Groundwater Quality assessment for Drinking Purpose using Traditional and Fuzzy-GIS based Water Quality Index in Gurugram District of Haryana, India

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Abstract

Primarily groundwater is consumed for the drinking and irrigation purpose. However, due to increasing anthropogenic activities, its quality and quantity have substantially declined over time. The focus of this study is to evaluate the pre-monsoonal groundwater quality and its spatial variability for drinking purposes in the Gurugram, Haryana, India. Ground Water Quality Index (GWQI) developed on the basis of the Geographical Information System is effective in the assessment of groundwater quality and its spatial variability, but it is unable to account for uncertainties related to environmental problems. Thus, a Hybrid Fuzzy-GIS based Water Quality Index (FGQI) has been proposed for the assessment of groundwater quality. The study conducted factor analysis to identify the prime factors responsible for groundwater contamination and collected pre-monsoonal groundwater samples through primary sampling. The groundwater quality was assessed based on eight hydro geochemical parameters (pH, TDS, Calcium, Chloride, Sulphate, Fluoride, Potassium, and Sodium). The spatial interpolation of each parameter was performed using appropriate techniques, selected based on a normality test. The guidelines of the World Health Organization (WHO) and Bureau of Indian Standard (BIS) were incorporated in the development of GWQI and FGQI, respectively. Correlation analysis was performed to determine the best fuzzy overlay technique for FGQI, and the Fuzzy GAMMA technique with gamma equal to 0.9 was selected. Finally, the GWQI and FGQI were classified into three classes: unsuitable, moderate suitable, and suitable using "natural break." A higher index indicates a higher water quality. The results show that the groundwater in the central part of Gurugram is suitable for drinking, while it is not suitable in the extreme north, south-east, and western regions. In conclusion, this study finds that FGQI effectively assesses the groundwater quality in the region better than GWQI.

1. Introduction

Groundwater is a highly valuable natural resource, and its utilization in multiple sectors makes it essential for the sustenance of millions of living beings. The escalating pace of industrialization, urbanization, and intensifying agricultural activities has had a negative impact on the quality of both surface and groundwater (Jha M.K. et al., 2020). Groundwater is the major source for drinking water in various countries. These countries are witnessing the rapid rate of population growth. Thus, demand side of the water is also gradually increasing over the period of time. As far as, the case of India is considered, it is recognized world's largest groundwater consumer by consuming approximately 230 km^3annually. In India, groundwater is utilized to meet 60% of the demand for agricultural irrigation and approximately 85% for drinking purposes (World Bank, 2012). The unsubdued demand for water has put forth a serious concern among policymakers and other concerned stakeholders about groundwater sustainability management (Foster and Chilton, 2003). Groundwater pollution is a global concern, and it is being contaminated in a variety of ways which effect the ecosystem directly or indirectly(Morris, B.L. et al., 2003; Reddy, P.S. et al., 2011; Rakib, M.A. et al., 2019). Groundwater contamination is difficult to trace than surface water contamination because of the slow movement of water in the subsurface environment, contamination can persist for a long time (Jha M.K. et al., 2020). Hence, it is necessary to develop an effective strategy for the sustainable management of the groundwater.

Various research works have been done globally for the management of groundwater sustainability. Initially water quality was measured with Water Quality Index (WQI). Horton, 1965 categorized it in the mid- twentieth century. Subsequently, a general WQI was developed by Brown et al., 1970. A novel environmental quality index summarizing the technical information on the Great Lakes ecosystem was developed by Steinhart et al., 1982. In the mid-1990s, WQI was introduced by Water Quality Guideline Task Group (WQGTG) of Canadian Council of Ministers of the Environment (H'ebert S., 1996). Subsequently, WQI is being frequently used by the US National Sanitation Foundation Water Quality Index (NSFWQI), Florida Stream Water Quality Index (FWQI), British Columbia Water Quality Index (BCWQI), Oregon Water Quality Index (OWQI) (Poonam, T. et al., 2013). In India, Bhargava developed the Water Quality Index (WQI) which varies from 0 -100, with 0 representing extremely contaminated and 100 representing uncontaminated water (Bhargava D.S., 1983). In 1985, Tiwari and Mishra conducted a study for the determination of the Water Quality Index (WQI) of major rivers in India. Willsand Irvine, 1996 estimated NSFWQI for the determination of the water quality in Cazenovia creek New York. Many similar studies have been done for the water quality analysis using WQI (Rao, S. 1997; Zanderbergen et al., 1998; Rudolf et al., 2002; Khan et al., 2005; Sanchez et al., 2006; Sahu and Sikdar, 2008; Samantray et al., 2009; Parmar et al., 2010; Cristina Roşu et al., 2011; Sharma et al., 2011; Mangukya et al., 2012; Jena et al., 2013; Jha M.K. et al., 2020).

Limited studies are performed for groundwater whereas numerous past researches work on WQI are primarily focusing on the surface water.

The assessment of surface water quality involves the determination of both biological and physiochemical parameters, while the quality of groundwater is evaluated based on hydro chemical parameters (Vadiati et al., 2016). Nowadays, various Geographic Information System (GIS) techniques are widely utilized for the calculation of water quality indices (Abboud, 2017; Arslan, 2017; Bodrud-Doza et al., 2016). Babiker, I. S. et al. was the first, who used statistical method for the calculation of Geographic Information System (GIS) based Groundwater Quality Index (GWQI) on the basis of World Health Organization (WHO) standards. Subsequently, this method was followed by a number of researchers for the determination the groundwater quality (Machiwal et al., 2011; El-Fadel et al., 2014; Vadiati et al., 2016).

Calculation of the Geographic Information System (GIS) based GWQI is made easier through the use of statistical techniques, using the fixed standards values of World Health Organization (WHO) and the Bureau of Indian Standards (BIS: 2012).But, traditional WQI based techniques are not able to deal with the various irregularities involved in the environmental problem assessment (Silvert, 2000). Various researchers used Artificial Intelligence (AI) based algorithms to overcome this issue (Maiti et al., 2013;Patki et al., 2015; Bagherzadeh et al., 2018). These algorithms include Neural Networks, Support Vector Machine, Bayesian Network, Fuzzy Logic (FL) System, etc. But FL is one widely used algorithm to overcome the complicated water quality related environmental concerns (Ghosh and Mujumdar, 2006; Chau, 2006; Mohebbi Tafreshi et al., 2018). Zadeh, 1965 introduced the FL on the basis of 'fuzzy' set-theory. Result of the FL is much effective and understandable for the public and other concerned authorities (Li et al., 2018). For the first time, Fuzzy Inference System (FIS) was used for the evaluation of the river-water quality in Spain by Ocampo-Duque et al., 2006. This fuzzy-WQI was found to be more effective than traditional-WQI. Groundwater suitability assessment through FL based overlay analysis within GIS environment is not too much explored. In India, there are various mega-cities and metropolitan cities where groundwater has not been extensively explored. Residents in these regions heavily rely on the municipal supply of drinking water, leading to unregulated and heterogeneous extraction of groundwater for various other purposes. This became the prime cause of the motivation for this research paper.

In this study pre-monsoonal water quality of the Gurugram district of Haryana, India was assessed. This study is intended to fulfill these following objectives:

a. Assessment of the groundwater quality and its spatial variability for drinking purpose.
b. Comparative study of the result of Fuzzy-GIS based WQI and GIS-based WQI in groundwater quality assessment.
c. Assessment of the responsible factors for the groundwater contamination and their effect on the society.

2. Overview of the Study Area

Gurugram is located in the southernmost region of Haryana and encompasses an area of 1253 km^2 between 28.19º N to 28.53º N Latitude and 76.65º E to 77.23º E Longitude. It consisted five tehsils - Gurgaon, Sohna, Pataudi, Farrukh Nagar, and Manesar - and four sub-tehsils - Wazirabad, Badshahpur, Kadipur, and Harsaru.

The district has a high population density of 1241 people per km^2, which is nearly three times the national average. Average elevation of the Gurugram is 217 m above mean sea level (MSL).

The region lies over a hard rock aquifer, mostly consisting of quaternary alluvium made up of sand, silt, and clay, and experiences unconfined and semi-confined aquifer conditions (CGWB). The groundwater level in the region varies between 45–90 m bgl (CGWB). The groundwater in the region is primarily alkaline, with dominance over alkaline earth materials. The study area is primarily composed of cropland (~ 40%) and built-up land (~ 33%) with the remaining area occupied by water bodies, trees, bare ground, rangeland, and flooded vegetation. The climate in Gurugram is hot semi-arid with spring, summer, autumn, and winter seasons. The annual rainfall in the Gurugram district is 596 mm (CGWB). Figure 1 represents the map of the study area.

3. Methodology

Overall methodological flowchart of this current study is shown in Fig. 2. The entire process is broken down into three stages. The first stage involves collecting and analyzing water samples from the study area. The second stage consists of gathering secondary reports on water quality. The final and third stage entails performing geostatistical analysis and creating a map that reflects the final drinking water quality based on both the traditional and Fuzzy-GIS based Ground Water Quality Index.

3.1 Sampling and Analysis of the Groundwater:

In June 2022, during the pre-monsoon season, groundwater samples were gathered from several villages situated within the Gurugram district. The samples were collected from 25 distinct locations, as illustrated in Fig. 1.

The samples were stored in pretreated 250ml capacity polyethylene bottles at 4°C until analysis. The pH of the samples was measured using a pH/°C meter (EUTECH Instruments). The concentration of Sulphate ($SO_4^{-2)}$ was assessed by the turbidimetric procedure (Chesnin & Yien, 1950) with the aid of a Spectrophotometer (DR 5000). Sodium (Na^+) and Potassium (K^+) concentrations were determined using Systronics Flame-photometer-128. The Fluoride (F^-) concentration in the water sample was evaluated using a 'Fluoride Testing Kit' based on the color change. Chloride (Cl^-) concentration was assessed through Argentometric titration and the Calcium (Ca^{+2}) concentration was determined by the EDTA titration method. The Total Dissolved Solids (TDS) was estimated using Systronics Conductivity Meter 306 and was calculated based on the electrical conductivity (EC) of the samples. A secondary report on water quality was obtained from the Public Health Engineering Department, Gurugram, for 70 different locations. Figure 3**(a)** and Fig. 3**(b)** are the few snaps of groundwater field sampling and lab testing.

3.2 Groundwater Quality Index Development:

The drinking water quality in the study region was evaluated through the creation of a hybrid water quality framework, consisting of the traditional Geographic Information System (GIS) based Groundwater Quality Index (GWQI) and the Fuzzy-GIS based Groundwater Quality Index (FGQI). The process of assessment was divided into three stages, including geostatistical analysis of the water samples, the establishment of GWQI, and the formation of FGQI.

3.2.1 Geostatistical Analysis of the Water Quality Parameters:

The initial step in developing the Water Quality Index (WQI) is the geostatistical analysis of the point data, specifically the spatial interpolation of the data. This is crucial in understanding the spatial distribution pattern of the data throughout the study region and sets the foundation for the subsequent stages of the WQI model development process. Since it is not possible to collect the field data for each and every point of the study area hence spatial interpolation techniques are widely used in this regard for the determination of the value at unknown point on the basis of known point. Inverse Distance Weighting (IDW), Kriging and Co-Kriging are popularly used interpolation techniques among various techniques. IDW is an example of the deterministic interpolation technique (Jha, M.K. et.al., 2020). It is used to determine the value of unsampled point on the basis of its closeness to sampled points. The geostatistical interpolation technique known as Kriging utilizes spatial statistics to estimate the value at an unoccupied point based on the values at known points. Co-Kriging, on the other hand, is an extension of Kriging and incorporates the use of an auxiliary variable that has a strong correlation with the primary variable to improve the Kriging prediction. For the spatial interpolation, Kriging/Co-Kriging is preferred over IDW in the case of near normal distribution of data (Kerry and Oliver, 2007a) and having no any extreme values (Kerry and Oliver, 2007b). In this study, the normality test was performed using SPSS, which indicated that except for pH, all the parameters were not normally distributed. As a result, Kriging was used to interpolate pH, while Inverse Distance Weighting (IDW) was used to interpolate the remaining parameters.

3.2.2 Development of the Traditional GIS based GWQI:

Preparation of Concentration Index:

Concentration Index (CI) is necessary to prepare for relating each pixel of the water quality data with standard WHO and BIS norms. Concentrations of the GWQ parameter and their respective threshold values for each parameter is mentioned in **Table. 1. Eq. (1)** is used for the calculation of the CI for each parameter.

$\mathrm{Concentration Index}\,(\mathrm{CI}) = \frac{\mathrm{P-T}}{\mathrm{P+T}}$ **Eq. (1)**

Where, ‘P’ represents the concentration of each parameter and their respective threshold value is represented by ‘T’. CI for each parameter is varying between (-1) and 1.

Table 1
Concentration and threshold limit of the water quality parameter.

SN	Parameter	Concentration			Desirable Limit (mg/L)	Permissible Limit (mg/L)	Source
		Min (mg/L)	Max (mg/L)	Mean (mg/L)			
1.	TDS*	181.312	6639.564	1219.682	500	2000	BIS 10500 :2012
2.	Calcium	6.509	579.757	61.807	75	200	BIS 10500 :2012
3.	Chloride*	1.708	2848.864	252.032	200	600	WHO
4.	Sulphate	0.524	404.833	44.155	200	400	BIS 10500 :2012
5.	Fluoride	0.101	2.153	0.758	1	1.5	BIS 10500 :2012
6.	pH*	7.174	7.630	7.442	6.5	8.5	BIS 10500 :2012
7.	Potassium	1.050	186.785	6.208	10	30	WHO
8.	Sodium*	30.101	911.728	239.387	200	400	WHO
*Critical groundwater quality parameters							

Preparation of the Rank Map

Subsequently, the ranking of each parameter was determined on a scale of 1 to 10 using the CI maps. The lowest rank value was assigned as 1, while the highest was assigned as 10. In the process of creating the rank map, a CI value of -1 was assigned a rank of 1, a CI value of 0 was assigned a rank of 5, and a CI value of 1 was assigned a rank of 10.Rank Map for each parameter was estimated using **Eq. (2)** (Babiker, I.S., 2007).

$$\mathrm{Rank}\,(\mathrm{R}) = 0.5.\mathrm{CI}^2 \times 4.5.\mathrm{CI} + 5$$ **Eq. (2)**

Estimation of Weight:

The rank maps of all parameters were used to assess their individual weight. Parameters that exceeded the threshold value were considered as critical parameters of groundwater quality. Accordingly, TDS, Chloride, pH and Sodium were considered as critical groundwater quality parameters (Table 1). All remaining parameters were treated as the concerned parameter. **Eq. (3)** was used to calculate the weight of all parameter.

$$\mathrm{W} = \begin{cases} mean\,(\mathrm{R}) + 2; ForTheCriticalGroundWaterQualityParameter \\ mean\,(\mathrm{R}); ForotherGroundWaterQualityParameter \end{cases}$$ **Eq. (3)**

Where, W is the weight for each parameter.

Groundwater Quality Index (GWQI) Development:

The Groundwater Quality Index (GWQI) was determined through the averaged linear combination of each parameter. This approach aimed to reduce the subjectivity in assigning weights to each parameter. The GWQI ranges from 1 to 100, where 100 represent a high-water quality index and 1 represents a low water quality index. **Eq. (4)** is used for the calculation of the GWQI.

$$GWQI = 100 - \frac{R_1.W_1 + R_2.W_2 + R_3.W_3.\ldots\ldots\cdots + R_n.W_n}{n}$$ **Eq. (4)**

Where, R_n represents the rank for n^{th} parameter, W_n shows the weight for corresponding parameter and n is the total number of parameters. According to Babiker et.al., 2007, these index values were classified in appropriate class for the generation of the traditional groundwater quality index map.

3.2.3 Development of Fuzzy-GIS based Water Quality Index:

The assessment of the earth system is subject to uncertainty and ambiguity, making it difficult to make precise estimations. (Jha, M.K. et.al., 2020). In such cases, Fuzzy Logic (FL) could be used by the researcher and other concerned stakeholders to persuade the human knowledge and skill for the précised estimation of the natural system (Zadeh, 1965).

Fuzzification of the Water Quality Parameters:

Fuzzification is a necessary step for the transformation of the crisp input into a standard input between 'zero to one' by using appropriate membership function (Aouragh et al., 2017; Zhang et al., 2015). "Membership fuzzy" and "Fuzzy Overlay" available within "Spatial Analyst toolbox" in ArcGIS 10.8 was used for carrying out the complete fuzzy process in this study. Appropriate membership function (MF) was selected on the basis of the basis of two factors, viz. 'midpoint' and 'spread' Mallik, S. et.al., 2020.

The crossover point is determined by the midpoint. Values greater than the midpoint represent the high membership and vice-versa. Furthermore, shape and the character of the transition zone is determined by the spread parameter (Kritikos, T., and Davies, T. 2015). In this study, the selection of parameters and appropriate membership functions (MF) was based on expert knowledge, BIS (Bureau of Indian Standards) and WHO (World Health Organization) standards. The "Small" MF was used to fuzzify all water quality parameters except pH. The purpose of using this MF was to assign higher membership values to smaller input values. The fuzzification of pH was performed using the "Gaussian" MF, in which the membership value decreases as the input deviates in either the positive or negative direction from the midpoint. **Eq. (5)** and **Eq. (6)** represent the formula for the "Small" and "Gaussian" MF (Tafreshi et al., 2018).

$$\mathrm{SmallMF}\,(\mu_{\mathrm{x}}) = \frac{1}{1+\left(\frac{\mathrm{X}}{\mathrm{f}_2}\right)^{\frac{1}{2}}}$$ Eq. (5)

$$GaussianMF\,(\mu_x) = e^{f_1 \times (X - f_2)}$$ Eq. (6)

Here, spread is represented by f_1 and midpoint is represented by f_2.

Fuzzy Overlay and Fuzzy-GIS based Water Quality Index Map:

. Fuzzy overlay techniques were used to overlay all the fuzzified raster. There are five different fuzzy overlay options available in ArcGIS (fuzzy AND, fuzzy OR, fuzzy SUM, fuzzy PRODUCT and fuzzy GAMMA). Minimum value of the sets the fuzzified raster is returned by the fuzzy AND overlay function. This technique is used for identification of the least common denominator for the membership of all the input criteria. Contrary to fuzzy AND, maximum value of the sets the fuzzified raster is returned by the fuzzy OR overlay function. This is useful to identify the highest membership values for any of the input criteria. The fuzzy value of the cell of set of rasters is added in fuzzy SUM overlay but it doesn't mean that location is more suitable. This overlay option is not often used. Fuzzy value of the cell of each raster is multiplied in fuzzy PRODUCT overlay type. Algebraic product of fuzzy PRODUCT and fuzzy SUM, with the power of gamma, is returned by fuzzy GAMMA operator (Ki and Ray, 2014; Lewis et al., 2014; Mohebbi Tafreshi et al., 2018).

In this study, the best overlay technique among the five was determined by calculating the coefficient of correlation among the fuzzified overlay maps and the traditional water quality index (WQI) map.

This was done using the "Band Collection Statistics" tool, which is available in the spatial analysis tool within ArcGIS. The selected fuzzy overlay raster was then classified into three classes: "unsuitable", "moderate suitable", and "suitable" using the natural break (Jenks) method in ArcGIS.

3.3 Factor Analysis:

The process of exploring how hidden constructs impact responses on a range of measured variables is known as factor analysis. It is a collection of methods employed for this purpose. (DeCoster J., 1998). Correlation pattern (or covariances) between the parameters (observed measure) are examined to perform the factor analysis. Highly correlated parameters are expected to be influenced by the same factors while the uncorrelated ones are expected to be influenced by the different parameter (DeCoster J., 1998). The quality of groundwater can be assessed by utilizing Factor Analysis, a widely applied multivariate statistical technique, which detects the significant parameters that have an impact on it. (Pandey, P. et.al., 2022; Kumar, M.P. et.al., 2020). Furthermore, light is thrown by it for the genetic understanding of the environment. Following procedure is performed for factor analysis. First of all, correlation coefficient matrix for all parameters is prepared. Varimax rotation with Kaiser normalization method is subsequently performed for the transformation of correlation coefficient matrix into diagonal matrix in order to obtain the eigenvalue. The highest Eigenvalue corresponds to factor X, which explains the most variance in the dataset, and the second factor (uncorrelated pairs of elements to the first factor) explains the majority of the remaining variance. In current study, all the eight water quality parameters were analyzed using factor analysis in SPSS v 26. By considering the eigen value (> 1), 3 factors were extracted. Table 2 represent the data of factor analysis and **Fig. 7**represent the scree plot. Correlation matrix for each parameter is given in the **ST1** in supplementary data.

4. Result

4.1 Spatial Variability of the Hydro geochemical Groundwater Quality Parameter:

Concentration maps for all the eight parameters were prepared using spatial interpolation techniques are shown in Fig. 4. The classification of the concentration map into three classes, namely suitable, moderately suitable, and unsuitable, is based on the desirable and permissible limits of water quality parameters shown in Table 1. The limits presented in the table are in accordance with the standards set by WHO and BIS. Figure 4 indicates that SO_4^{-2} and K^+ are safer parameters since they fall within the suitable limit in most parts of Gurugram. The majority of the groundwater in the district has a moderate level of pH and TDS. However, the remaining water quality parameters, namely Na^+, F^-, Cl^- and Ca^{+2}, exhibit varying levels of suitability from suitable to unsuitable in the study area during the pre-monsoon season.

4.2 Traditional Water Quality Index:

Traditional GIS-based Water Quality Index (GWQI) of the research area is depicted in Fig. 5 **(a).** Values of the GWQI for pre-monsoon are varying between 61.07 to 82.03 with mean value 74.15. As mentioned earlier, this map was classified into three classes viz. suitable, moderate suitable and unsuitable according to natural breaks (Jenks). Majority of the groundwater of the Sohna tehsil is moderate to not suitable for drinking purpose. Groundwater of the eastern part of the Gurugram tehsil is suitable while as in the case of western Gurugram, it is moderately suitable in terms of drinking purpose. Bajghera is the only village of the Gurugram tehsil which has entirely unsuitable groundwater. The groundwater of the Farrukhnagar tehsil varies in terms of suitability for drinking purposes. The western part of the tehsil has unsuitable groundwater, while the eastern part has suitable groundwater. Additionally, there are a few patches of moderate suitable groundwater present in the central Farrukhnagar tehsil. Majority of the groundwater of Pataudi is moderately suitable for the drinking purpose while its westernmost section has unsuitable drinking water.

Majority of the groundwater of Manesar, Wazirabad, and Badshahpur is found suitable for the drinking purpose in this study. Similarly, most of the groundwater in the Kadipur and Harsaru sub-tehsil falls under the suitable to moderately suitable category for drinking purposes.

4.3 Fuzzy-GIS based Groundwater Quality Index:

As mentioned in the methodology section, best fuzzy overlay method for the preparation of Fuzzy-GIS based Groundwater Quality Index (FGWQI) map was selected using the coefficient of correlation method. The Fuzzy-GAMMA overlay method with a gamma value of 0.9 was found to be the most effective method for this purpose. Fuzzy overlay maps by each technique are represented in Fig. 6**(a) and (b).** Figure 5**(b)** depicts the FGWQI map of the study area. FGWQI for the pre-monsoon season is varying between 0.013 to 0.741 with mean value 0.393. Natural break (Jenks) was used for to classify it in three classes viz. suitable, moderate suitable and unsuitable. The FGWQI reveals that, contrary to the GWQI, most of the groundwater in the Gurugram tehsil is unsuitable for drinking. The Sohna tehsil also has a lack of suitable drinking water in its eastern parts, with gradual improvement in water quality towards the west. Most of the groundwater in the Pataudi tehsil is moderately suitable to suitable for drinking, except for a few patches of the westernmost region where the water is unsuitable. In the Farrukhnagar tehsil, the eastern part has good water quality while the western part has an absence of suitable drinking water. The central part of the Farrukhnagar tehsil has moderately suitable drinking water. Most of the groundwater in the Manesar tehsil has suitable drinking water, while the groundwater in the Badshahpur sub-tehsil is suitable to moderately suitable for most parts, with the exception of Behrampur, Tikri, and Islampur villages where groundwater is not suitable for drinking. The FGWQI shows a different trend than the GWQI for the Kadipur sub-tehsil, where the groundwater is delineated as not suitable for drinking. However, the Wazirabad sub-tehsil has moderately to suitable drinking groundwater, and the Harsaru sub-tehsil has mostly moderately suitable to suitable drinking groundwater, similar to the GWQI results.

4.4 Factor Analysis:

The factor analysis in this study identified three factors, as shown in the scree plot (Fig. 7). The first, second, and third factors accounted for 42.694%, 25.197%, and 14.966% of the variance, respectively. Together, these three factors accounted for a cumulative variance of 82.858% (Table 2). The groundwater quality assessment reveals that Chloride, Calcium, and Sulphate have the highest loading on the first factor. The second factor is characterized by the high loading of Fluoride and Sodium, while pH and Potassium are given significant loading by the third factor.

Table 2
Result of the Factor Analysis

Component Matrix			
Parameter	**Component**		
	1	**2**	**3**
TDS	.818	.292	− .380
Calcium	.921	− .283	− .138
Chloride	.950	− .248	− .050
Sulphate	.909	− .317	− .008
Fluoride	.255	.779	− .084
Ph	.366	− .410	.705
Sodium	.472	.648	.146
Potassium	.336	.566	.560
Total	3.416	2.016	1.197
Variance (%)	42.694	25.197	14.966
Cumulative (%)	42.694	67.892	82.858

5. Discussion

Groundwater is the vital source of drinking water thus it plays a crucial role in the survival of the living beings. With the passage of dramatic population growth, global consumption of the freshwater has been increased by six times in the last 100 years (Zhongming, 2021). Groundwater consumption is mostly increased due to increased in industrialization, urbanization and agricultural activities. These are expected to cause serious deterioration of groundwater quality in the near future. As a result of these activities, the concentration of various hydro-geochemical parameters in groundwater is increasing. Once the concentration of these parameters surpasses the permissible limit, it may pose a severe threat to the health of living beings and may lead to serious health concerns.

In current study, concentration of TDS, Na^+, Cl^-, and pH is above the desirable limit in the groundwater. In this section, cause of occurrence and impact of these four parameters is briefly described. Excessive sodium in the region is caused by pollution from sewage effluent, leachate from landfills, industrial sites, natural brackish water, and contaminated surface water from road salt etc. High levels of sodium in the groundwater can cause health issues such as hypertension, heart disease, and kidney failure etc. Chloride is another anion found abundantly in the groundwater of Sohna and Farrukhnagar tehsil. Sources of chloride include weathering of soil, salt-bearing geological formations, and deposition of salt spray etc. Although high levels of chloride are not harmful to human health, it can cause problems such as the weathering of soil and decay of building materials etc. TDS concentration in the study area is more than two times the desirable limit of 500 ppm. The northern part of Gurugram and Kadipur tehsil has particularly high levels of TDS due to the structure of the aquifer in the area and excessive groundwater extraction. High levels of TDS can cause health issues such as nausea, lung irritation, rashes, and vomiting. The pH of the groundwater is within a moderate suitable limit of 6.5–8.5 throughout the study area. pH is a measurement of the acidity and alkalinity of the water. Natural water is neutral with a pH of 7, but environmental factors can affect pH levels in groundwater. Rapid changes in pH levels can indicate water contamination, which can make it unsafe for drinking. Maintaining a pH of around 7 is necessary to maintain the body's homeostatic neutral state, as higher or lower levels can be harmful to health. Furthermore, result of the factor analysis identified three factors that contribute to the quality of drinking water. The first factor indicates the presence of permanent hardness of the groundwater due to high correlations between Ca^{+2}, Cl^{-}, and $SO_4{}^{-2}$, which can damage piping, boilers, and other pressurized systems. The second factor represents high loading of fluoride in the groundwater, indicating the prevalence of industrial waste in the region. Excess intake of fluoride can cause dental and skeletal fluorosis, arthritis, bone damage, osteoporosis, and muscular damage etc. The third factor represents high loading of pH, which has already been discussed. To remediate the groundwater contamination, Al-Hashimi et al. (2021) discussed various techniques such as pump and treat method, air sparging and soil vapor extraction, and permeable reactive barriers (PRBs). Overall, the groundwater quality is suitable for drinking purpose in the East Farrukhnagar, Northern Sohna, East Patudi, and Manesar, but in the other parts of the district it is moderate or not suitable for drinking. It is suggested that policymakers and stakeholders focus on these areas to ensure a sustainable supply of drinking water.

6. Conclusion

The purpose of this study is to develop the Water Quality Index. In this regard, traditional GIS-based Water Quality Index and Fuzzy-GIS based Water Quality Index were developed to assess groundwater quality for drinking purposes. The study is based on a case study conducted in Gurugram. Pre-monsoonal water samples were collected from selected sites and analyzed in the laboratory. Secondary water samples were obtained from the Public Health Engineering Department. Eight geochemical parameters including Sodium, Potassium, Calcium, Sulphate, Chloride, Fluoride, pH, and TDS were considered for groundwater quality estimation in the study region. Fuzzy logic was used to remove non-linearity/uncertainty in the natural environment system. Initially, geostatistical analysis was carried out to determine the spatial variation of these parameters. The indices (GWQI and FGQI) were developed based on the standards set by the World Health Organization (WHO, 2004) and Bureau of Indian Standards (BIS, 2012). Fuzzy GAMMA operator with GAMMA value 0.9 was found to be the best fuzzy overlay operator compared to other operators. The study compared FGQI and GWQI and concluded that FGQI was more effective and efficient in representing water quality in the region. The FGQI results revealed that most of the groundwater in the central part of Gurugram is suitable for drinking, while groundwater in the extreme northeast, southwest, and west part of Gurugram is not suitable. Groundwater in Gurugram contains high levels of Na^{+}, Cl^{-}, TDS, and pH. Factor analysis using PCA indicated that groundwater in Gurugram is mainly deteriorated due to leaching from industries and landfill sites, agricultural activities, and subsurface rock interaction. The study was unable to efficiently address the prime cause of excess concentration of these parameters in the study area. It is crucial to prevent aquifer/surface water contamination to safeguard groundwater and surface water resources and ensure sustainable use and management of available water resources. Further studies could be performed by periodically testing groundwater and surface water samples to assess the origin, impact, and mitigation of excess concentrations in detail. The study suggests applying machine learning models for future prediction of groundwater suitability. The similar approach could also be adopted for the analysis of suitability and vulnerability of land for various purposes.

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Figures

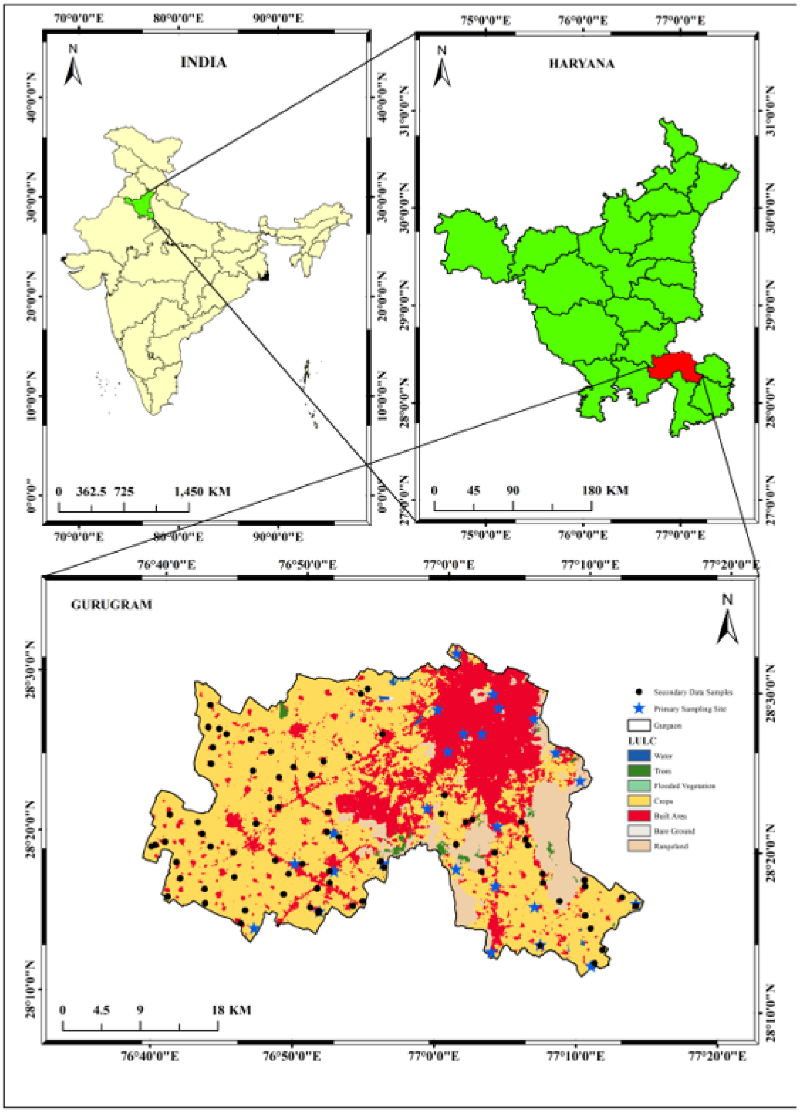


Figure 1

Study Area Map

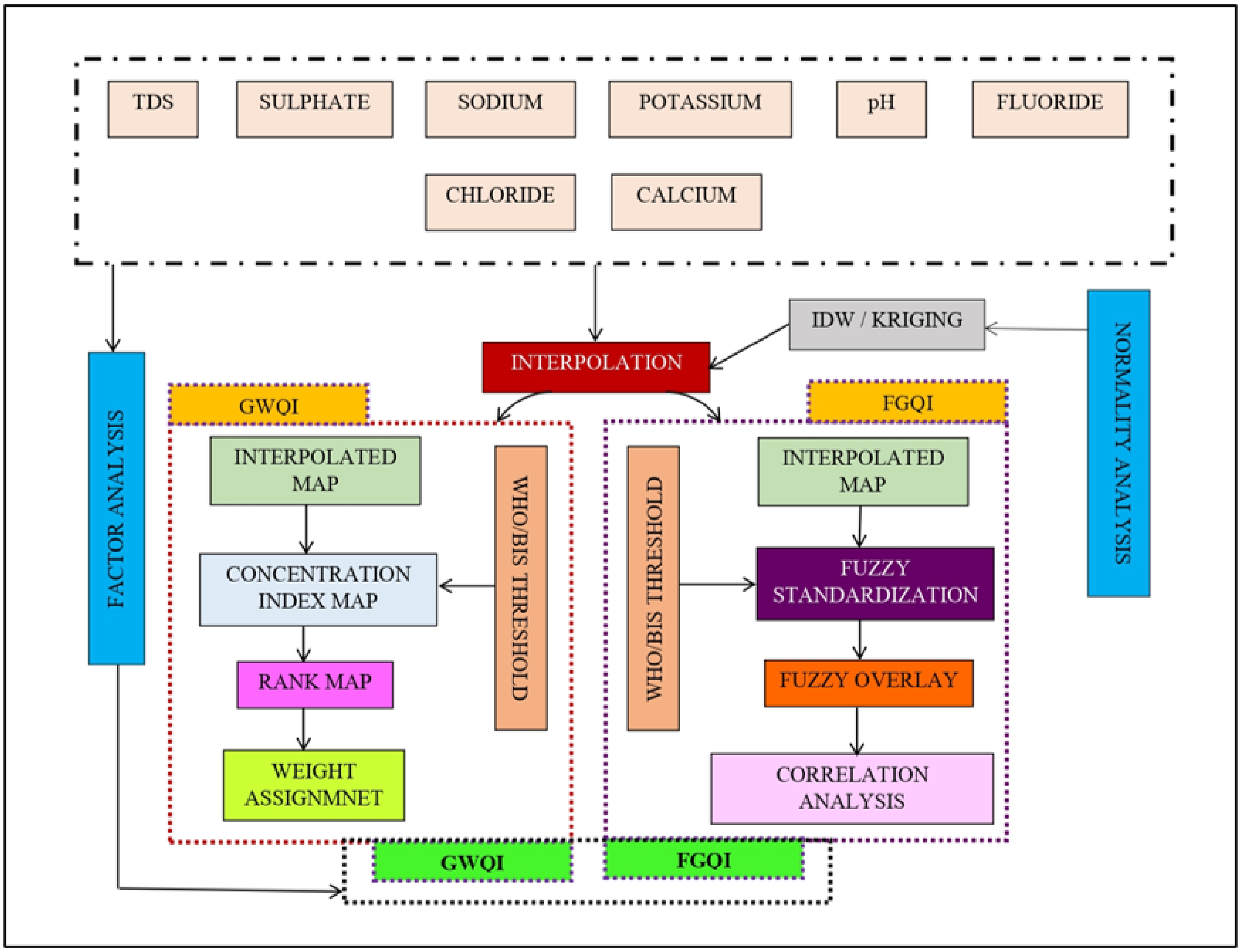


Figure 2

Flowchart of the Methodology

Figure 3

(a): *Groundwater Sampling Sites: Raiseena, Binola and Bohra Kalan (From left to right)*

(b): *Groundwater Testing: Systronics Electrical Conductivity Meter, Systronics Flame-photometer-128 and Spectrophotometer-DR 5000 (From left to right)*

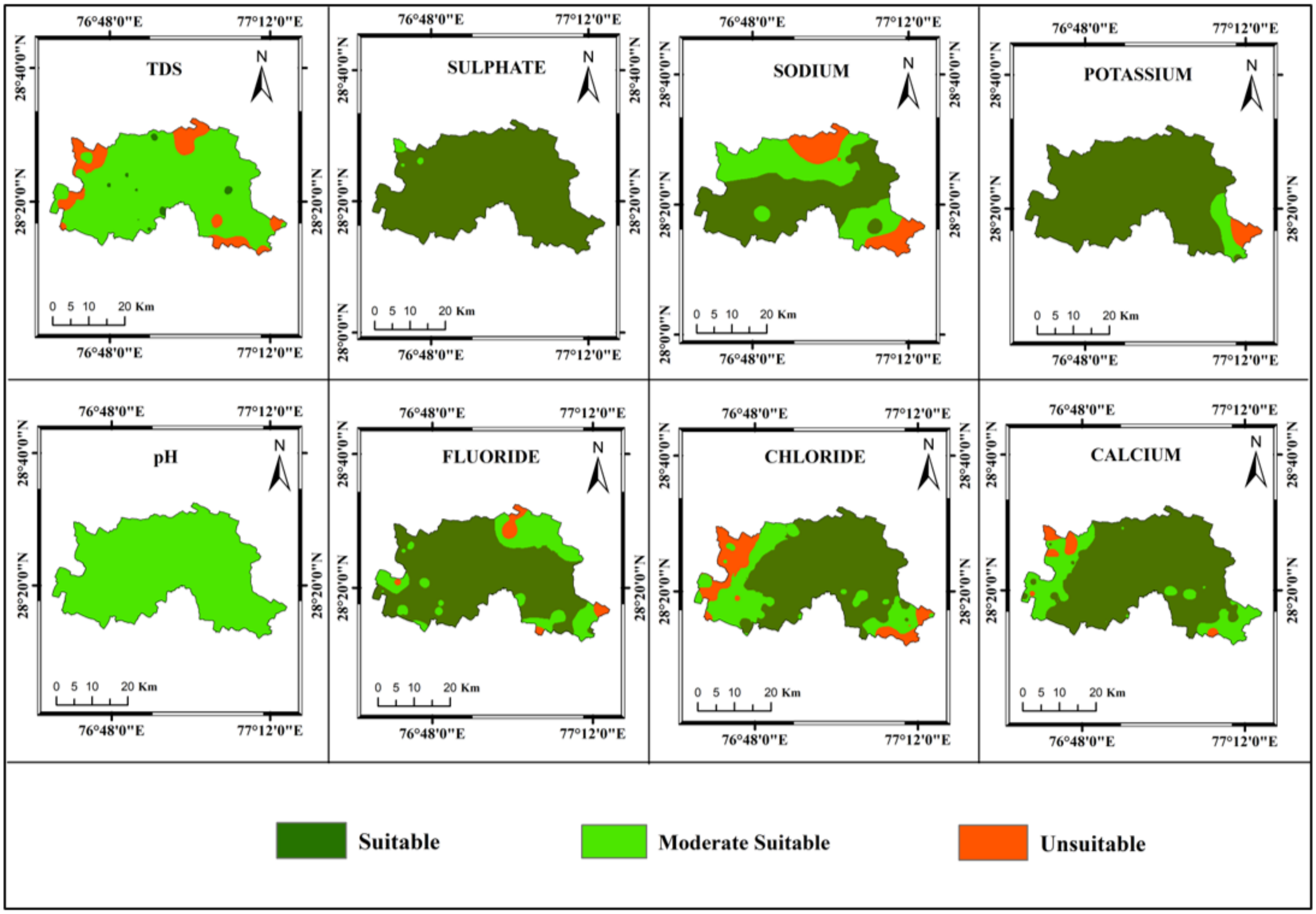


Figure 4

Concentration Maps for the Water Quality Parameter

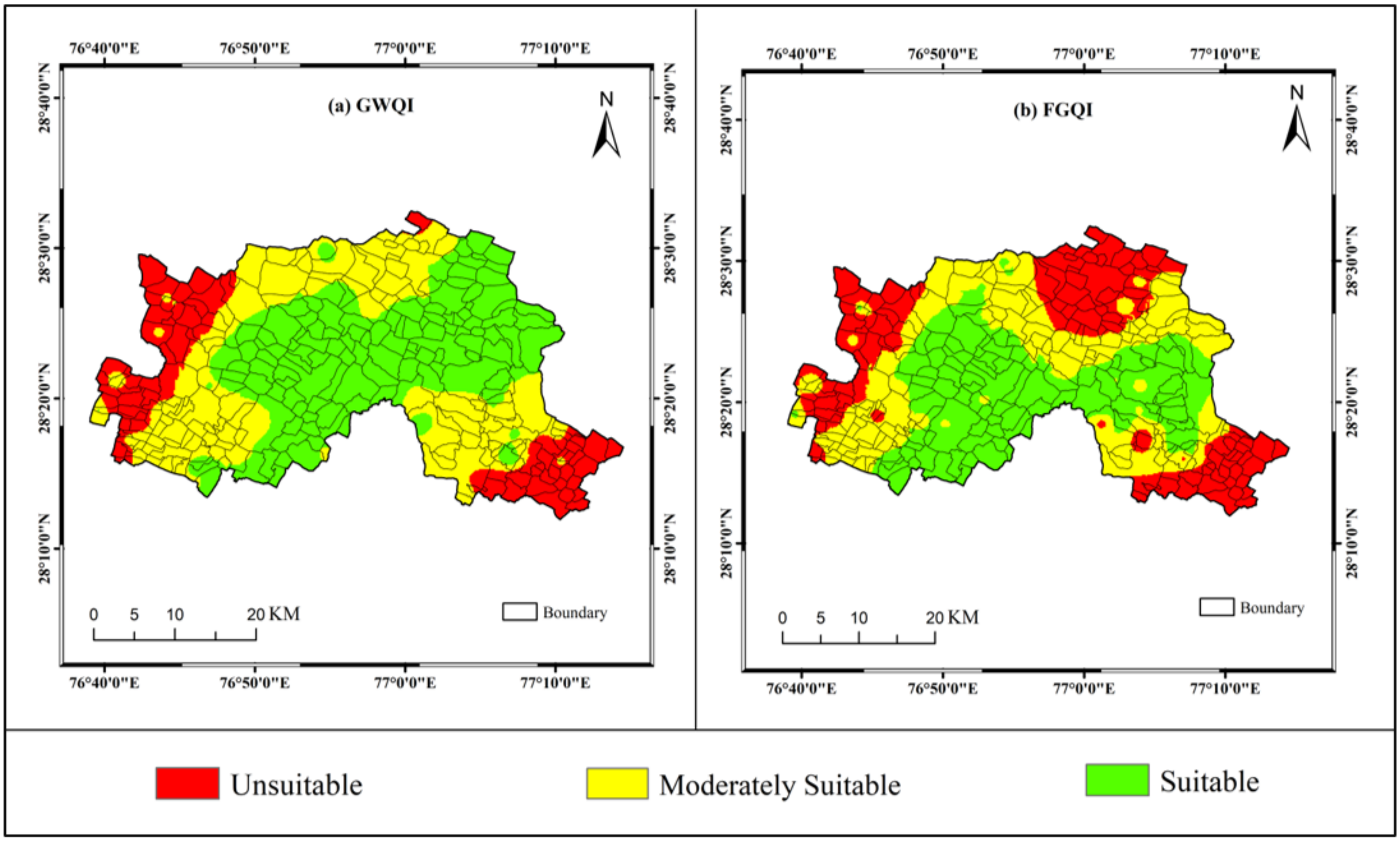
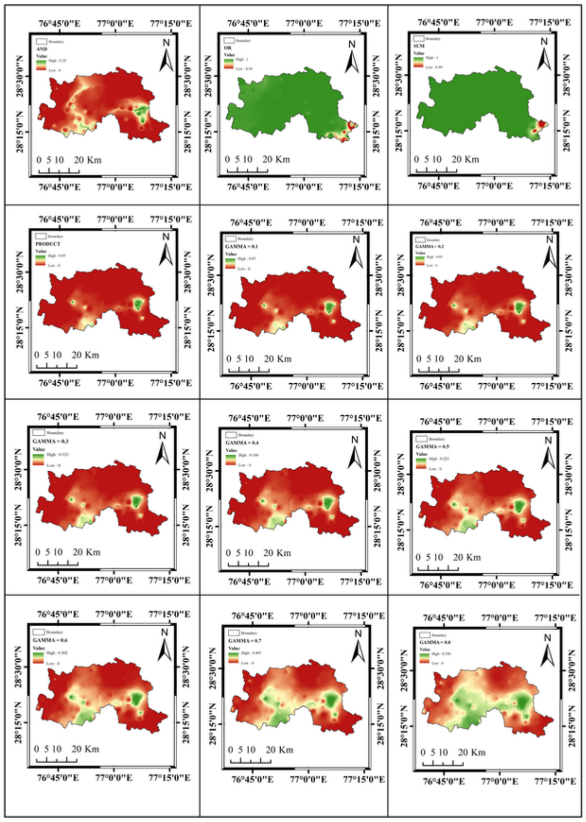


Figure 5

(a). GWQI Map, (b). FGQI Map

a



b

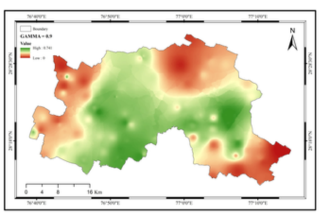


Figure 6

(a). Fuzzy Overlayed Map (Without GAMMA = 0.9)

(b). Fuzzy Overlay Map on the basis of GAMMA = 0.9 (Best overlaying method in this study)

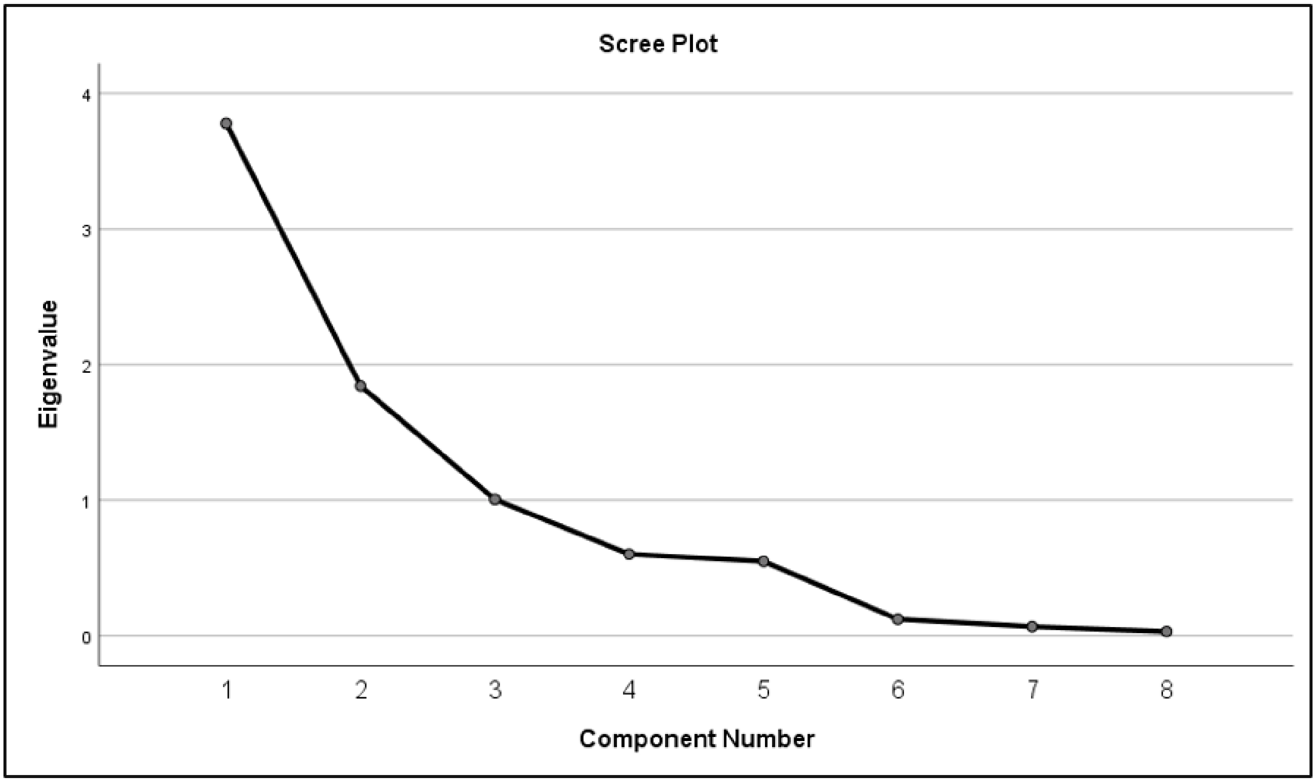


Figure 7

Scree Plot of factor analysis