INDICATOR KRIGING APPROACH USING A GIS TO CLASSIFY GROUNDWATER QUALITY PARAMETERS OF EAST GODAVARI DISTRICT, ANDHRA PRADESH, INDIA.

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ABSTRACT

Groundwater is a tremendous hotspot for all purposes behind water prerequisites in India. The improvement and scattering of groundwater in the state differ normally relying upon the geomorphology, geography and precipitation. The present examination zone is East Godavari region of Andhra Pradesh state, India. The prime focal point of this assessment was (1) To examine groundwater quality parameters (viz; Chloride (Cl), Magnesium (Mg), Fluoride (F), potential Hydrogen (pH), and Total Dissolved Solids (TDS) equal to or greater than the pollution threshold values i: e; Probability Maps. Total 116 groundwater samples were collected. The chemical analysis results were distinguished with BIS: 10500 (2012) to examine the nature of water for drinking purpose. It was seen that the semivariogram parameters fitted well in the Gaussian model for Chloride, Magnesium, and TDS parameters, Exponential model for pH, and Fluoride parameters. The spatial interpolation technique indicator kriging was used to dissect groundwater quality parameters equivalent to or more prominent than the contamination edge esteems. This assessment displays that geostatistics and GIS techniques give an incredible asset in understanding the improvement, resources and nature of groundwater.

Key words: *Geostatistics; Indicator Kriging; Probability maps; Drinking water quality standards; and Semivariogram.*

INTRODUCTION

Groundwater is a major source in India for all purposes. Groundwater plays a vital role in India for economic development and food security. For drinking water more rural population than of urban population depends on groundwater. Groundwater is an important source of drinking water for many people around the world, especially in rural areas. Groundwater resources are dynamic in nature and affected by such factors as the expansion of irrigation activities, industrialization, and urbanization. Hence, monitoring and conserving this important resource is essential. The existence and spreading of groundwater significantly vary based on geomorphology, rainfall, and geology. Amarnath et al. (2016) Spatial variation of water quality parameters along the shrimp culture ponds in East Godavari district. Simeonova et al. (2003) Water quality along the Struma river(Bulgaria and Greece) was estimated by using the statistical analysis of seasonal patterns, data set structures and long term trends.

The most important quality parameters for drinking water are potential for Hydrogen (pH), Magnesium (Mg), Chloride (Cl), Fluoride (F), and Total Dissolved Solids (TDS), these are the common constituents. They should be within the permissible limits otherwise they are harmful. Groundwater is less vulnerable to pollution than surface water. Since, the soil and rocks into and out of which groundwater flow separate most of the bacteria. Chatterjee et al. (2010) Spatial distribution maps of $HCO_{3,}$ pH, Hardness, $NO_{3,}$ Mg, Ca, Cl, F, and TDS are created, by using the Water Quality Index (WQI) the quality of water was assessed.

Dash et al. (2010) Indicator kriging was used to generate probability maps. Taylor et al.(2009) Probabilistic calculation of hydrological case relying upon geostatistical examination, by utilizing the variography of estimated areas and arrangement of kriging conditions unmeasured areas were anticipated. Webster and Burgess (1980) Universal kriging accounts the neighborhood patterns to limit the blunder of estimation and simultaneously calculates semi-variance of the distinction of actual data and cluster. Bobba. (2009) By the impact of ocean level changes and human exercises spatial and transient direct of freshwater and ocean water course through the Godavari delta were examined.

Carol A. Gotway (1992) Depicting the interpolation and spatial variability between two sampled areas inverse distance squared and kriging were utilized. Hu et al. (2005) The risk of NO_3 pollution in groundwater was estimated and to determine the groundwater depth by using kriging methods. ESRI (2010) By referring the geostatistical analyst tutorial exploring the data, creating the surface map, comparing the models, and mapping the probability of exceedance of the threshold limit. Lee et al. (2007) Based on the estimated arsenic concentrations the potential health risk of arsenic affected areas was identified by using indicator kriging.

Merino et al. (2001) For hourly and day by day estimation of solar irradiance, linear and spherical semivariogram models were utilized and mean absolute error also noted. Natural resources and environmental concerns, including groundwater, have benefited greatly by the use of GIS. East Godavari district of Andhra Pradesh has plenty of groundwater resources and having an idea of water quality of that area will be useful for effective utilization of groundwater resources.

MATERIALS AND METHODS

STUDY AREA

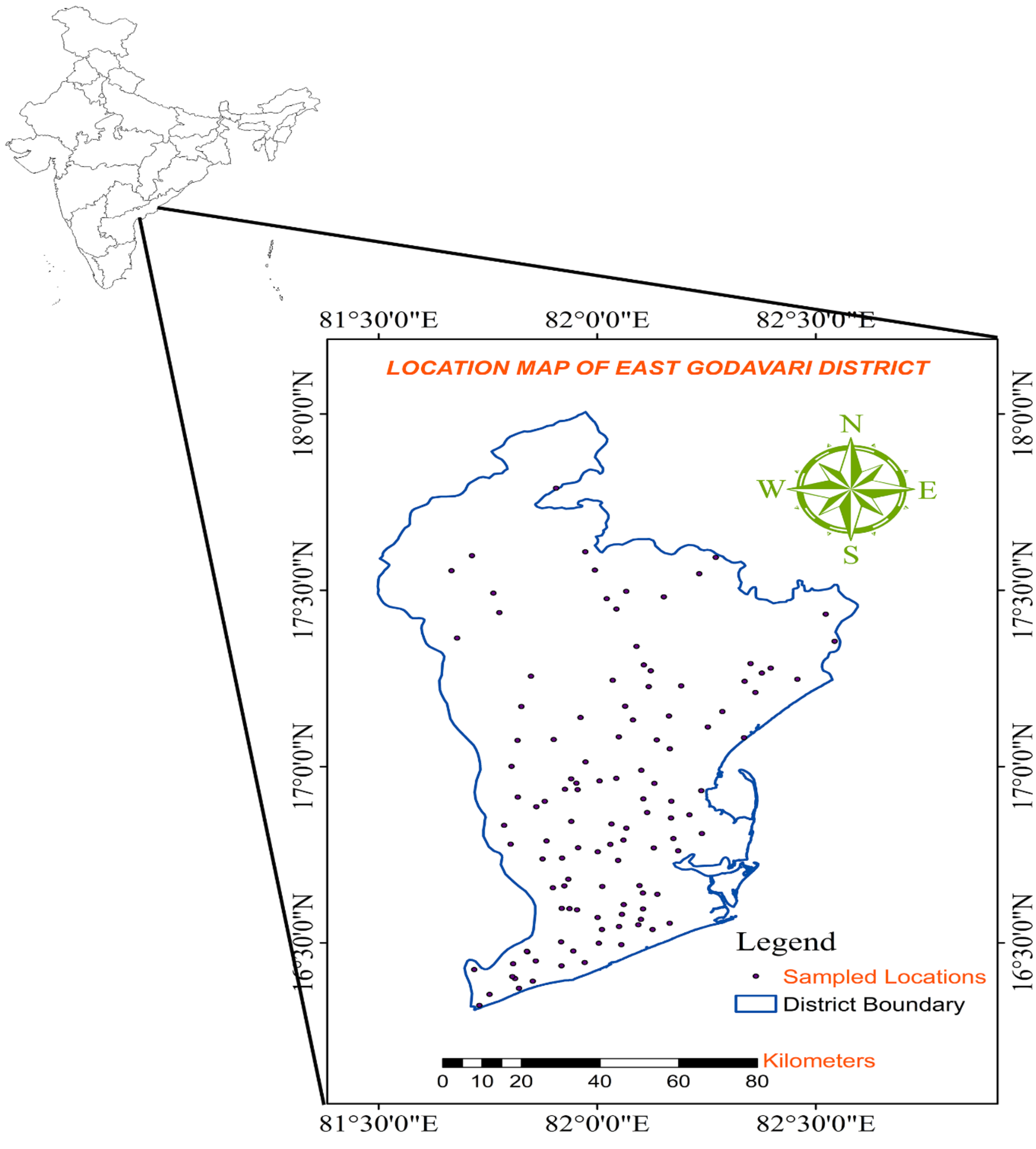


Figure 1 Location Map of the Study Area

The examination zone East Godavari District shown in Fig.1 is in Andhra Pradesh-India having directions of 17.3213° N and 82.0407° E. According to statistics 2011, the region has a population of 5,151,549 having a density of population is 477/Km^2 and the urban population is 25.52%. Perhaps the biggest locale in the state has an all-out region of 12,805km^2.

DATA COLLECTION

The groundwater samples were collected from General observation wells, APERP OB Wells, Open wells, Piezometers, Aquaculture closest bore wells were utilized for preliminary information investigation. A sum of 116 groundwater samples locations shown in fig.1 is obtained from the groundwater board Kakinada-Andhra Pradesh. Samples were examined in the chemical laboratory (GWB KKD 2017).

GEOSTATISTICAL APPROACH

The geostatistical wizard helps the analyst over the course of build-up and judge the accomplishment of an interpolation model. The satisfaction of a model can be achieved by using cross-validation results. The geostatistical wizard is a powerful setting in which to construct interpolation models, only because of the wizard's flexibility, dynamic data, and surface examination. Geostatistical techniques rely on statistical approaches that are based on a random function theory to model the uncertainty associated with geospatial assessment and simulation.

Interpolation methods are divided into two main types: geostatistical and deterministic methods. The variography (spatial patterns) can be modelled by using geostatistical techniques. At least some observed data by normal experience can be shaped by random process accompanied with spatial autocorrelation. Unmeasured location values are forecasted by using variographs and their uncertainty is assessed.

Indicator kriging helps to produce probability maps, based on predefined threshold values. By using geostatistical analysis, continuous (or) surface map was generated, from measured sampling points stored in a raster layer (or) a point feature layer (or) by using polygon centroids. The sampling points can be assessments such as depth to the water table, elevation (or) levels of pollution. Geostatistical Analyst tools can be used to evaluate probabilities that sill values are exceeded, standard errors (uncertainty) of predictions visualize and understand the geospatial phenomenon.

SEMIVARIOGRAM MODELING

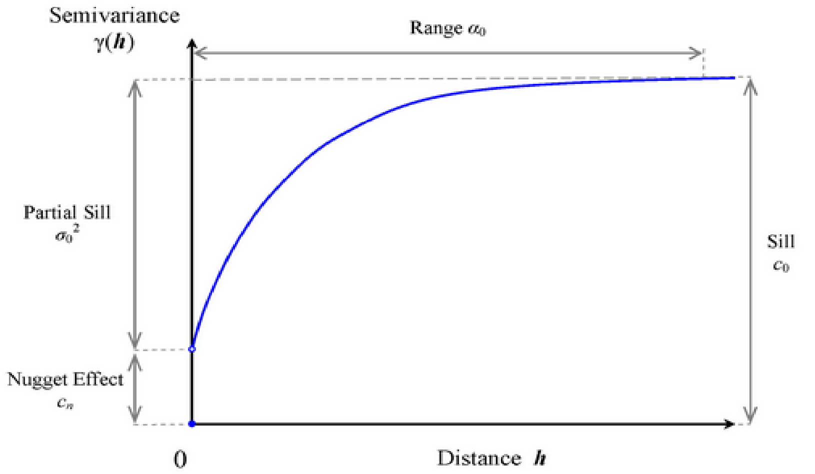


Figure 2 Semivariogram model

Nugget, Sill, and Range are the measures of a variogram shown in **Fig 2**

Variability in the field data referred by the nugget and it can't be described by the distance between the observations.

Kriging

Kriging is a kind of spatial interpolation that employs mathematical formulae to calculate values at unknown points based on the values at known points. Abnormality in the surface can be explained by spatial autocorrelation. Kriging comprises exploring the data, modelling of variogram, generating the surface, and investigate a variance surface.

Indicator Kriging

Indicator kriging is a type of nonparametric geostatistical method. No assumptions made in indicator kriging around the underlying invariant distribution and 0 to 1 indicator transformation of data makes the predictor strong to exemptions. The indicator function of sample *z (x)* at location *x* is associated with the threshold value *z* as Hu et al. (2005) follows

$$I(x;z) = \begin{cases} 0, & if z(x) \geq z \\ 1, & otherwise \end{cases}$$

The exact proportion of grades $z\ (x)$ below the threshold z with any area A is written as

$$ø(x;z) = \frac{1}{A}\int_A^z I(x,z)dx \in [0,1] \quad (1)$$

Where $ø\ (A;z)$ is the bivariate function on $z(x)$ and z, namely, the average of all the indicator values $I(x;z)$ with $z(x) \leq z\ (x \in A)$. The estimator of $ø(A; z_{ik})$ can be written as

$$ø^{\wedge}(A; z_{ik}) = f(x) = \sum_{\alpha=1}^{n} \lambda(z)\,.\,I(x\alpha; zik) \quad (2)$$

The weights $\lambda_\alpha\ (z_{ik})\ (\ \alpha = 1,2,\ldots,n)$ associated $I(x_{\alpha;}\ z_{ik})$.

The indicator $I\ (x_{\alpha;}\ z)$ can be interpreted as

$$I\ (x_{\alpha;}\ z) = prob\ \{z(x_\alpha) \leq z \mid z\ (x_{\alpha)} = z_\alpha\} \quad (3)$$

Consequently, the estimator $I^{\wedge}\ (x_{\alpha;}\ z)$ appears as an estimate of the unknown conditional probability:

$$I\ (x_{\alpha;}\ z) = prob\ \{z(x_\alpha) \leq \text{surrounding data}\}$$

The estimator $ø^{\wedge}(A;z)$ *of* $ø(A;z)$ in the unknown region A can be written as

$$ø^{\wedge}(A; z) = \frac{1}{A}\int_A^z prob\ z\{(x) \leq z)\text{surrounding data}\ \}dx \quad (4)$$

finally, the average estimator $[z(x)]^{\wedge}$ of unknown region A is given as follows:

$$[z(x)]^{\wedge} = \sum_{l=1}^{L} [I_{ik}(x)]^{\wedge}[z(x) \mid x \in z_{ik}]^{\wedge} \quad (5)$$

Exploratory semivariograms parameters were determined for pH, F, TDS, Mg, and Cl of East Godavari District, Andhra Pradesh, India.

DETERMINATION OF SILL LIMITS OF GROUNDWATER QUALITY PARAMETERS FOR INDICATOR KRIGING

Tolerable standards have been set by various organizations for drinking purposes, the exceedance of these limits would lead to a human health hazard. For example, the desirable limit of Chloride 250 mg/l was used as a pollution threshold BIS (2012); WHO (2011). Likewise, for other parameters, the desirable limits are tabulated in Table.1 as per the Bureau of Indian standards BIS (2012), which was considered as the threshold values for drinking water purposes.

Table 1 Bureau of Indian standards (BIS) for Drinking water quality IS:10500

Parameter	Desirable Limit	Permissible Limit
Cl, mg/l	250	1000
Mg, mg/l	30	100
F, mg/l	1	1.5
pH	6.5	8.5
TDS, mg/l	500	2000

RESULTS AND DISCUSSION

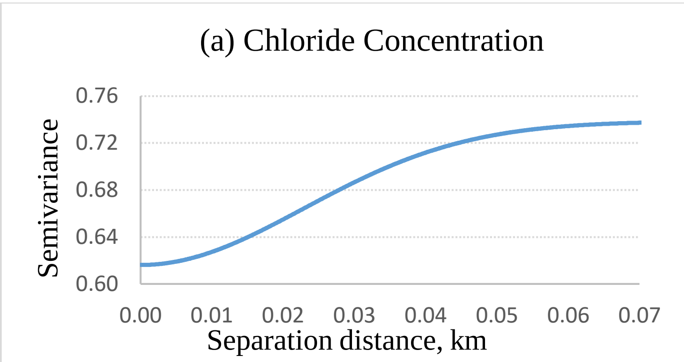
Various transformations such as lognormal, Box-cox, and Arcsine to make sure data normally distributed tabulated in **Table 2.** Since, the data sets obtained were not normally distributed hence to make the data distribution normal various mathematical transformations were carried out for the analysis.

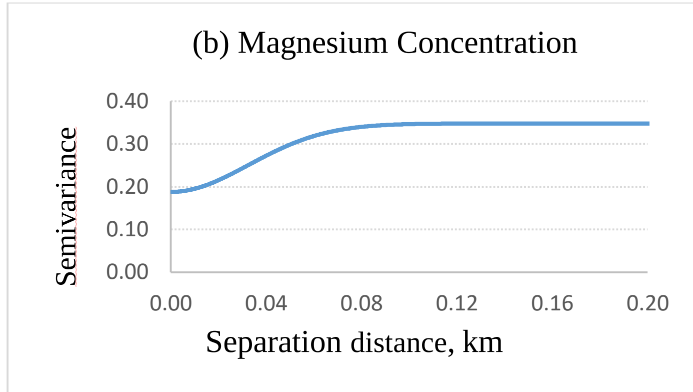
Table 2 Distinct measurements on groundwater quality parameters estimated in observation wells, APERP OB Wells, Open wells, Piezometers, Aquaculture nearest bore wells across the study area.

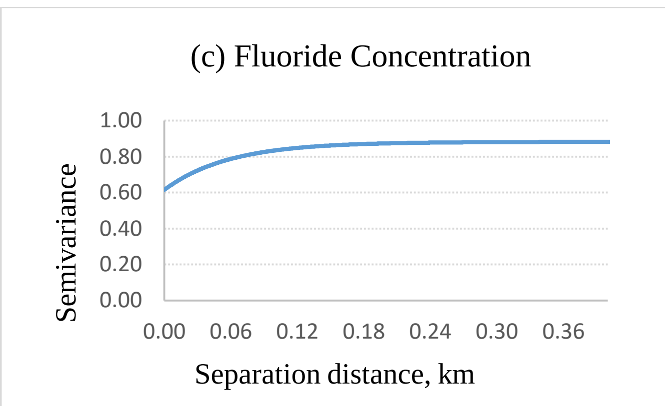
Parameter	Mean	Minimum	Maximum	Transformation
Cl	212.5	10	1040	Lognormal
Mg	41.69	10	190	Lognormal
TDS	801.28	141	2609	Lognormal

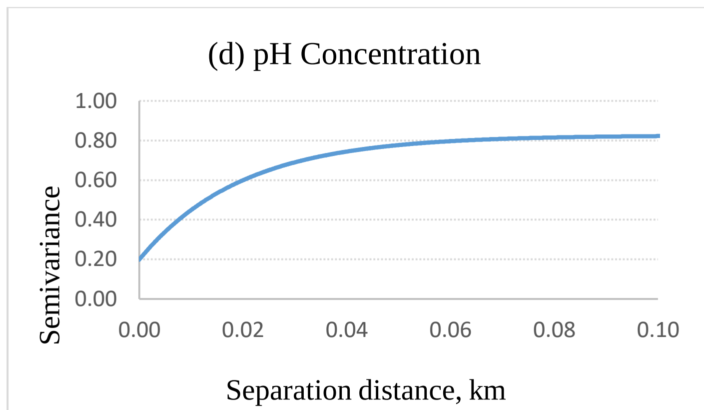
BEST FITTED SEMIVARIOGRAM OF GROUNDWATER QUALITY PARAMETERS OF EAST GODAVARI DISTRICT, ANDHRA PRADESH, INDIA

Semivariogram criterion for every theoretical model such as Linear, Gaussian, Circular, Spherical, and Exponential was generated. The most suited model was selected based on regression statistics. Such as $R^2 \cong 1$(Max) and Regression Sum of Squares (RSS) should be minimum. The corresponding nugget (c_0), the range (A_0), and the sill ($c_0 + c$), values of the most suited theoretical model was identified and their semivariograms were showed in **Fig. 3**.









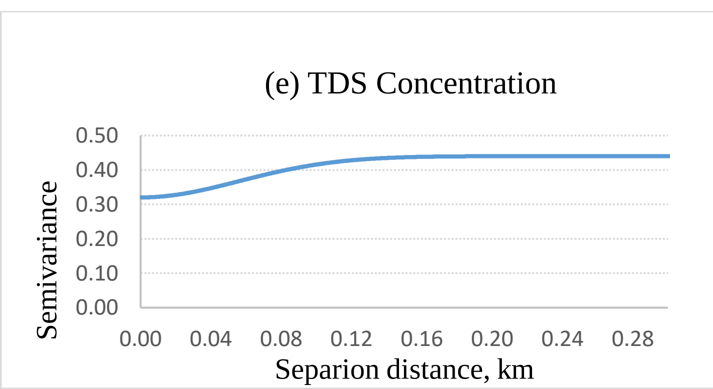


Figure 3 Best fitted semivariogram models for groundwater quality parameters of East Godavari District

SYNOPSIS OF BEST-FIT MODEL FOR GROUNDWATER QUALITY PARAMETERS OF EAST GODAVARI DISTRICT

Based on the cross validation tests the predictive performance of the most suited model was examined. The values of $R^2 \cong 1$, Mean Error (ME) ≅0, Regression Sum of Squares (RSS) should be minimum, Mean Square Error (MSE) ≅ minimum, Root Mean Square Standard Error (RMSSE) ≅1, Root Mean Square Error (RMSE) and Average Standard Error (ASE) nearly equal.

Table 3 Synopsis of best-fit model for different groundwater quality parameters.

Parameter	Number of Observations	Most suited model	Nugget, (c_0)	Sill, (c_0+c)	Range, (A_0)	R^2	RSS
Cl	116	Gaussian	0.61	0.12	0.07	0.93	1.78
Mg	116	Gaussian	0.18	0.15	0.15	0.62	1.58
F	57	Exponential	0.56	0.37	0.41	0.60	2.29
pH	116	Exponential	0.19	0.62	0.10	0.69	16.43
TDS	113	Gaussian	0.32	0.11	0.32	0.64	1.09

Table 4 Statistics for model derived parameters of quality by semivariogram techniques.

Parameter	ME	MSE	RMSE	ASE
Cl	0.671	-0.055	199.743	307.202
Mg	0.112	-0.105	27.473	33.160
F	0.007	-0.130	0.5043	0.549
pH	0.024	0.024	0.935	0.911
TDS	4.394	-0.055	515.588	618.016

GROUNDWATER QUALITY PROBABILITY MAPS OF EAST GODAVARI DISTRICT BASED ON SILL/THRESHOLD VALUES

Figure (a) Chloride Probability Map

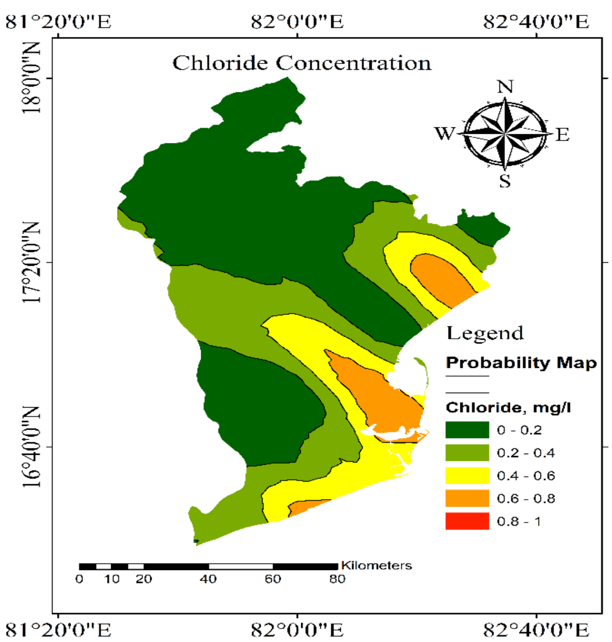


Figure (b) Magnesium Probability Map

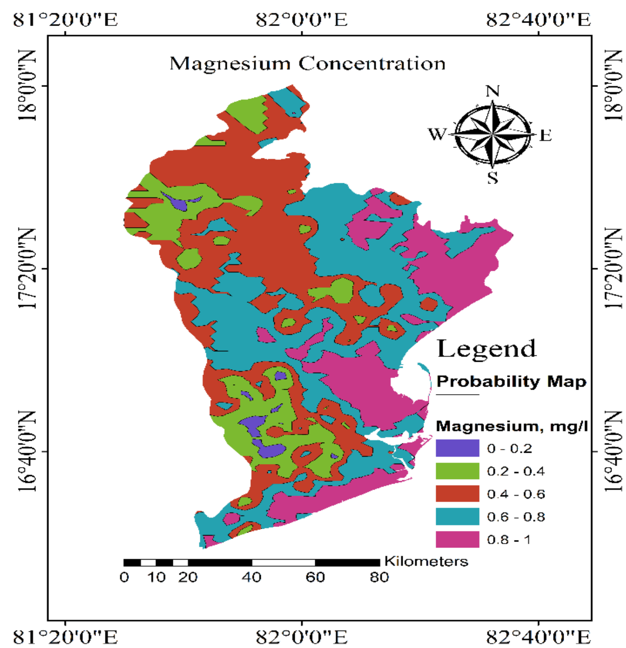


Figure (c) Fluoride Probability Map

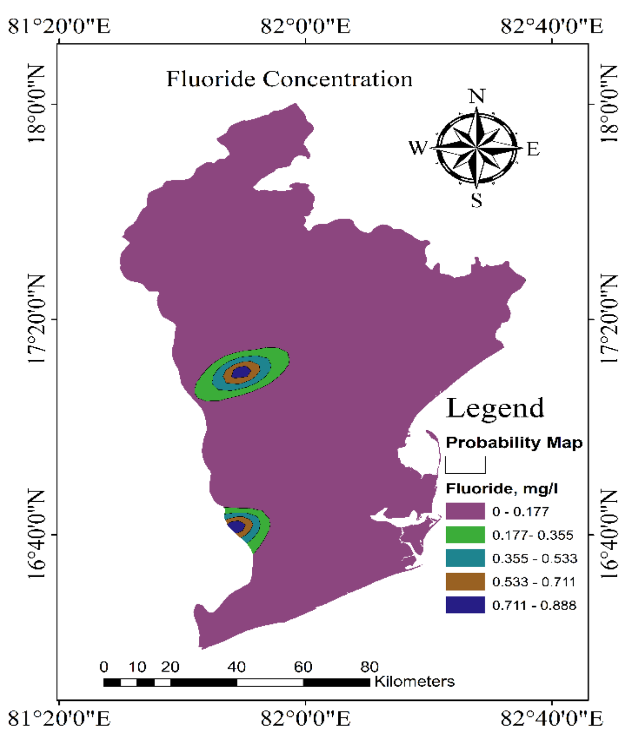


Figure (d) pH Probability Map

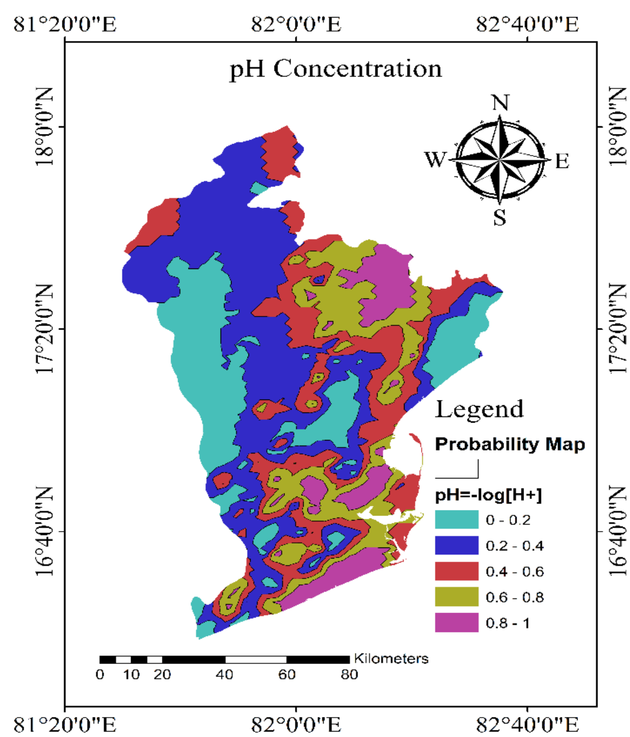


Figure (e) TDS Probability Map

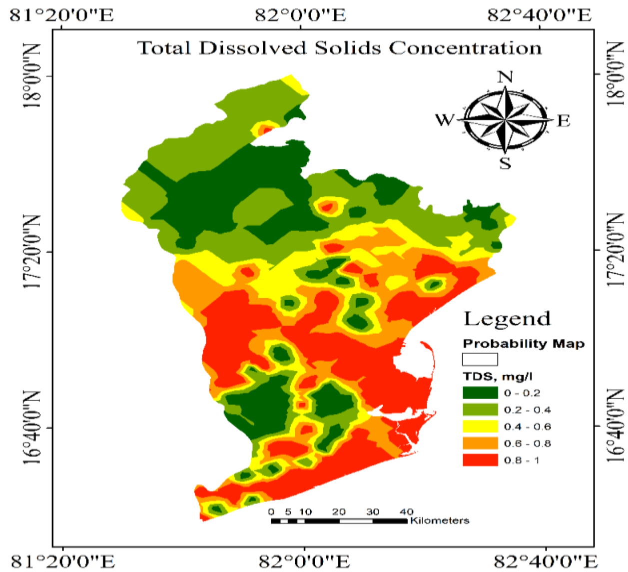


Figure 5 Probability maps of various groundwater quality parameters (a) Chloride (b) Magnesium (c) Fluoride (d) pH (e) TDS.

To display the probability of exceedance of the sill/threshold value contaminant level in groundwater, the most fitted theoretical model and the equivalent semivariogram parameters were used. For generating the probability maps the indicator kriging was used. The probability of exceedance of the sill/threshold value and their related area was presented in Table 5.

Chloride, Magnesium, Fluoride, pH, and TDS probability maps were developed and displayed in Fig 5. From the probability map of Chloride Fig 5(a) very less amount of high Chloride, value is found. Table 5 displays that for about 0.83 % of the study area is exceeded the pollution threshold/ sill value of chloride concentration. From the probability map of Magnesium Fig 5(b) high magnesium values are found in the central part of the study area and along the coastal region i: e; southeast region. Table 5 displays that for about 29.32 % of the study area is exceeded the pollution threshold/ sill value of magnesium concentration was more. From the probability map of Fluoride Fig 5(c) very less amount of high fluoride values was found in the Western part and border of the Southwest region of the study area. Table 5 displays that for about 0.19 % of the study area is exceeded the pollution threshold/ sill value of Fluoride concentration was more. From the probability map of pH high pH values Fig 5(d) is found in the Northeast and Southeast region of the study area. Table 5 displays that for about 8.49 % of the study area is exceeded the pollution threshold/ sill value of pH concentration was more. From the probability map of the TDS Fig 5(e) major area is affected with high TDS values in the Southeast, Southwest region of the study area. Table 5 displays that for about 28.06 % of the study area is exceeded the pollution threshold/ sill value of TDS concentration was more.

Table 5 Delineated areas with distinct probability ranges of threshold concentration limits of groundwater quality parameters for drinking water of East Godavari District.

Probability Range	**Parameter**	**% Area (km^2)**
0.8-1.0	Cl	0.83
0.8-1.0	Mg	29.32
0.71-0.88	F	0.19
0.8-1.0	pH	8.49
0.8-1.0	TDS	28.06

The risk posed by various contaminants that outreach the desirable value in drinking water was assessed by using indicator kriging method for the development of systematic groundwater management plan of action for the East Godavari district.

CONCLUSIONS

The water quality parameters were log-normally changed to guarantee the ordinariness of the information pattern for analysis. In any case, thinking about the target of the examination, indicator kriging strategies was utilized to outline spatial variability and the probability of exceedance of groundwater quality data and influenced regions were assessed utilizing geostatistical and ArcGIS platforms.

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