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Assessment of Groundwater Vulnerability Index based on DRASTIC Model for Sustainable Management of Ground Water Resources using Remote Sensing Techniques and GIS Approach of Delhi, Northern India

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ABSTRACT

In many of the cities and industrial clusters one of the most rising concerns is pollution of ground water due to industrial and municipal wastes which if once penetrates the system is very difficult to remediate and also in developing countries like India such remediation may practically be impossible. Needless to mention that for sustainable thriving of human race pure and pollution free water is indispensable. Thus, it is important to delineate areas susceptible to contamination from anthropogenic sources for sustainable management of groundwater resources. Vulnerability Assessment of Groundwater is one such approach to secure the quality of the valuable Ground Water resource which is undoubtedly a precious asset. This is achieved by evaluating the weak spots which are at highest risk of easy infiltration and exposure. This in turn provides an excellent opportunity to delineate zones which needs protection in priority to prevent their exploitation before they may be exposed and contaminated to unrepairable level. Preserving the groundwater quality has been a major challenge and the same is addressed by the concept of vulnerability assessment. The assessment of groundwater vulnerability to contamination acts as an effective tool for water resource management. Different approaches are used for estimating groundwater vulnerability. The present research aims at estimating vulnerability index of ground water using DRASTIC model which considers seven parameters viz. depth to water level, net recharge, aquifer material, soil material, topography, impact of vadose zone and aquifer's hydraulic conductivity out of which depth to water level affected the vulnerability most. DRASTIC Vulnerability estimation method may be visualized as a tool for evaluation of ground water protection and it works by step-by-step systematic analysis of different hydrological and geological parameter that has a potential impact on aquifer pollution.

***Keywords**: Aquifer, vulnerability, contamination, groundwater pollution*

INTRODUCTION

Groundwater is a significant and principal freshwater resource in most parts of the world which constitutes a major portion of the hydrologic cycle and occurs in permeable geologic formations known as aquifers. The potential groundwater contamination by human activities at or near the surface of groundwater is a major challenge to the sustainable management of groundwater resources in different parts of the world. Urban and industrial effluents are one of the major anthropogenic inputs responsible for physical and chemical contamination of groundwater which needs much attention as unlike surface water, once an aquifer gets polluted, it is difficult to remediate it and it can be even irrecoverable (Freeze and Cherry 1979). Groundwater vulnerability defines the sensitivity of an aquifer to get contaminated from anthropogenic activities on the land surface (Vrba and Zeporozec 1994)[21] i.e. a measure of how easy it is for contamination at the land surface to reach a production aquifer.[2,3]

Groundwater weakness assessment is in many cases directed utilizing different techniques among which the GODS (Ghazavi and Ebrahimi, 2015),[8] IRISH (Daly and Drew, 1999), [5]AVI (Raju *et al.*, 2014),[17] and DRASTIC (Neshat *et al.*, 2014; Baghapour *et al.*, 2014, 2016)[14,15,3] strategies are generally utilized. The Radical list, initially proposed by Aller *et al.*, (1985), stands apart as one of the best and broadly used approaches for assessing groundwater weakness. A higher DRASTIC index shows an expanded potential for defilement while a lower record implies diminished weakness to pollution. Subsequent to working out the Exceptional list, it ought to be feasible to distinguish the zones that are more inclined to contamination. This record which gives just an overall assessment fills in as an important device for surveying the vulnerability of groundwater to poisons. The target of this study is to decide the weakness list of groundwater utilizing the uncommon model, which consolidates seven key physical and hydrogeological factors. These elements incorporate profundity to water (D), net re-energize (R), spring media (A), dirt media (S), geology (T), effect of vadose zone (I), and water powered conductivity (C). By coordinating these elements into the Uncommon model, we expect to extensively assess the vulnerability of groundwater to possible pollution, subsequently working with in the plan of methodologies for groundwater security and the executives.[4,6]

MATERIALS AND METHODS

Study Area [Fig 1]

The National Capital Territory of Delhi, lies between latitudes 28°24’15” and 28°53’00” N and longitudes 76°50’24” and 77°20’30” E which occupies an area of 1483 sq.km. The area is covered under Survey of India Toposheet Nos. 53D and 53H. For administrative purposes, NCT Delhi is divided into 9 districts and 27 tehsils. As per the census of India (2011), NCT Delhi has 3 Statutory Towns, 110 Census Towns and 112 Villages. Population of Delhi has increased at a rate of 2.1% per annum during the decade 2001-2011. The typical yearly precipitation of NCT Delhi adds up to 611.8 mm. Precipitation designs display an increment from the southwest toward the upper east of the locale. Roughly, 81% of the yearly precipitation happens during the rainstorm months explicitly in the long periods of July, August and September. The leftover part of the yearly precipitation is circulated as winter downpour and tempest downpour in the pre and post rainstorm months. Geographically, NCT of Delhi is described by quartzite between had relations with mica schist having a place with Delhi Super Gathering. These developments are overlain by unconsolidated silt going from Quaternary to Late progress in years fundamentally comprising of aeolian and alluvial stores. These sedimentary layers act as the essential supply of groundwater inside the locale. The geology of NCT Delhi incorporates various miniature watersheds starting from the quartzite edge. The locale is additionally portrayed into seven waste bowls, all eventually depleting into the Yamuna Stream. Swampy areas are prevalent along the floodplains of the Yamuna, contributing to the hydrological dynamics of the area. (Aquifer Mapping and Ground Water Management Plan of NCT Delhi, CGWB, New Delhi, 2016)[7,16]

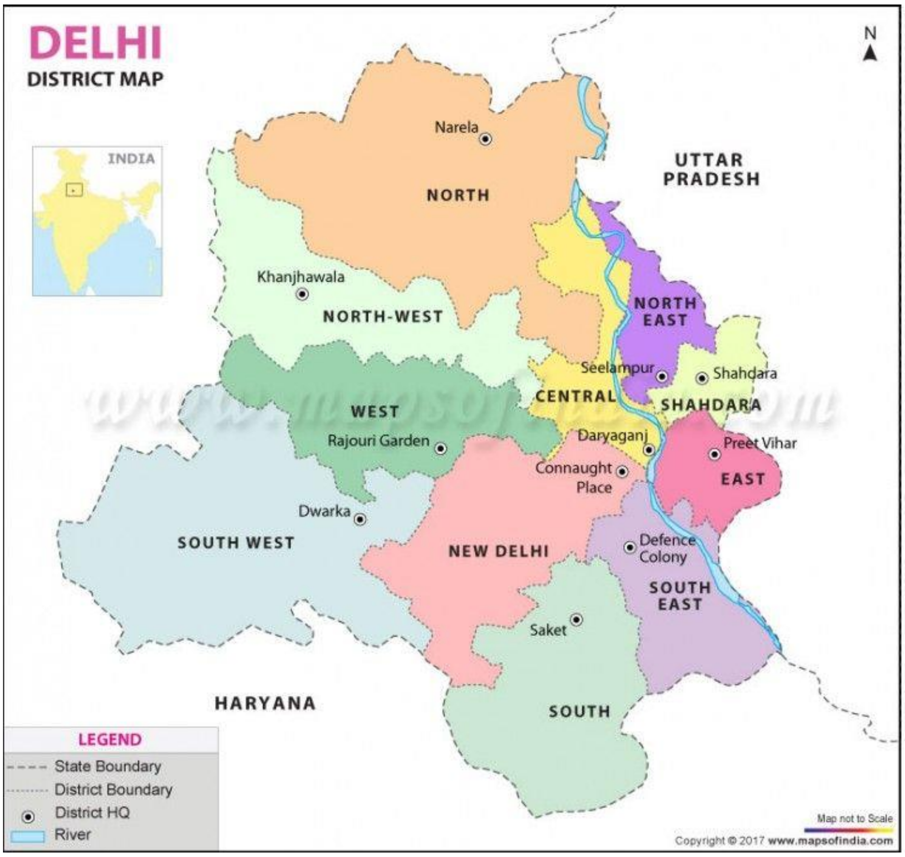

Fig. 1: *Study Area (Image Ref: https://www.pinterest.com/pin/324259241913101802/)*

Methodology

The Drastic method is a procedure developed by the United States Environmental Protection Agency (US EPA) in order to obtain standardized evaluation of potential for groundwater contamination (Aller et al., 1985). DRASTIC involves seven physical and hydrogeological factors, viz., depth of water (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I) and hydraulic conductivity (C). This vulnerability rating system utilizes a two-tier numerical ranking approach for accessing the primary factors related to hydrological and geological media. The final vulnerability index is derived by calculating the weighted sum of these individual factors. Each of the physical /hydrogeological parameters is given a weight based on its importance (most important as 5 and least as 1). Depending upon the relative prominent role in impacting pollution potential, a factor score is given for each parameter with a rating between 1 and 10, 10 being the most important and least important as 1. This method is adopted in this paper for the NCT, Delhi, where most part of the societal water demand is extracted from the aquifers. For sustainable use of ground water it is important to assess the vulnerability of ground water considering the significant dependence on aquifers, which are quite potential in nature. The DRASTIC index is calculated using the following equation, as defined by Kardan Moghaddam et al. (2017) and Neshat and Pradhan (2017):[12]

DRASTIC index = $D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w$

In the equation, DRASTIC signifies the vital components of the DRASTIC index, with D, R, A, S, T, I, and C on behalf of water table depth, net recharge, aquifer media, soil media, topography, the influence of the vadose zone, and hydraulic conductivity, respectively as shown in Table 1. The symbols "r" and "w" represent the rating and weight assigned to each factor, respectively.

Table 1: *Ratings and weights related to DRASTIC index factors (Aller et al., 1985).*

DRASTIC parameters	**Range**	**Rating (r)**	**Weight (w)**
Water table depth (m)	0.0-1.5	10	5
	1.5-4.6	9	
	4.6-9.1	7	
	9.1-15.2	5	
	15.2-22.9	3	
	22.9-30.5	2	
	>30.5	1	
Net recharge	11-13	10	4
	9-11	8	
	7-9	5	
	5-7	3	
	3-5	1	
Aquifer media	Rubble and sand	10	3
	Gravel and sand	7	
	Gravel, sand, clay, and silt	5	
	Sand and clay	4	
	Sand, clay, and silt	3	
Soil media	Rubble, sand, clay, and silt	9	2
	Gravel and sand	7	
	Gravel, sand, clay, and silt	6	
	Sand	5	
	Sand, clay, and silt	3	
	Clay and silt	2	
Topography or slope (%)	0-2	10	1
	2-6	9	
	6-12	5	
	12-18	3	
	>18	1	
The impact of the vadose zone	Rubble, sand, clay, and silt	9	5
	Gravel and sand	7	
	Gravel, sand, clay, and silt	5	
	Sand, clay, and silt	3	
Hydraulic conductivity (m d^{-1})	0-4.1	1	3
	4.1-12.2	2	
	12.2-28.7	4	
	28.7-40.5	6	
	>40.5	8	

The fundamental assumption underlying the implementation of the DRASTIC vulnerability model are as follows:

- Contamination originates from the ground surface.

- Rainfall infiltrates through the surface and reaches the water table, carrying contaminants along.
- The contaminants migrate within the groundwater, at the same pace as water movement.
- The model is applicable to areas covering up to 100 acres.
- The aquifer is considered unconfined although adjustment can be made for a confined aquifer.
- Primary pollutants do not include pesticides, though modifications can be made to incorporate them if necessary.

RESULTS AND DISCUSSION

For representing each parameter eight thematic layers were prepared on the ArcGIS platform based on the data generated through field work and collected from different Government departments as well as from online open source platforms for 12 different locations of Delhi.

Vulnerability Assessment Parameters

Depth to water level

Water table depth is the distance of the water table from the ground surface in a well (Baghapour *et al.*, 2016) which defines the uppermost surface of the zone of saturation. Water table depth is an important factor as it finds out the length of a path which a contaminant must travel before reaching the water level which in turns determines the duration of contact between the percolating water which contains pollutants and the various constituents in the vadose zone. In general, the contamination chances of the groundwater become less with the extending of water table depth.

Water levels data has been collected for 12 different locations of NCT, Delhi and a depth (below ground) to water level map was prepared using the water levels measured from 12 monitoring stations. Pre monsoon and post monsoon data for May and November 2020 have been used as base input to develop DrDw map. Water table is deepest near Dhansa in the period under observation. Dr. Dw map depicts the same in Figure 2.

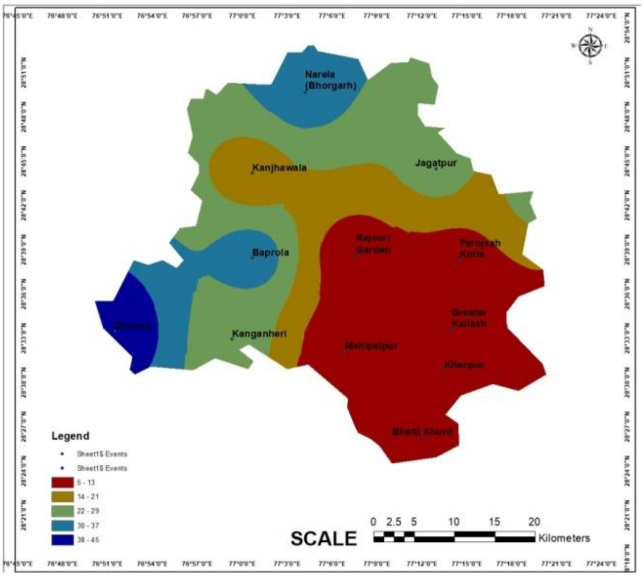

Fig. 2: *DrDw map of the study area.*

Net recharge

Net recharge is the volume of water that has penetrated into the ground through the surface and has reached the aquifer (Singh *et al.,* 2015; Ghosh and Kanchan, 2016)[19,9] which is the principle vehicle

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for transportation of contaminates through percolation (Voudouris *et al.* 2010).[20] The higher the volume of net recharge, the more is the vulnerability of the aquifer. The weight and rating of the parameter have been adopted on the basis of annual rainfall of the area. According to Fig 3 & 4, the highest net recharge value was observed in the south western parts of the NCT, Delhi near Dhansa. However, on calculating the weightage factor of R_R R_W as per the index, the entire study area has one single point value of 36. Hence this parameter only on the basis of map for the given study area is in- conclusive.

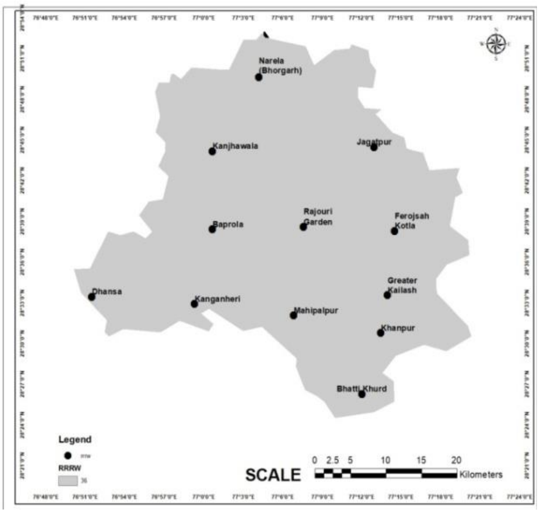

Fig. 3: *R_RR_W Map of Delhi.*

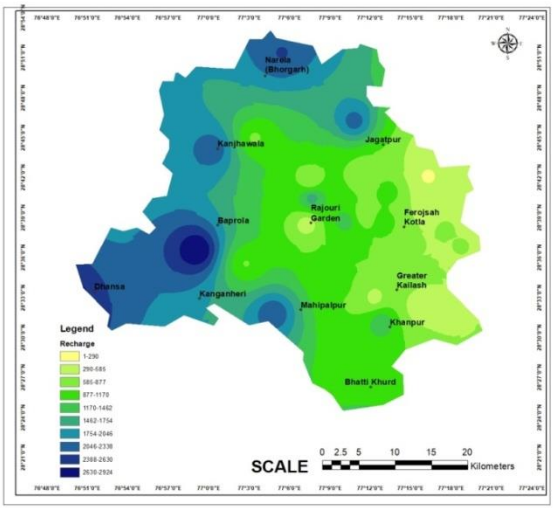

Fig. 4: *Recharge Map of Delhi.*

Aquifer media

Aquifer media [Fig 5] indicates the nature of geologic formation which controls the movement of groundwater in the aquifer (Aller *et al.,* 1985; Singh *et al.,* 2015). Media is the framework materials of an aquifer like sand and gravel in case of alluvium which controls the nature and rate of flow (hydraulic conductivity) of the aquifer. It is observed from Fig 6 that most of the parts of NCT, Delhi is covered by alluvium. Only a smaller portion of the south eastern part is covered by Quartzite. More porous aquifer media have been given high ratings, whereas impervious aquifer media was given to low rating. The rating of 4 has been assigned to alluvium and 8 to quartzites. Accordingly, the south eastern part is at least threat on the basis of this single point parameter data whereas location of Narela (Bhorgarh) Kanjhawala Jagatpur, Dhansa etc with A_RA_W of 24 are at greatest risk.

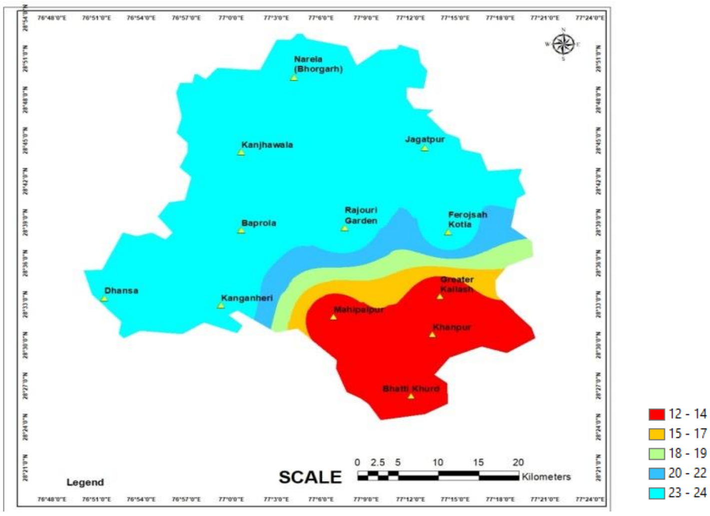

Fig. 5: *A_RA_W Map for 12 spot location in Delhi.*

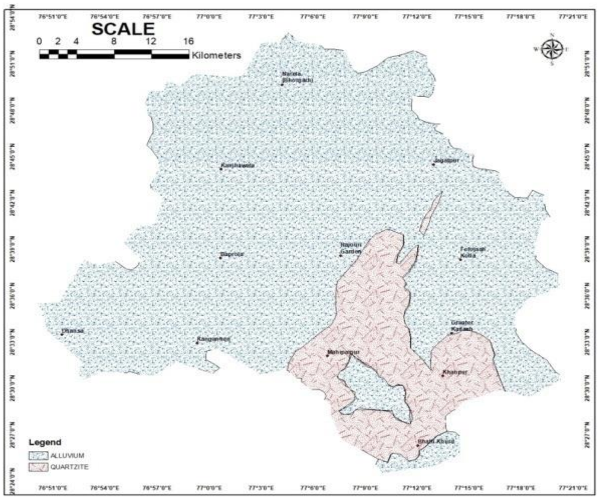

Fig. 6: *Aquifer media map of the study area.*

Soil media

The soil media has a considerable impact on the rate of infiltration, which in turn controls attenuation processes like filtration, sorption, degradation and evaporation during the process of percolation through the soil (Aller *et al.* 1987). Presence of fine-grained materials in soil like clay, silt and organic matter decrease the permeability and help effectively in reducing the contamination load. Base soil map of the under consideration was obtained from GSI which has been used to develop final representative map of this parameter (Figure 7) of this parameter .The rating as assigned to these parameter range from 4-10.

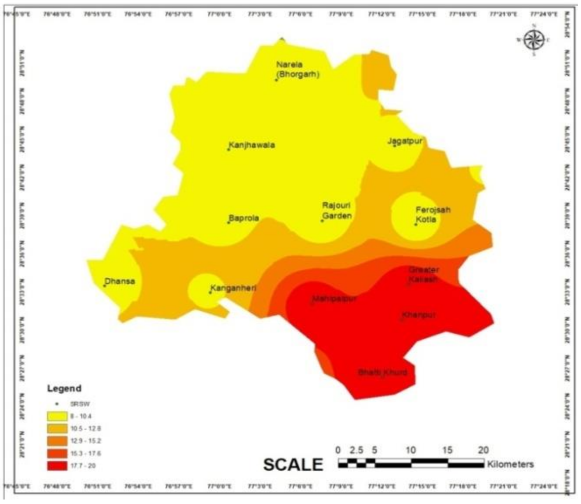

Fig. 7: *S_RS_W map of the study area.*

Topography

Topography describes the slope of land surface which controls the residence time of water inside the soil and the degree of penetration (Singh *et al.*, 2015). Areas with low slope allows run –off water to be retained for longer periods which in turns allowing higher infiltration, thus having a greater pollution potential. As the slope increases, the runoff increases as well (Israil *et al.*, 2006),[10] leading to less penetration (Jaiswal *et al.*, 2003).[11] Slope was obtained from the topographical map using a digital elevation model. The topographical layer representative map as shown in Figure 8 has a uniform rating value of 10 for the entire area under consideration.

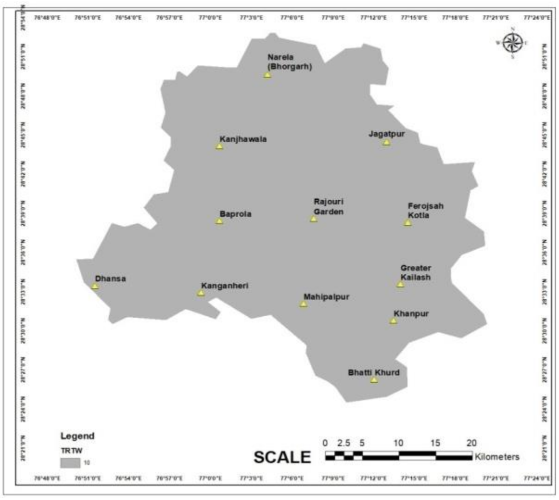

Fig. 8: *T_RT_W Map of the study area.*

Impact of vadose zone

Vadose zone is the unsaturated area located between the topographic surface and the groundwater level (Singh *et al.*, 2015) which plays a significant role on percolating water and decreases groundwater contamination by pollutant debilitation processes such as purification, chemical reaction, and dispersal (Shirazi *et al.*, 2012)[18] depending on the type of material in this zone. The information on vadose zone was extracted from the lithological logs of 12 borewells collected from Government departments as well as from the geological maps available from Geological Survey of India. Based on

Figure 9 it is apparent that highest value of I_RI_W is in the northern part of the study area.

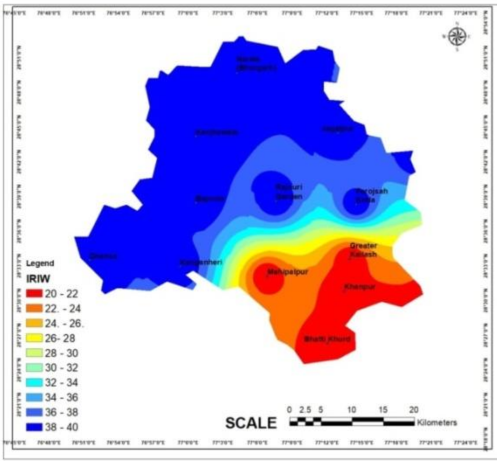

Fig. 9: *I_RI_W map of the study area.*

Hydraulic conductivity
The capacity of an aquifer to transmit water is termed hydraulic conductivity, which governs the speed at which pollutants traverse through the aquifer

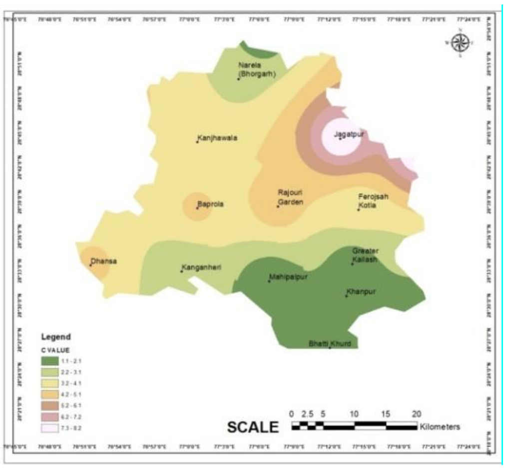

Fig. 10: *Hydraulic conductivity map of the study area.*

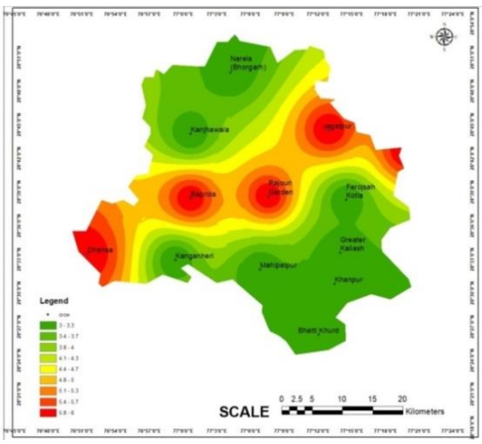

Fig. 11: ***CrCw map of the study area***

(Aller *et al.*, 1987). [1]This conductivity is contingent upon factors such as porosity and the degree of connectivity among intergranular pore spaces. A greater grain size corresponds to heightened hydraulic conductivity, indicating an elevated risk of groundwater contamination (Singh *et al.*, 2015; Aller *et al.*, 1985). Besides the grain size, two other factors that impart effect on hydraulic conductivity are sphericity of the grains and their packing. The findings showed that the hydraulic conductivity of the NCT, Delhi varies from 1.1-8.2 m/d. The potential for groundwater contamination was greater mostly in northern parts and south eastern of Delhi with high hydraulic conductivity (Figure 10 and Figure 11).

Vulnerability Mapping [Table 2]

Table 2: *Zoning on basis of vulnerability index.*

Vulnerability Group	Index Range
Low Vulnerability	<110
Moderate Vulnerability	110-129
High Vulnerability	130-149
Very High Vulnerability	>150

DRASTIC model which is based on seven hydrogeological parameters has been used to determine the GW vulnerability index of the area [Table 2]. The conclusive table obtained on basis of DRASTIC parameter is shown in Table 3.The derived groundwater vulnerability index varies from 106 to 171 and was classified into four zones. Zonation in the study area have been delineated as follows “very-high-, high moderate-, low -vulnerability” (Table-3). Based on the drastic model Fig: 12 the most vulnerable areas were found to be in Narela, Jagatpura, Baprola and Dahnsa. The south eastern part of Delhi is at the lowest risk as per the analysis of DRASTIC model.

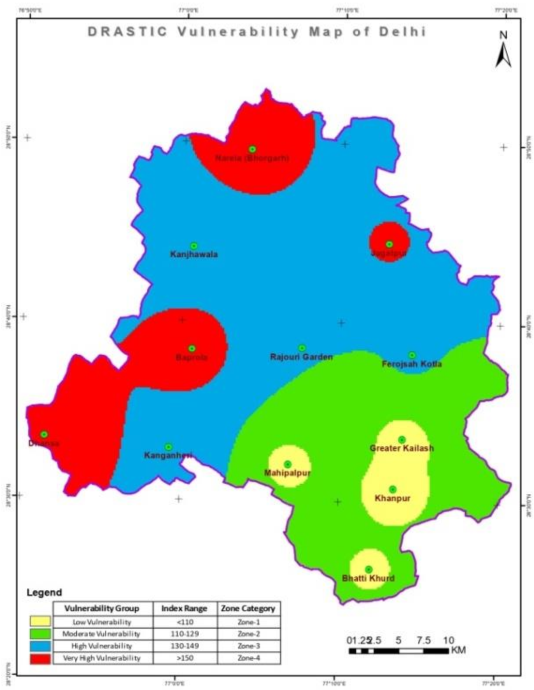

Fig. 12: *DVI map of Delhi.*

Table 3: *Vulnerability division of the study area*

SL. No.	Location	Lat.	Long.	D_R D_W	R_R R_W	A_R A_W	S_R S_W	T_R T_W	I_R I_W	C_R C_W	DVI	Zone Category
1	Narela (Bhorgarh)	28.82709	77.06949	35	36	24	10	10	40	3	**158**	**4**
2	Kanjhawala	28.73598	77.01073	15	36	24	8	10	40	3	**136**	**3**
3	Jagatpur	28.74118	77.21518	25	36	24	10	10	40	6	**151**	**4**
4	Baprola	28.64017	77.01052	35	36	24	10	10	40	6	**161**	**4**
5	Rajouri Garden	28.64297	77.12580	5	36	24	8	10	40	6	**129**	**2**
6	Ferojsah Kotla	28.63828	77.24138	10	36	24	8	10	40	3	**131**	**3**
7	Dhansa	28.55749	76.85782	45	36	24	10	10	40	6	**171**	**4**
8	Kanganheri	28.54855	76.98797	25	36	24	10	10	40	3	**148**	**3**
9	Mahipalpur	28.53448	77.11330	5	36	12	20	10	20	3	**106**	**1**
10	Greater Kailash	28.55933	77.23263	5	36	12	20	10	20	3	**106**	**1**
11	Khanpur	28.51295	77.22392	5	36	12	20	10	20	3	**106**	**1**
12	Bhatti Khurd	28.43776	77.20025	10	36	12	18	10	20	3	**109**	**1**

CONCLUSION

The present study has attempted to assess groundwater vulnerability in the NCT, Delhi region using seven hydrogeological factors. The present study is an endeavor to assess the groundwater vulnerability in the NCT, Delhi region. The management of aquifer needs chemical quality aspects also as now a days ground water pollution has increased from anthropogenic sources. Higher vulnerable areas worked out using DRASTIC model and have been found to be clustered in two zones i) Northern part and ii)South Western part, while south eastern part is found to be low to moderate vulnerability. Similar research should be undertaken in other areas to have a wider understanding of vulnerability of aquifers from anthropogenic sources.

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