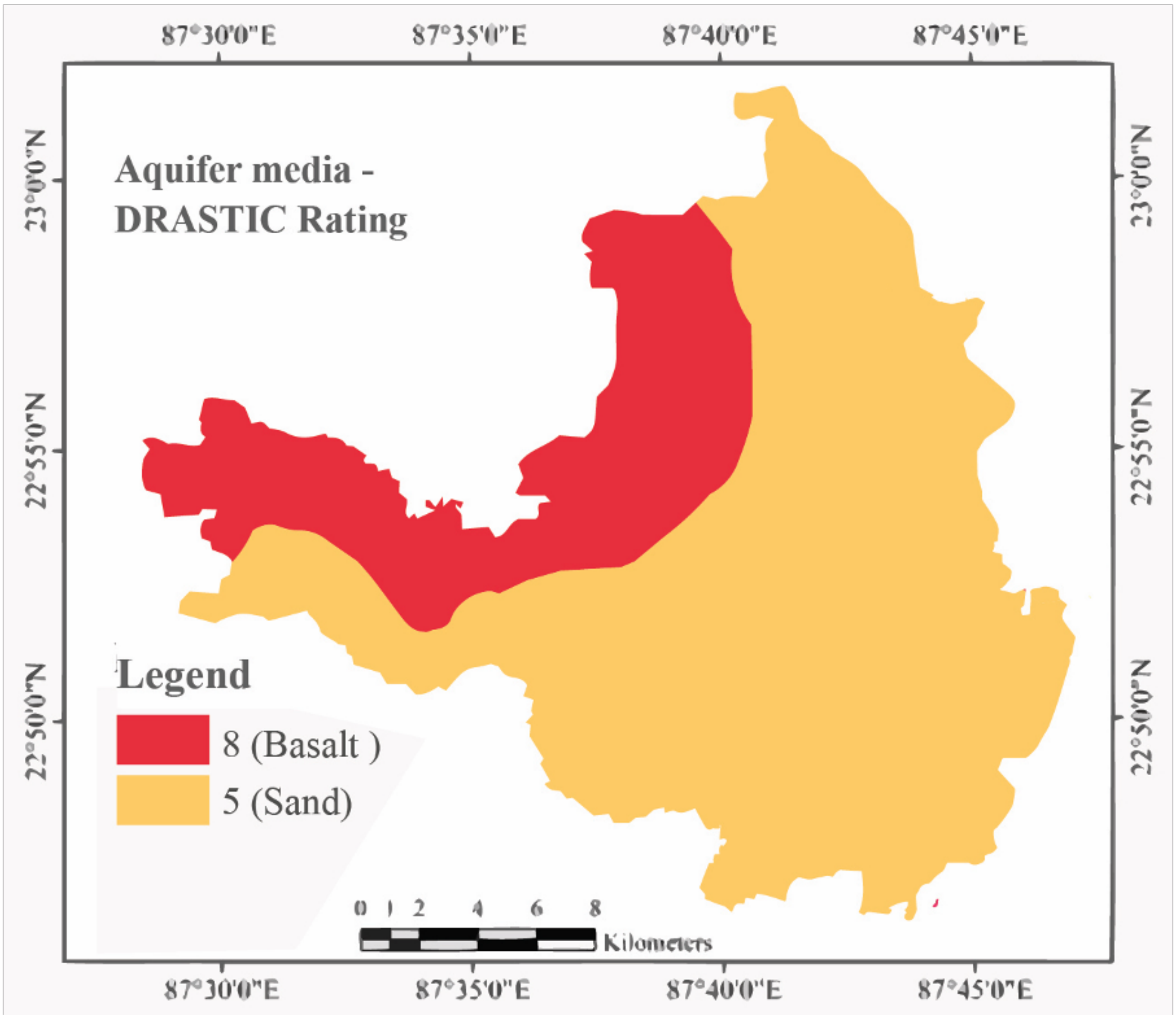
Net recharge plays a crucial role in the migration of pollutants, as it reflects the quantity of water that reaches the groundwater table after penetration through the ground surface. Precipitation is the primary source of recharge. More recharge leads to a greater probability for the contaminants to reach the water table. Millimeter per year unit is used to define net recharge. Land uses/land covers (LULCs) and soils are sensitive parameters in calculating the recharge amount. Consider regional LULC and soil characteristics, the Soil Conservation Service (SCS) runoff curve number (CN) method was used to estimate potential recharge with precipitation, soils, and LULCs.



Map 7.2 - Net Recharge

7.3 Aquifer Media

The aquifer media refers to the consolidated and unconsolidated rock, which serves as a storage of water. The aquifer is defined as a layer lying under the ground, consist of water-bearing rocks of permeable nature, rock fractures, or unconsolidated materials from which groundwater can be obtained using a water well. The aquifer is defined as a rock formation that will yield sufficient quantities of water for use. An aquifer media map was prepared from the Geological Survey of India, Kolkata, and lithology data from India Water Resources Information System India. In general, with an increment in the grain size and the number of fractures or openings within the aquifers, the permeability increases, and the attenuation capacity becomes lower, resulting in higher pollution potential. So coarser (saturated or unsaturated) media is assigned a higher rating value as compared to finer media. The aquifer system of a region is considered to be a necessary parameter in describing the potentiality of groundwater in that region. This selected factor represents a wide range of geological and meteorological conditions of the given study area.

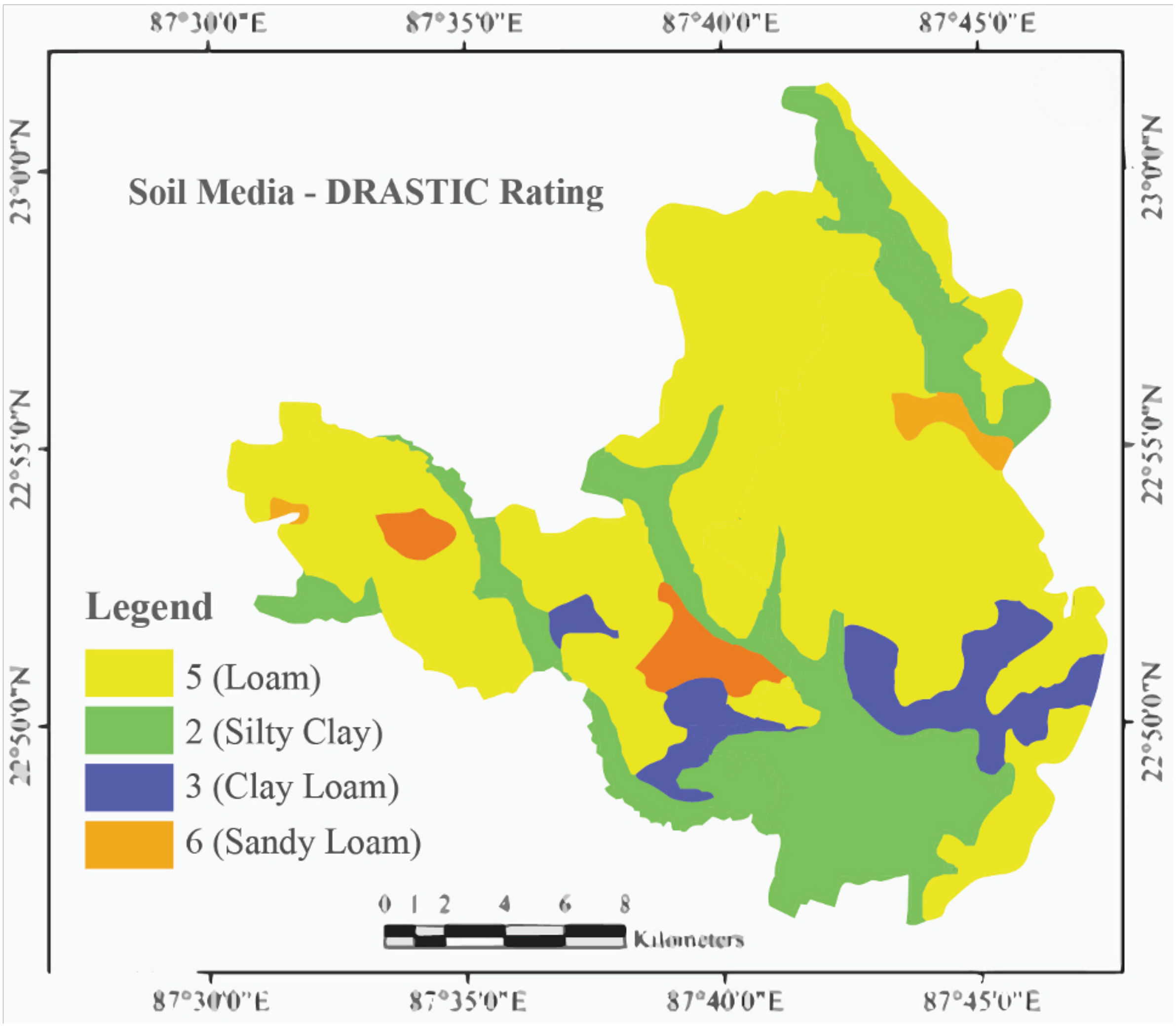


Map 7.3 - Aquifer Media

7.4 Soil Media

Soil is considered as the weathered portion above vadose zone which is average 1.8 meter or less. The soil type is important in terms of amount of net recharge which can reach the groundwater system. In fact, pollution potential of soil is mainly affected by the type of clay and grain size of soil.

Thus, more clay and smaller grain size implies less amount of pollution potential. The ratings were assigned according to the original DRASTIC system. Based on this classification, coarse soil media have high rates in comparison to fine soil media. Occurrence of groundwater in the Goghat- I and II region is influenced by the texture of underlying soils. This is because the magnitude of groundwater recharge is dependent upon the porosity and permeability of the soil, which in turn is controlled by the texture of the soil.

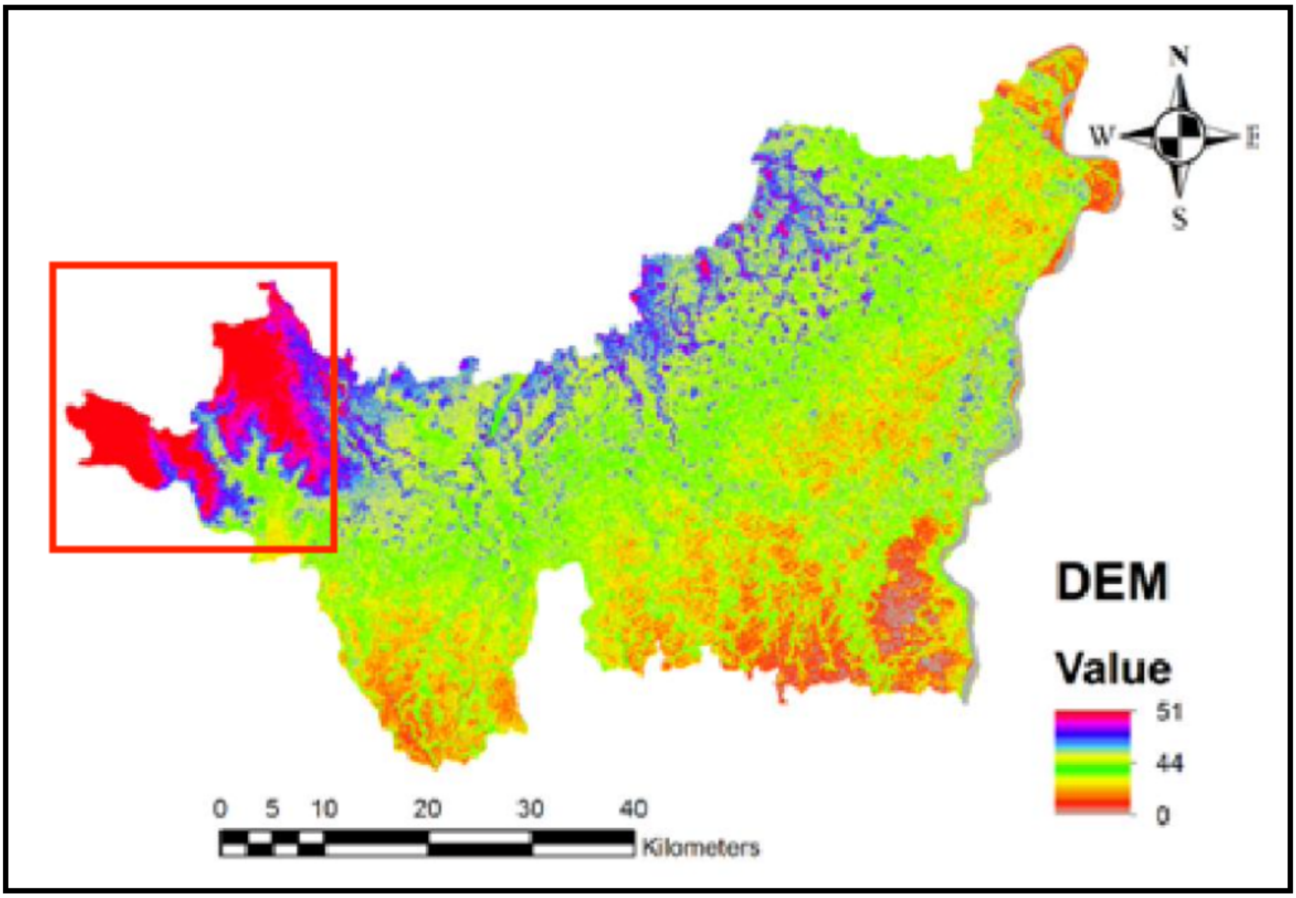


Map 7.4 - Soil Media

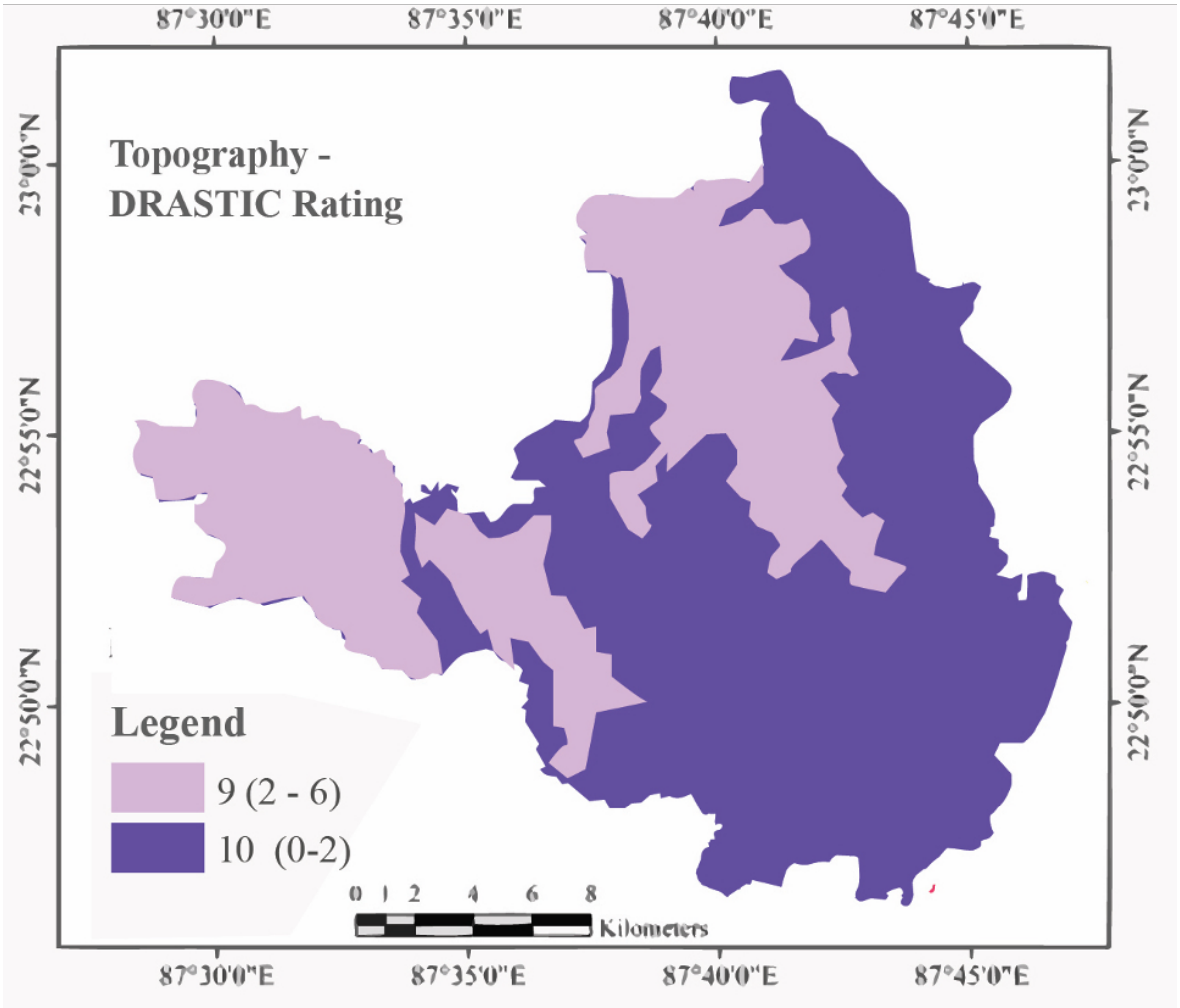
7.5 Topography

It refers to the slope of an area. It allows a more significant infiltration of recharge water and a greater possibility for contaminant migration. It will be related to higher groundwater contamination.

Topography controls the direction of contaminant flow. Areas with low land slopes tend to hold water for a longer time and enable more significant infiltration or recharge to generate greater potential contaminant transportation.



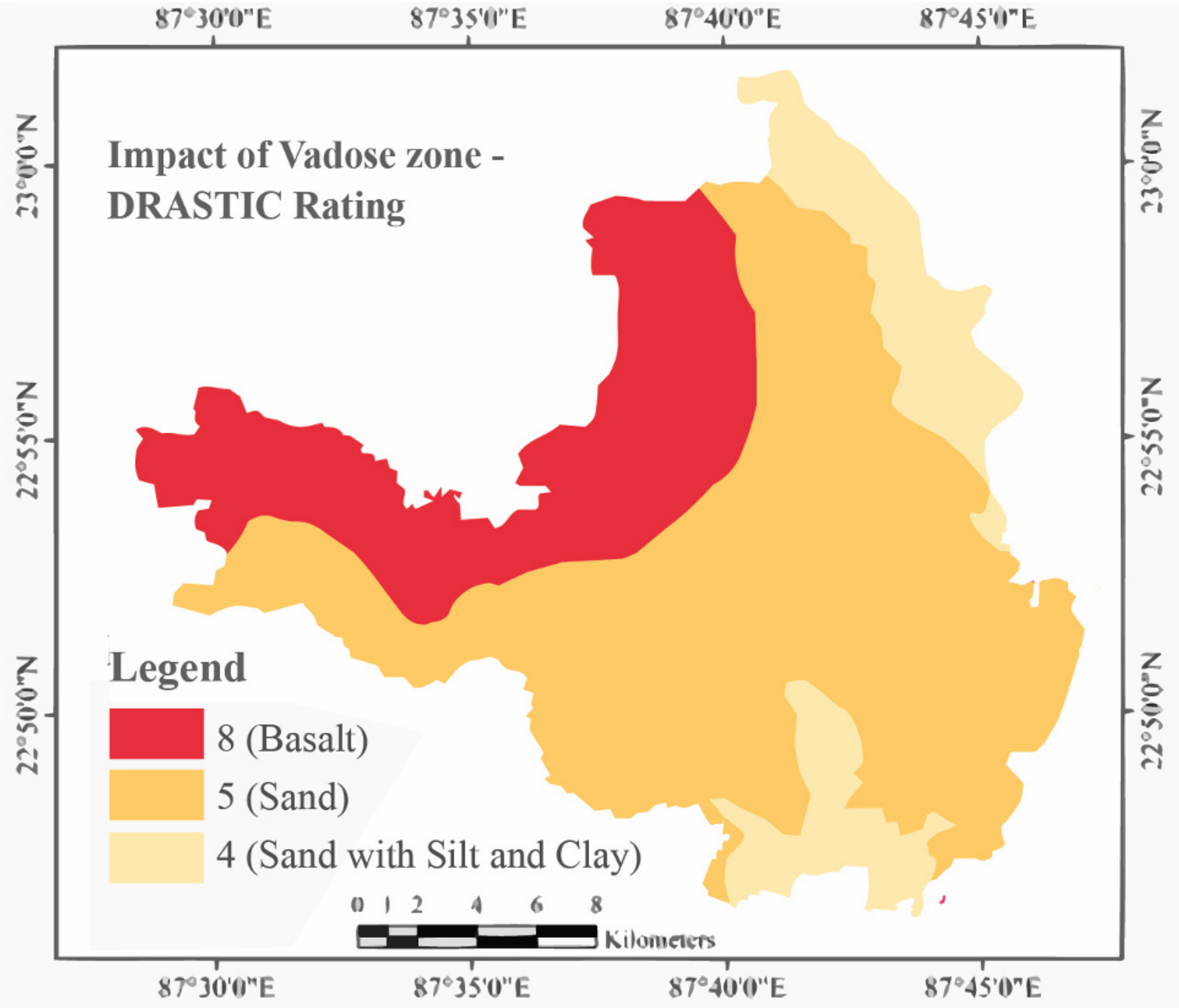
Map 7.5 - Digital Elevation Model of Hooghli District



Map 7.6 - Topography

7.6 Impact of Vadose Zone

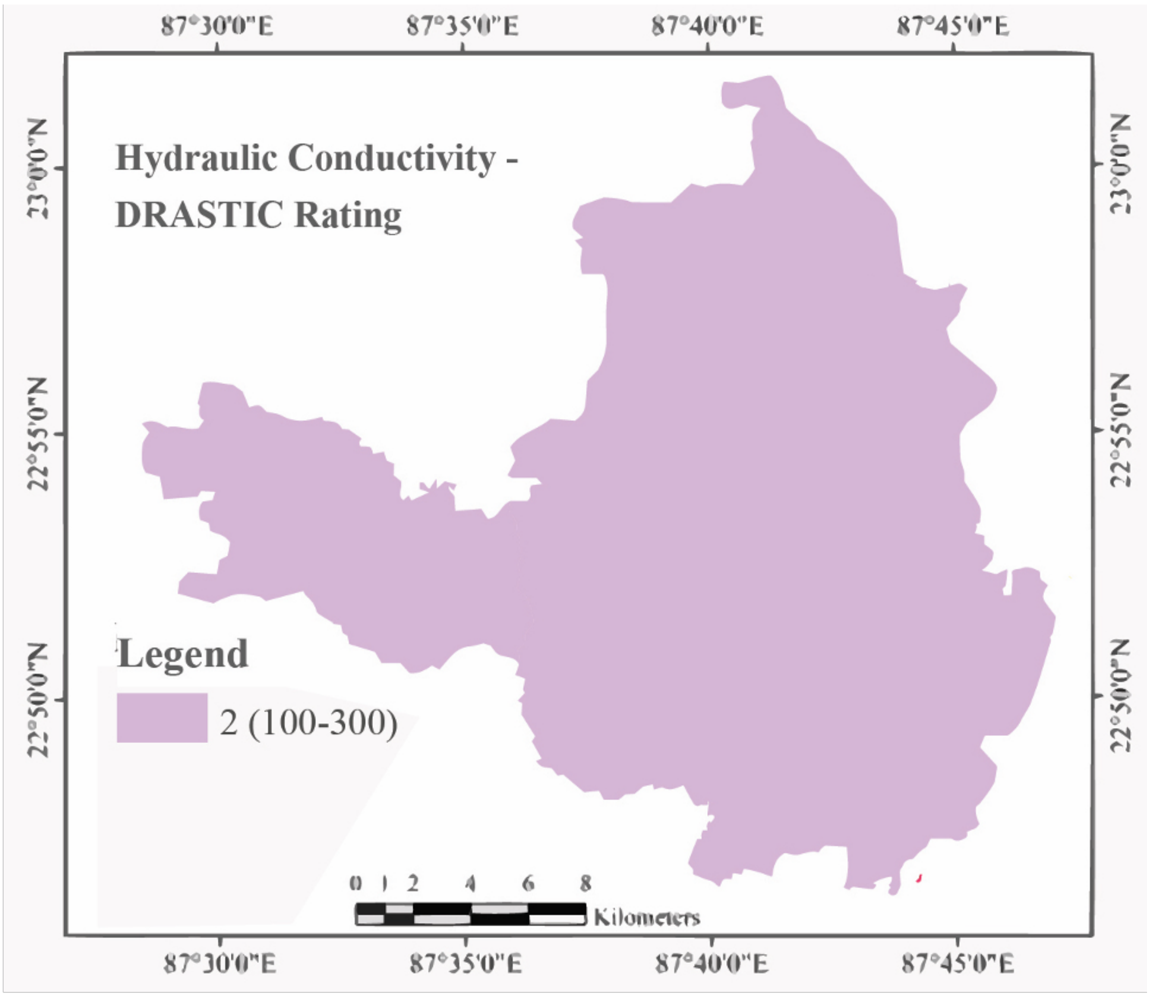
The vadose zone's influencing and essential component for determining potential of aquifer pollution. The impact of vadose zone to groundwater vulnerability is the combination characteristics of topography and aquifer media. Vadose zone layer is the in between the saturated and unsaturated aquifer and has great influence on solute transport. Impact of vadose zone map was delineated from the analysis of lithological data of the study area. The vadose zone has a high impact on water movement if it is composed of a permeable material.



Map 7.7 - Impact of Vadose Zone

7.7 Hydraulic Conductivity

Hydraulic conductivity is the rate of water flow through horizontally an aquifer layer. Hydraulic conductivity of an aquifer is the ability of the aquifer to spread water depends on its permeability and the amount of saturated zone. As the conductivity increase, dispersion of contaminants in aquifer also increases. Accurate values of the hydraulic conductivity are not easy to obtain and it is also reflected as a drawback of the DRASTIC approach. An area with high conductivity is vulnerable to considerable contamination of groundwater. However, the contaminant can immigrate immediately through the aquifer. This phenomenon is distinct from an aquifer which has an impermeable media, it can still water content in the presence of fractures.

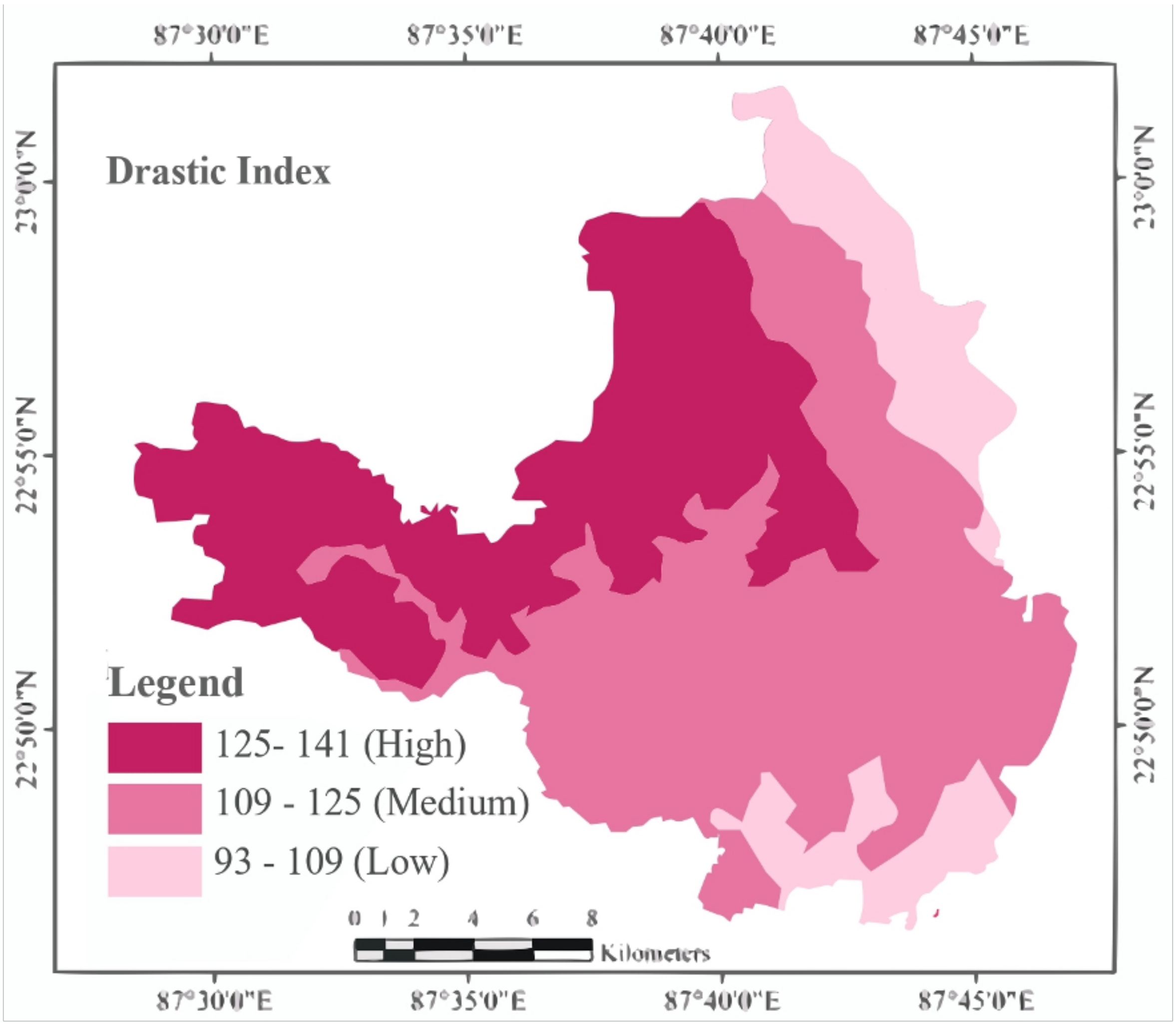


Map 7.8 - Hydraulic Conductivity

7.8 Preparation of DRASTIC Index Map

The parameters of the DRASTIC Model vary from 1 to 10, with the higher values describing higher pollution potential. The groundwater vulnerability map was mapped and analysed that the Goghat-I and II blocks of Hooghli district fall under three main categories of ratings namely- Low (93 - 109), Medium (109 - 125) and High (125 - 141) with the D.I value ranging from 93 to 141. The Lalgarh formation has high groundwater vulnerability owing to various aspects ranging from climatic conditions, aquifer media characteristics, lithology, hydrogeology, and other aspects.

So the vulnerability value is higher in that area in comparison to the other locations in our study area. This analysis suggests that this can be used for the prioritisation of vulnerable areas in order to prevent further pollution and groundwater withdrawal to already more polluted areas. There should be detailed and frequent monitoring in high and very highly vulnerable zones to monitor the changing level of pollutants. The intrinsic vulnerability index and the corresponding area percentages for IDW class is presented in map.



Map 7.9 - DRASTIC Model Map

CHAPTER - 8

CONCLUSION AND RECOMMENDATION

The GIS based aquifer vulnerability map of Goghat-I and II has been developed using the DRASTIC method which reflects an aquifer's inherent capacity to become contaminated. Recent reports have also shown a major drop in the ground water level in Goghat-II owing to the geology of the landscape, the aquifer conditions, and the overuse of groundwater due to the blocks' dependency on agriculture as the primary source of livelihood. It has therefore become imperative to consider a holistic water management plan for Goghat-I and II addressing the dip in water level and the contamination potential of the region.

Analysis shows that water depth is the most influential parameter for groundwater vulnerability, followed by aquifer media and vadose zone. The present study reveals that the vulnerability zones were classified three-zone, namely low, moderate and highly vulnerable zones. These results were included as raster or vector layers in the database together with generated thematic maps. GIS spatial analysis functions have permitted to development of a groundwater prospective zone map by means of overlaying thematic maps. GIS technology and remote sensing are beneficial for demarcating the critical zones on a scientific basis where further remedies should be taken. The output map is obtained to determine the vulnerability of groundwater in the areas underlain by hard rocky terrain plateau aquifers and to identify the vulnerable groundwater zones.

The DRASTIC model, which is used for preparing the pollution potential map, can be used as a screening tool to assess the degree of groundwater vulnerability to pollution of a particular area. The study suggests that this can be used for the prioritisation of the vulnerable regions in order to prevent further decay to already more polluted areas. There should be detailed and frequent monitoring in high and very highly vulnerable zones in order to monitor the changing level of pollutants. As evaluated, the DRASTIC Index range is found to lie from 93 to 141. The range has accordingly been taken as 93-109 as low, 109 – 125 as medium and 125 – 141 as high.

8.1 Limitations of the Study

Despite its popularity, the DRASTIC method does have some disadvantages, which have been stated as follows -

- The influences of regional characteristics are not accounted for in the technique, and so the same weights and rating values are used everywhere.
- In addition, there is no standard algorithm to test and validate the method for an aquifer.
- Recently, some researchers have tried to correlate the vulnerability index with chemical or contaminant parameters. Others have attempted to associate land use with vulnerability but have not used it to correct the rates or weights of the DRASTIC model.
- The lack of representative data with relation to the scale of the map;
- Inadequate knowledge of the soil-rock-groundwater system

8.2 Future Scope of the Study:

A DRASTIC Model Analysis provides further research scope with the option of adding contaminant-oriented parameters to modify the model based on the location. The research will allow further investigation to promote policy-oriented research for water stressed areas like Goghat-I and II. The research might also provide an extension the domain of climate change studies and trying to incorporate climate metrics into the DRASTIC Model. The model can be further modified with specific area wise parameters like the levels of various contaminants like Fluoride or Nitrate content in the soil. The model can also be applied across a broader area in Hooghly district for evaluation of the groundwater conditions and planning for sustainable management of the same.

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