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# Sintacs Model for Groundwater Vulnerability Mapping using Remote Sensing and GIS Techniques: A Case Study on Dindigul Block

**J.Colins Johnny*, M.C.Sashikkumar[1], P.A.Anas[2], E.Abiram Kishan[2]**

*Assistant Professor, Regional Office of Anna University, Tirunelveli, India
[1]Assistant Professor, University college of Engineering, Dindigul, India
[2]UG Student, Regional Office of Anna University, Tirunelveli, India

**Abstract:** Groundwater is considered to be a better resource for water requirements because of its economic and hygienic reasons. Almost all the countries are giving top priorities for envisaging exploration and exploitation of ground water reserves in their respective regions. The water available for utilization should be free from pollution. So the groundwater vulnerability analysis is essential for identifying the regions that has to be prohibited from contamination. The SINTACS model is the most extensively used method for identifying the areas where ground water supplies are most vulnerable to contamination. The SINTACS model uses seven environmental parameters like water table depth, effective infiltration, unsaturated zone, soil media, aquifer media, hydraulic conductivity and topographic slope. These parameters characterize the hydro-geological setting and aquifer vulnerability. The study area where the SINTACS model is going to be applied is a block in Dindigul city, Tamil Nadu. In this paper, vulnerability mapping is done for the whole region and the area is classified as very low, low, moderate and highly susceptible to pollution using a computer based geographic information system (GIS).
**Keywords :** *Groundwater, SINTACS, Vulnerability, GIS.*

## Introduction:

Groundwater is an important natural resource which depends on the subsurface and hydro-geological characteristics. Millions of gallons of groundwater are being pumped out every day in the globe to meet all our needs. With population explosion and industrialization groundwater is being contaminated and exploited at a tremendous rate. The theory of groundwater vulnerability was first introduced in France to create awareness and alertness about contamination of groundwater. Intrusion of pollutants by various anthropogenic activities alters its real property and risk is thus increased. Vulnerability is generally an intrinsic property of a groundwater system that depends on its sensitivity to human impact. Different approaches have been adapted for assessing the risk and vulnerability of the groundwater. Groundwater intrinsic vulnerability deals only with the hydro-geological setting and does not include pollutant attenuation. The natural hydro-geological factors affect the different pollutants in various ways depends upon their interaction and chemical properties[6].In this paper, application of SINTACS model for evaluating the intrinsic vulnerability of groundwater has been described. The SINTACS model depends mainly on both aquifer characteristics and hydro-geological environment. The acronyms SINTACS stands for the seven parameters are (i) Water table depth (S), (ii) Effective infiltration (I), (iii) Unsaturated zone (N), (iv) Soil media (T), (v) Aquifer media (A), (vi) Hydraulic conductivity (C) and (vii) Topographic slope (S). Various hydro-geological settings are represented by seven parameters which are further sub-divided into ranges or zones. The various approaches developed for evaluating aquifer vulnerability include process – based, statistical, overlay and index methods. This model is much suitable for regional scale assessment. The inputs for the SINTACS model is acquired from remote sensing and geographic information system (GIS) techniques.

**Study Area:**

The study area (shown in figure- 1) is Dindigul block in Tamil Nadu, India. The Dindigul block covers an area of 253 sq.km with a perimeter of 124.59 km. It lies in 10.35° N latitude and 77.95° E longitude. The average elevation of the study area is 265 m. It is a plain and hilly area with moderate variations in climatic conditions. The study area is located between Palani and Sirumalai hills. Lock making and tanning are the major industrial activities. Dindigul block is located 420 km south-west of Chennai and 100 km from Trichy. In summer the temperature reaches a maximum of 37° C and minimum of 29° C. During winter the temperature ranges from 26° C to 20° C.

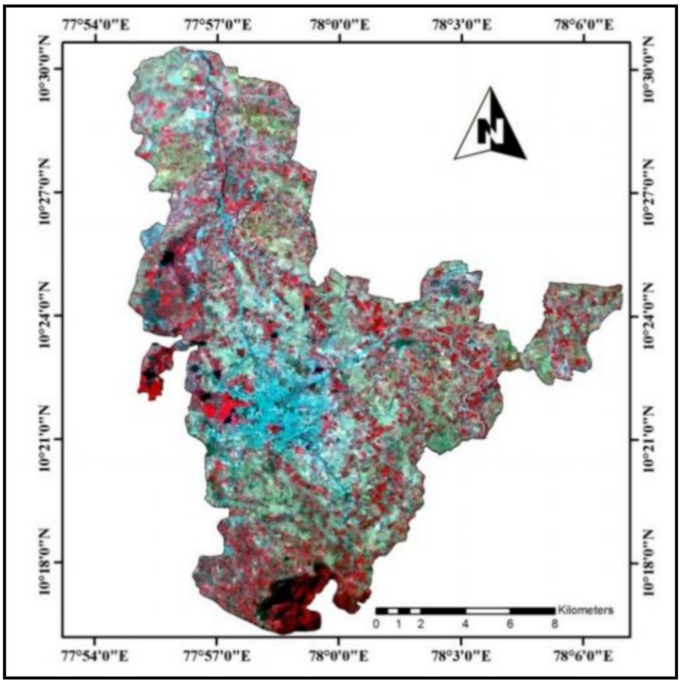


**Figure 1: Location map of Study area**

## Materials and Methodology:

**SINTACS model:**

Several systems and models are available for determining the groundwater pollution and vulnerability index. Among these models, the SINTACS model used in this study was developed by Civita (1990 b, 1993, 1994) and Civita&DeMaio (1997) to evaluate relative groundwater pollution vulnerability by assigning ratings and relative weights of each hydro-geologic parameters[11].

The SINTACS model is a development of the United States DRASTIC model adapted to Mediterranean conditions. The SINTACS model is preferred for different considerations which include its low cost, depending on available data sets, and relative, dimensionless and non-measurable properties that depend on aquifer characteristics[6].SINTACS model is a point count system model group with all factors has not only its own score but also an additional weight is set to increase or decrease its importance during the analysis.

**SINTACS Intrinsic Vulnerability Index (SIVI):**

The seven parameters are used to define the hydro-geological setting on any area and they are further subdivided into ranges (or) zones. Each zone has been assigned different ratings in a scale of 1 in 10 based on the rating chart[5]. The relative importance within each parameter to determine aquifer vulnerability is indicated by ranges or zones. The weights in the scale of 1 to 5 are assigned to each of seven parameters (table 1). Then computation of SINTACS vulnerability index is done using following equation.

**Table 1: SINTACS ratings and weighting values for various hydrogeological parameter settings**

| S. No | Parameters | Area covered (in %) | Intervals/ Classes | Rank | Weight | Index value |
|---|---|---|---|---|---|---|
| 1 | Water table depth | 3.51 | >22.8 | 1 | 5 | 5 |
| | | 1.55 | 15.2 - 22.8 | 3 | | 15 |
| | | 27.41 | 9.1 - 15.2 | 5 | | 25 |
| | | 65.55 | 4.6 - 9.1 | 7 | | 35 |
| | | 1.98 | 1.5 - 4.6 | 9 | | 45 |
| 2 | Recharge | 7 | 5 – 7 | 3 | 4 | 12 |
| | | 43.55 | 7 – 9 | 5 | | 20 |
| | | 41.15 | 9 - 11 | 8 | | 32 |
| | | 8.30 | >11 | 10 | | 40 |
| 3 | Unsaturated zone | 3.89 | Charnokite | 1 | 5 | 5 |
| | | 96.11 | FHB4 | 5 | | 25 |
| 4 | Soil media | 0.92 | Forest Unsurvey | 1 | 4 | 4 |
| | | 6.31 | Vertisol | 2 | | 8 |
| | | 21.94 | Altisol | 3 | | 12 |
| | | 66.34 | Inceptisol | 5 | | 20 |
| | | 4.48 | Entisol | 6 | | 24 |
| 5 | Aquifer media | 3.95 | Charnokite | 1 | 3 | 3 |
| | | 0.07 | Charnokite (lineament) | 3 | | 9 |
| | | 90.06 | FHBG | 5 | | 15 |
| | | 5.92 | Fissile Hornblende Biotite Gneiss (FHBG)(lineament) | 7 | | 21 |
| 6 | Hydraulic conductivity | 13.92 | 0.04 - 4.1 | 1 | 3 | 3 |
| | | 49.94 | 4.1 - 12.3 | 2 | | 6 |
| | | 36.14 | 12.3 - 28.7 | 4 | | 12 |
| 7 | Slope/Topography | 6.72 | >18 | 1 | 2 | 2 |
| | | 15.20 | 10 - 18 | 3 | | 6 |
| | | 41.84 | 6 - 10 | 5 | | 10 |
| | | 31.04 | 2 - 6 | 9 | | 18 |
| | | 5.17 | 0 - 2 | 10 | | 20 |

SIVI= $\sum_{i=1}^{T} Pi * Wi$

Where$P_i$ - ratings for seven parameters

$W_i$- relative weight for each parameter

**Preparation of Parameter Maps:**

Water Table Depth (S): The depth from the ground level of the water table is considered as the depth to water table. Depth to water affects the time available for a contaminant to undergo chemical and biological reaction. A low depth to water parameter will lead to a higher vulnerability rating. This parameter was derived from water level data of control wells from the public works department (PWD). The well location vector layer was prepared based on the GPS survey and the spatial distribution map of water table was obtained through IDW interpolation techniques in terms of raster data.

Recharge (I): Net recharge is the amount of water entering the aquifer. It transports the contaminant to the water table vertically. The total recharge for the study area was estimated by adopting the water table fluctuation method (WFD) which is considered to be the preferable field based method for estimating the amount of infiltration. The net recharge is directly proportional to the potential for ground water pollution. The general recharge component of water table fluctuation equation is the difference between the highest water level and lowest water level.

Unsaturated zone (N): The zone lying below the typical soil horizon and above the water table is unsaturated or discontinuously saturated. More weight is assigned to unsaturated zone as it is an important parameter in evaluating vulnerability assessment. The ratings assigned as per SINTACS model to the various classes of unsaturated zones are given in the table 1. The unsaturated zone map for the study area was prepared from well lithology data by Public Works Department (PWD).

Soil Media (T): Soil media affects the transport of the contaminant and water from the soil surface to the aquifer It plays a vital role in assessing the vulnerability index of ground water as it restricts the vertical flow of contamination into subsurface. Also it has a significant impact on the amount of recharge that will infiltrate into the ground. The groundwater intrinsic vulnerability is highly controlled by the textural characteristics of the soil[7]. The rating system was based on hydrological transport of the contaminant to the aquifer.

Aquifer Media (A): Aquifer media has the potential to store water and it contains sufficient saturated permeable material to yield significant quantities of water to wells. The aquifer media parameter was prepared using a subsurface geology map. The ratings assigned as per SINTACS model to the aquifer media parameters are mentioned in table 1. High permeability allows more water and more contaminants enter the aquifer. High permeability yields a high vulnerability index.

Hydraulic Conductivity (C): Hydraulic conductivity is a measure of ability of an aquifer to transmit water and relates the fractures, bedding planes and inter granular voids in the aquifer. Hydraulic conductivity controls the rate at which the ground water will flow under a given hydraulic gradient. The hydraulic conductivity values are obtained from the Public Works Department (PWD) and Tamil Nadu Water Supply Board (TWSB). There values are used to develop the hydraulic conductivity surface.

Slope / Topography (S):Topography refers to the slope of the bed and has an influence on vulnerability assessment with regard to whether water & pollutant will preferably run off or remain on surface long enough to infiltrate. Topography affects the groundwater vulnerability. With a low slope the contaminant is less likely to runoff and therefore more likely to infiltrate the aquifer. Slope map was prepared from the DEM data and it has been assigned a minimum weight in the SINTACS model. It is expressed in degree and if refers to the steepness.

## Results and Discussion:

In this paper we have determined the intrinsic vulnerability of groundwater in the Dindigul block, by employing the SINTACS model of the U.S Environmental protection Agency (EPA). Seven parameters that were used to represent the natural hydro-geological setting of the Dindigul block are Depth to water (S), Recharge (I), Unsaturated zone (N), Soil media (T) ,Aquifer media (A), hydraulic conductivity (C) and slope / topography (S).The parameter maps are generated by reclassification techniques and raster overlay process is used to generate the intrinsic vulnerability map.

The various characteristics and influence of the SINTACS parameters in evaluating the intrinsic vulnerability are discussed below.

### Water Table Depth (S)*:*

The depth to water level is an important parameter in assessing the groundwater contamination and evaluating the vulnerability index. The intrinsic vulnerability is indirectly proportional to depth-to-water parameter. The water table depth was prepared from 19 wells in and around the study area. Around 65.55% of the study area has been assigned a rank of 7 in the depth-to-water parameter map. The ranks 1, 3, 5 and 9 are assigned for 3.51%, 1.55%, 27.41% and 1.98% respectively. Depth to water parameter map is shown in figure-2.

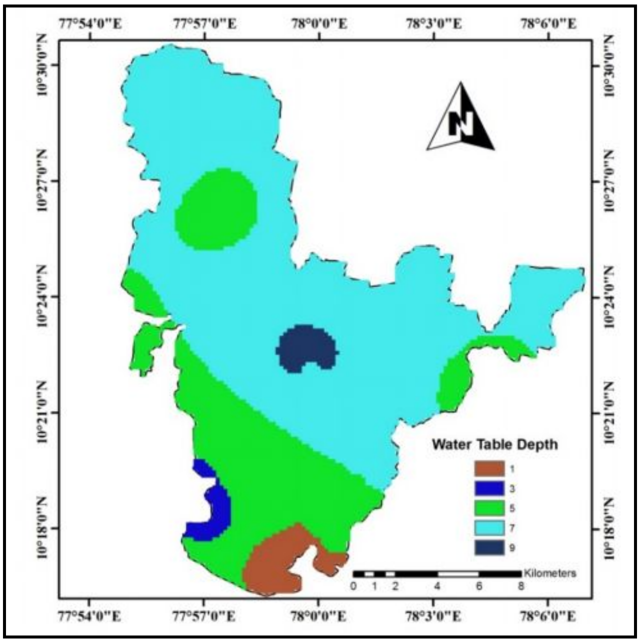


**Figure 2: Depth to water table map**

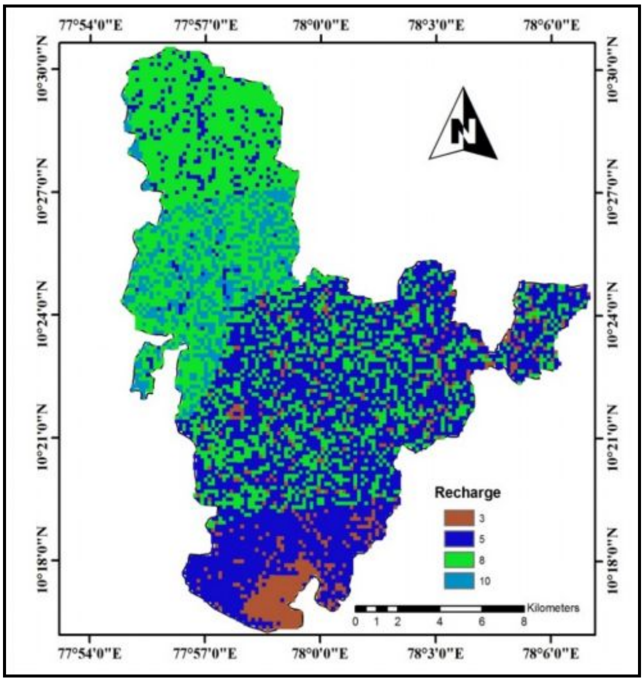


**Figure 3: Recharge map**

**Recharge(I):**

Net recharge or effective infiltration is the amount entering the ground per unit area of land which percolates into ground and thus reaches the water table. Recharge parameter map is depicted in figure- 3. In the study area 7% of land has been assigned with a rank of 3, 43.55% with rank 5, 41.15% with rank 8 and a rank of 10 for 8.30% of the study area. The 8.30% of study area with rank 10 is highly prone to contamination. Higher the rank of effective infiltration, the more is the intrinsic vulnerability of the groundwater.

**Unsaturated Zone(N):**

The unsaturated or vadose zone plays a prominent role in the assessment of ground water vulnerability. This zone protects the aquifer from pollutants for an extent.The contaminants are diluted by process of physical and chemical operations within this zone. Unsaturated zone parameter map is depicted in figure- 4. From this map it is clear that only 3.89% of study area has been assigned a rank of 1 and a rank of 5 to 96.11% of the remaining study area.

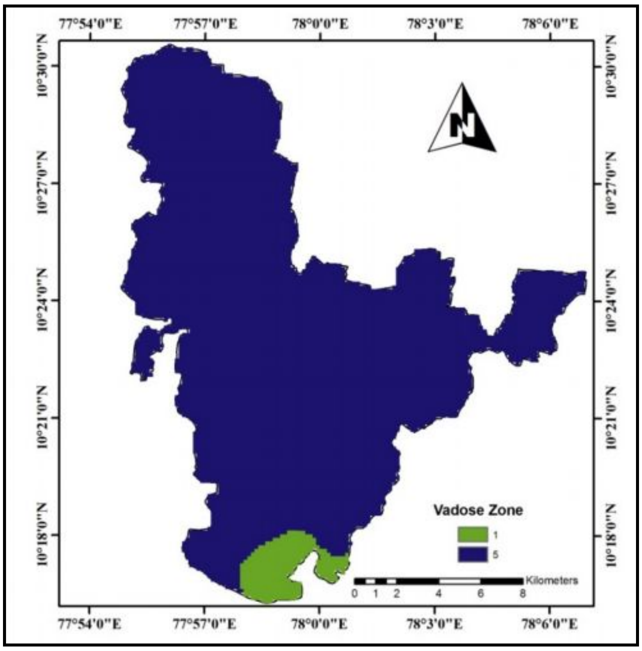


**Figure 4: Unsaturated zone map**

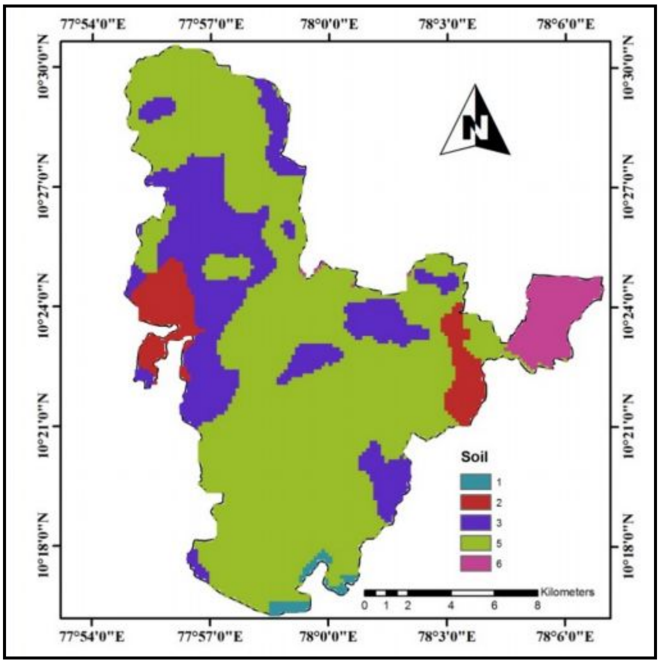


**Figure 5: Soil map**

**Soil media(T):**

The textural properties of the soil media control the groundwater vulnerability and it has an important role in determining the intrinsic vulnerability. Various five zones in the study area each with different ranks are shown in figure- 5. The 66.34% of study area has been assigned with a rank of 5 and rank 6 to 4.48% of the Dindigul block. The ranks 1, 2, 3 are assigned to 0.92%, 6.31% and 21.94 % of the study area.

**Aquifer media(A):**

The aquifer media parameter depends on the types of rocks in the study area. Aquifers may occur under various depths. Around 5.92% of study area has assigned with a rank of 7 and a rank 1 to 3.95% of study area. The ranks 3 and 5 are assigned to 0.07% and 90.06% of the study area respectively. These ratings are based on the infiltration capacity. Aquifer media parameter map is shown in figure- 6. The higher ranks depicts the higher permeability of the aquifer media which in turn allows more contaminants to pass through it.

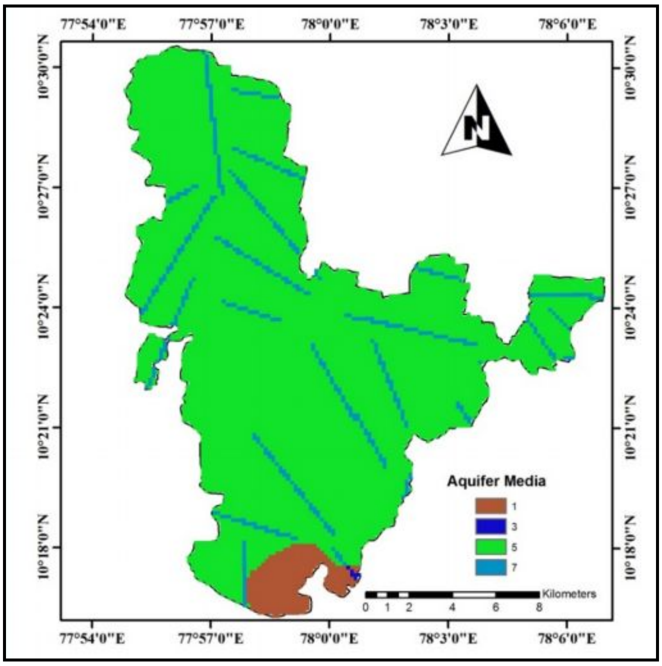


**Figure 6: Aquifer media map**

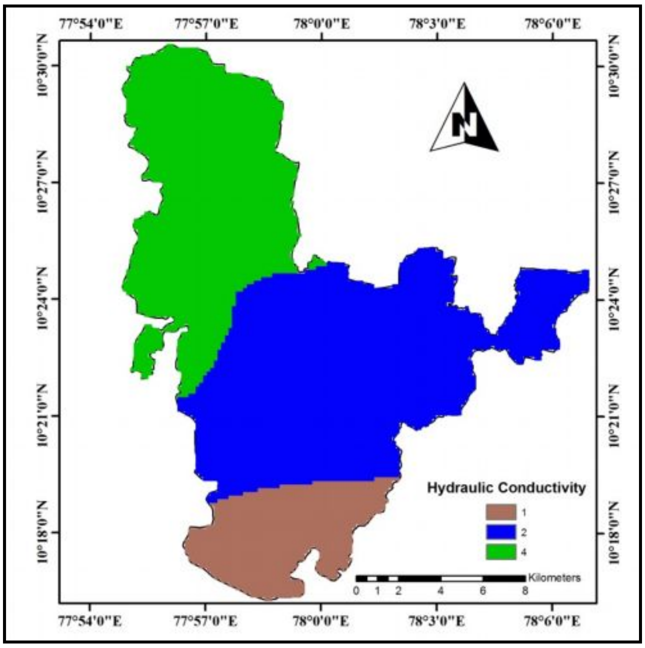


**Figure 7: Hydraulic conductivity map**

**Hydraulic Conductivity(C):**

Hydraulic conductivity test is obtained from field pumping test results of 19 wells in and around the study area. Around half (49.94%) of the study area has been assigned with a rank 2. Both hydraulic conductivity and intrinsic vulnerability are directly proportional. The hydraulic conductivity parameter map is shown in figure- 7 is generated by reclassification and IDW techniques in GIS environment.

**Slope(S):**

The slope parameter map of the study area is generated from SRTM DEM data. This parameter map is shown in figure- 8.The decrease in slope angle increases the intrinsic vulnerability of any area. Areas with low slope have been assigned a rank of 10 and rank 1 to high slope areas.

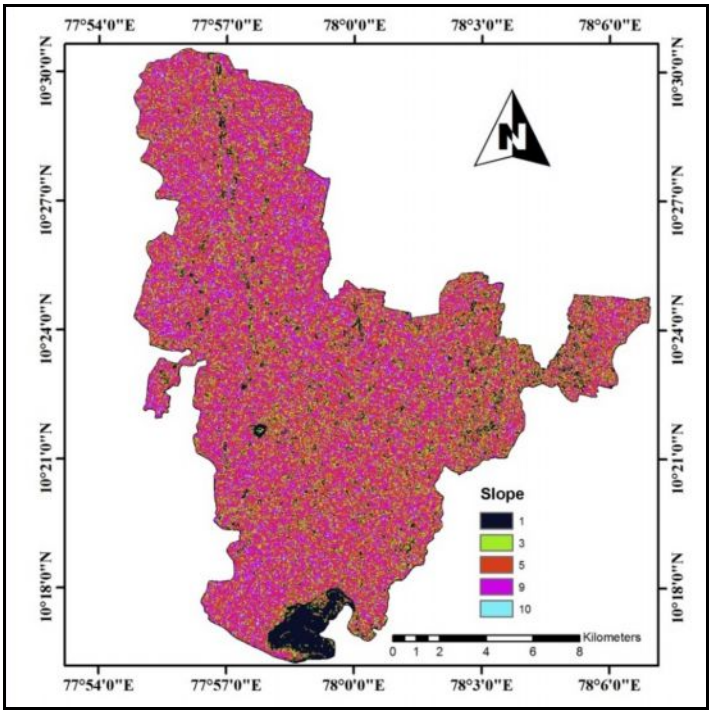


**Figure 8: Slope map**

**SINTACS Vulnerability Index:**

Vulnerability index map was prepared based on the overlay process using reclassified input parameters with desired weights in the Raster Calculator tool of GIS environment. The resultant vulnerability index shows that the study area is in the range of very low to high vulnerability in the SINTACS vulnerability index. Vulnerability index map is useful in assessing the susceptibility of ground water contamination. The degree of intrinsic vulnerability is assigned based on table-2. The northern part of the study area and few parts in central region are highly vulnerable. Very few regions in southern part of the study area are very less vulnerable to ground water contamination.

**Table 2: Classes of intrinsic vulnerability**

| SINTACS Vulnerability index | Degree of vulnerability |
|---|---|
| 26-80 | Very Low |
| 80-105 | Low |
| 105-140 | Medium |
| 140-186 | High |

## Conclusion:

The intrinsic vulnerability map for the study area generated from the SINTACS model is similar to that of DRASTIC model. The SINTACS model is considered to be superior due to its unique and the nature in weightage characteristics. The vulnerability index map shown in figure- 9 portrays that the study area has very low, low, moderate and high classes in vulnerability range. Nearly 40.81% of study area is highly vulnerable and 54.91% is in moderate vulnerable range. Only 3.58% and 0.7% 0f the study area falls under very low and low vulnerability. The ground water was contaminated in the high vulnerable areas while the safer zones of ground water is found in very low and low vulnerable spots.

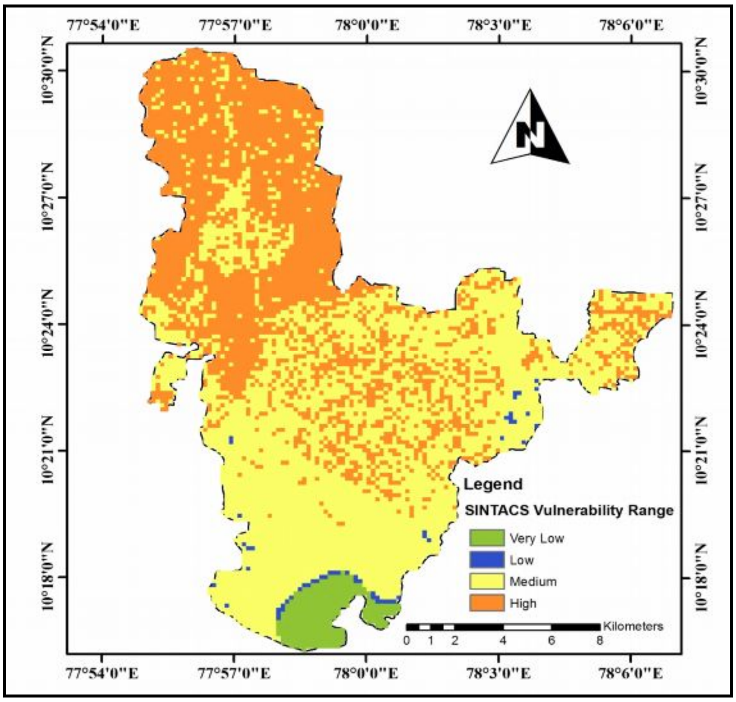


**Figure 9: SINTACS Vulnerability index Map**

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