ORIGINAL ARTICLE

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Geospatial distribution modeling and determining suitability of groundwater quality for irrigation purpose using geospatial methods and water quality index (WQI) in Northern Ethiopia

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Abstract

Determining suitability and vulnerability of groundwater quality for irrigation use is a key alarm and first aid for careful management of groundwater resources to diminish the impacts on irrigation. This study was conducted to determine the overall suitability of groundwater quality for irrigation use and to generate their spatial distribution maps in Elala catchment, Northern Ethiopia. Thirty-nine groundwater samples were collected to analyze and map the water quality variables. Atomic absorption spectrophotometer, ultraviolet spectrophotometer, titration and calculation methods were used for laboratory groundwater quality analysis. Arc GIS, geospatial analysis tools, semivariogram model types and interpolation methods were used to generate geospatial distribution maps. Twelve and eight water quality variables were used to produce weighted overlay and irrigation water quality index models, respectively. Root-mean-square error, mean square error, absolute square error, mean error, root-mean-square standardized error, measured values versus predicted values were used for cross-validation. The overall weighted overlay model result showed that 146 km^2 areas are highly suitable, 135 km^2 moderately suitable and 60 km^2 area unsuitable for irrigation use. The result of irrigation water quality index confirms 10.26% with no restriction, 23.08% with low restriction, 20.51% with moderate restriction, 15.38% with high restriction and 30.76% with the severe restriction for irrigation use. GIS and irrigation water quality index are better methods for irrigation water resources management to achieve a full yield irrigation production to improve food security and to sustain it for a long period, to avoid the possibility of increasing environmental problems for the future generation.

Keywords Elala · GIS · WQI · Maps · Water quality

Introduction

Groundwater is an important issue for successful crop production and to assure food security in developing countries of the world. It is one of the most vital widely geospatially distributed valuable natural resources that play a great role in sustainable green socioeconomic development and environmental protection in the world especially in arid and semi-arid regions of the glove. Groundwater resources are used for various purposes throughout the world that should be continuously determined and investigated (Arslan 2017). Water quality is a term used to describe the physical, chemical and biological parameters of water characteristics concerning its suitability for a particular utilization (Diersing and Nancy 2009). Determining groundwater quality in developing countries has become a critical issue due to surface water scarcity. Groundwater quality and quantity is a dynamic process that has equal importance (Omran et al. 2014). Exercising irrigation action has an important role to elevate irrigation production rate and to meet continuously increasing food demands of the growing population (Alemu and Desta 2017). Irrigation water quality is evaluated by the total amounts of soluble salts and the types of salts present within the irrigation water. Geographic information system (GIS) is a powerful computer-based technology that is used to manage, understand, manipulate, process, integrate, model, identify vulnerable and suitable groundwater zones, analyze and display geospatially groundwater data sets. GIS is a powerful tool to map groundwater vulnerability to solve and determine

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water quality problems, to assess water availability, to prevent flooding and degradation, understanding the natural environment and managing water resources at a local and regional level (Tjandra et al. 2003; Al-Rawabdeh et al. 2014; Hussain et al. 2017). Geostatistics and geographic information systems are commonly employed to determine spatial and temporal distributions of groundwater and soil characteristics (Jasmin and Mallikarjuna 2014). The combination of GIS and geostatistical analysis is becoming an important tool for groundwater studies (Manap et al. 2013). Irrigation groundwater quality index (IWQI) model is also an efficient tool to determine, classify and manage the overall groundwater quality as a single parameter. It measures the quality of water for different purposes by transferring several water variables to give only a single value to determine the overall water quality (Akter et al. 2016; Boateng et al. 2016). WQI is a mathematical model used to convert a lot of water quality variables into a single indicator value which represents the water quality level at a certain location and time (Rabeiy 2017; Boah et al. 2015).

Groundwater quality can be influenced by multiple types of human-induced activities in addition to the geological factors which include by-products from factories, agricultural practices, industrial, municipal activities and residential (Nas and Berktay 2010). The quality of irrigation groundwater honestly affects the physical and chemical structure of the soil which has a significant problem with crop production rate (Simsek and Gunduz 2007). In the present study, irrigation water quality problems are highly increased an evident marked difficult and a key alarm for several stakeholders that affect their irrigation production. This is due to an increasing demand, fast growth of population density, rapid expansion of urbanization, high development of factories and industrial activities as micro- and macroscales, very poor management wastes and watershed management. Groundwater quality problems may have serious influences on soil infiltration and soil structure such as sodicity hazard, soil salinity hazard, bicarbonate hazard, and specific ion toxicity problems that affect growth and irrigation production rate. Poor irrigation water quality may disturb the crop production and soil physical conditions of the catchment. Generally, irrigation groundwater quality problems that affect growth and agricultural production rate are arising from both anthropogenic and geological factors such as residential, municipal, commercial, industrial, agricultural usage and geological sources. Water pollution not only affects the water quality, but also affects the human health, economic development and social prosperity (Milovanovic 2007). Irrigation with poor quality waters may bring undesirable elements to the soil in excessive quantities affecting its fertility (Nishanthiny et al. 2010). Studying groundwater quality based on GIS and WQI is one of the most key issues for sustainable green socioeconomic development, to understand groundwater

quality vulnerability and to obtain reliable information about the current status of water quality over the catchment and that may also help to support as input source of data for the growth and transformation plan (GTP II) of Ethiopia.

The current study has been conducted (1) to determine groundwater quality for irrigation use by considering the physicochemical groundwater quality variables such as EC, pH, TDS, SAR, RSC, % Na, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^{-1}, HCO_3^{-1}, SO_4^{-2} and CO_3^{-2}; (2) to witness the spatial patterns and temporal trends of the groundwater quality parameters; (3) to evaluate and classify the suitability of irrigation water quality based on irrigation water quality index (IWQI), salinity, sodicity, bicarbonate and specific ion toxicity hazards; and (4) to generate spatial distribution and weighted overlay maps of groundwater quality variables using the application of GIS, geostatistics and WQI techniques.

Methods and materials

Description of the study area

The study was conducted in Northern part of Ethiopia around the Mekelle City (Fig. 1). The area coverage of the catchment is 341 km^2 with shape, and length of the longest river flow path is 131 km length. The UTM geographic location is lined between 13°35′22.2″–13°29′34.0″N latitude and 39°22′36.8″–39°42′33.5″E longitude. The topographic elevation or altitude of the catchment is ranging from 1740 to 2676 m (Fig. 2). In the upper, middle and the lower part of the watershed has been practiced irrigation for a long period of time such as in Semha irrigation land, Hashenge check dam site irrigation land, Elala site irrigation land and Messena site irrigation land. At the middle and upper scenario of the catchment, there is high population density, high expansion of urbanization, deforestation, dispose of wastes, increase in microindustrialization and factories, high agricultural practice.

In this article, the quality of irrigation water is assessed.

During field surveying assessment made on the catchment were identified six major land use types: these are built-up area (residential area), forest land, irrigated land, rainfed crop land or cultivated land, shrub land and water body. Cultivated land constitutes 156.25 km^2 (45.82%) from the total area coverage that covers the largest portion from the identified six major land use types in the study area. Shrub land constitutes 103.15 km^2 (30.24%) which covers the second largest portion from the six major identified land use types in the catchment. Built-up area or residential area constitutes 41.46 km^2 (12.15%) from the total area coverage, and forest land covers 35.15 km^2 (10.30%) of the total area coverage of the catchment. This forest land includes both scattered and densely forested area in the catchment, which is covered
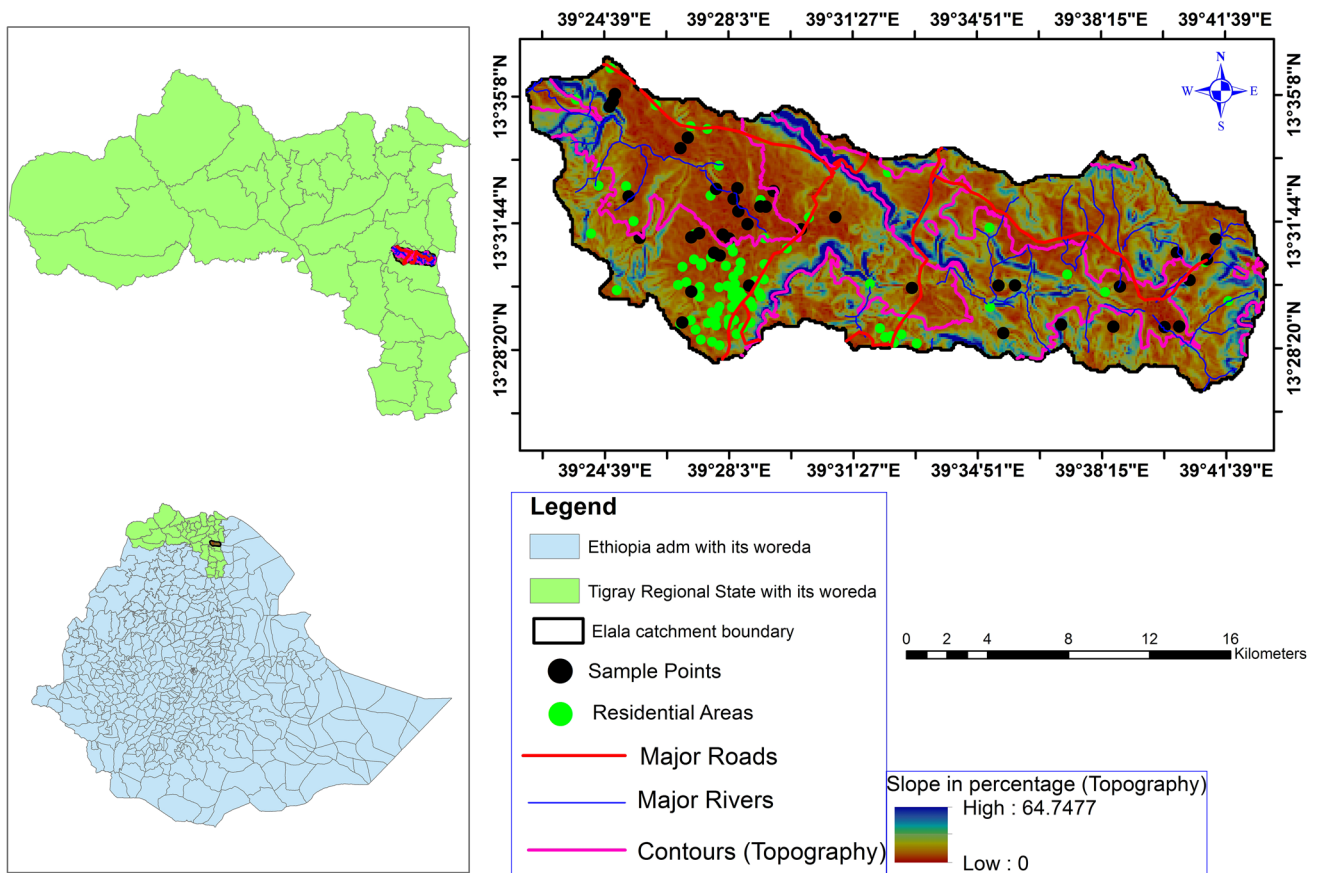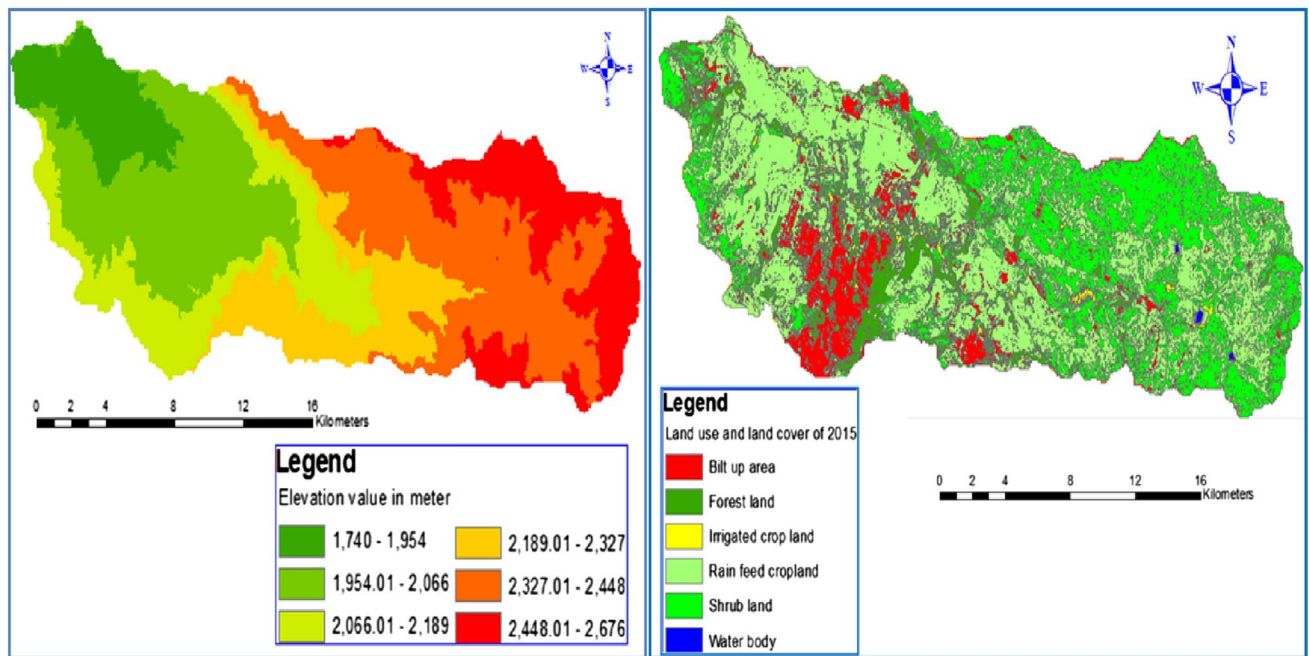
Fig. 1 Location map of the study area

Fig. 2 Land cover and topographic map of the study area

with very scattered acacia trees, eucalyptus trees, cactus and bushes. Irrigated crop land covers 4.67 km^2 (1.36%) of the total area coverage of the catchment. The rest of the land use types cover water body 0.29 km^2 (0.08%) from the total area coverage.

The major agricultural crops and vegetations produced in the area are maize, barely, wheat, sorghum, cabbage, bean, pea, salad, lentil, pepper, garlic, onion, tomato, potato and carrot. From these types of crops, barely is the most salinity-tolerant crop, sorghum and wheat moderately tolerant crops, maize and potato moderately sensitive, and also bean, lentil and pea are most sensitive crops that was easily affect their agricultural yields because of salinity hazards and specific ion toxicity. In the study area, during field observation there were high problems on tomato, potato and maize ask via interviews for the stakeholders which was the reason for this problem. The stakeholders said there is enough amount of water and there is no water scarcity here, but this problem might be because of linking of liquid wastes from liquid waste tanker around here. The analytical laboratory result showed there were salinity hazard, hardness and specific ion toxicity problems that reduced the yield of agricultural production in the catchment.

Figure 2 indicates the land cover and topography of the study area. This is important to understand the topography and land use type and to understand urban and agricultural expansions in the study area.

Groundwater sampling and physicochemical analysis

Thirty-nine groundwater samples were collected from open hand-dug wells, boreholes and spring to investigate groundwater quality for irrigation use during the year 2014–2015 from September to June. The location of each site, the coordinates and its elevation of the sampling location of the water samples were harvested using Garmin handheld GPS receiver ± 5 m or better accuracy. Water samples were collected using 1-l vials or plastic bottles. During field preparation, all the vials had been cleaned first with tap water and then secondly by distill water. Lastly, the vials had been washed by the sample water itself from a water body before sampling. The vials were rinsed thoroughly with the sample water so that the sample was representative of the surface water source. After collecting the water samples, the vials were labeled properly for identification and packed in cooler box and transported to the laboratory for laboratory analysis. Water samples were stored at 4 °C refrigerator cooler until laboratory analysis began. These samples were analyzed in the Geochemistry Analytical Laboratory of Earth Sciences Department at Mekelle University. Groundwater quality parameters used in the examination included potential hydrogen (pH), electrical conductivity (EC), sodium

absorption ratio (SAR), total dissolved solids (TDS), total hardness, percentage sodium (%Na), residual sodium carbonate (RSC); major cations include sodium (Na), potassium (K), magnesium (Mg) and calcium (Ca); and major anions include chloride (Cl), sulfate (SO$_4$), carbonate (CO$_3$) and bicarbonate (HCO$_3$). Atomic absorption spectrophotometer (AAS) method was used to determine major cations, ultraviolet spectrophotometer (UV) method was used to measure major anions, titration method was used to determine for bicarbonate, and other calculation methods were used to analyze the water quality variables. These various water quality parameters were calculated and classified to determine the suitability of irrigation groundwater quality based on the recommendation of Eaton (1950), Ayers and Westcot (1985, 1994, 1999) and Todd and Mays (2005)

$$\text{Percentage sodium (\%Na)} = \frac{(Na + K) \times 100}{(Ca + Mg + Na + K)}. \quad (1)$$

$$\text{Residual sodium carbonate (RSC)} = \left[HCO_3 + CO_3 \right] - \left[Ca + Mg \right]. \quad (2)$$

$$\text{Sodium absorption ratio (SAR)} = \frac{Na}{\frac{\left(\left[Ca + Mg \right] \right)^{0.5}}{2}}. \quad (3)$$

$$\text{Total hardness} = \left[2 \times \left(\frac{Ca}{40} \right) + \left(2 \times \frac{(Mg)}{24} \right) \right] \times 50. \quad (4)$$

The laboratory result reliability checking was done using duplicated method and electroneutrality method

$$\text{Electroneutrality} = \frac{\sum \text{Cations} - \sum \text{Anions}}{\sum \text{Cations} + \sum \text{Anions}} \times 100. \quad (5)$$

Suitability of groundwater quality for irrigation use

Several methods were used to investigate the suitability of groundwater quality for irrigation purpose. During the present study, EC and TDS were used to determine for salinity hazard, SAR and %Na were used to measure for sodicity hazard and RSC for bicarbonate hazard, and Na and Cl were used to determine for specific ion toxicity problems.

GIS and geospatial modeling for groundwater quality

To comprehend the spatial and temporal variation of groundwater quality in irrigation use was done using Arc GIS software v.10.4 and Geospatial Analysis Tool. GIS and geospatial analysis tools, various semivariogram model types including Gaussian, K-Bessel, J-Bessel, circular, spherical, exponential and stable, and different interpolation methods including

kriging, inverse distance weighted (IDW) and spline (RBF) had been used to interpolate the groundwater quality parameters. Weighted overlay model was used to understand the overall suitability of irrigation water quality as a single variable by considering multiple parameters. Twelve different water quality variables were used for the weighted overlay method: EC, pH, TDS, SAR, RSC, %Na, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^{-1} and HCO_3^{-1}. Multi-criteria investigation method was a very helpful method for water quality and suitability analysis because different water quality variables can be incorporated to evaluate the suitability and each variable was classified and weighted according to their % influences values. Log transformations and trend removal were used for data normalization to make the water quality data normally distributed throughout the catchment. If the water quality data by default were symmetrical (i.e., normally distributed), there was no need of log transformation. And also if the data were asymmetrical (i.e., not normally distributed by default), the data need to apply the log transformation and trend removal analysis for each irrigation water quality variables for normal distribution.

Irrigation water quality index (IWQI) model

Irrigation groundwater quality index (IWQI) method provided a good model to determine the overall combined impact of the various water quality parameters for irrigation use as single variable. It is one of the most vital tools to analyze the suitability of groundwater quality and to understand the information about the overall quality of water for irrigation purpose in the catchment. Also, it is an important method to measure and classify the suitability of groundwater quality for irrigation use as single parameter by considering various water quality variables. During the present study, IWQI model was developed by combining the integration of eight water quality parameters: they were SAR, RSC, %Na, EC, pH, TDS, Na and Cl. This water quality parameter was calculated and classified based on some recommendation standards of Meireles et al. (2010) and Hussain et al. (2014). The irrigation water quality index was calculated using the following methods:

$$Qrv = \frac{(Cv)}{(RSv)} \times 100 \tag{6}$$

$$Wcv = \frac{1}{RSv} \tag{7}$$

$$IWQI = \frac{\sum_{1=0}^{n} Wcv \times Qrv}{\sum_{1=0}^{n} Wcv} \tag{8}$$

where Qrv represents the quality rating values, Cv stands for the observed concentration values from laboratory, RSv stands for the recommended standard values of the water

quality variables, Wcv stands for the relative weight coefficient values of the parameters, IWQI represents for water quality index, and n stands for the number of water quality variables. IWQI is a dimensionless parameter ranging from 0 to 100.

Cross-validation methods

Cross-validation was used to determine the best method from the different interpolation techniques (Yao et al. 2014). The root-mean-square error (RMSE), mean error (ME), validation/prediction using Arc GIS interpolation techniques and a comparison between the measured values with the predicted values were used to determine for cross-validation.

The RMSE and ME were calculated based on the following methods

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} \left(Ai - \hat{A}i\right)^2}{N}}. \tag{9}$$

$$ME = \frac{1}{N} \sum_{i=1}^{N} \left(Ai - \hat{A}i\right). \tag{10}$$

where Ai is the measured value, whereas Âi is the predicted value of the variables and N is the number of observations.

Result and discussion

The overall summary of the descriptive statistical analysis results of water samples of the catchment is shown in Table 1.

Table 1 shows the overall descriptive statistics of irrigation groundwater quality variables. The physical and chemical compositions of irrigation groundwater variables including statistical measures such as the maximum concentration, minimum concentration and average concentration are given in Table 1. The chemical composition of the groundwater samples ($N = 39$) in the study district shows a wide range. Electrical conductivity (EC) in the groundwater samples of the study region has been varied from 467.00 to 3058.00 µS/cm (microSiemens per centimeter) with an average value of 1370.51 µS/cm. The total dissolved solids (TDS) ranged from 312.89 to 2048.86 mg/l (mg per l) with average value of 918.24 mg/l. The pH concentration of irrigation groundwater samples in the study district varies from 5.68 to 8.64 with an average value of 7.556, which indicates that the dissolved carbonates are predominantly in the HCO_3, indicating alkaline nature of the groundwater samples.

The major cations of the ground water samples of the study region were in the order of $Ca^{2+} > Na^+ > Mg^{2+} > K^+$.

Table 1 Descriptive statistical analysis result of water samples ($N = 39$)

Water quality variables	N	Minimum	Maximum	Mean
Descriptive statistics				
pH	39	5.68	8.64	7.55
EC	39	467	3058	1370.51
TDS	39	312.89	2048.86	918.24
Hardness	39	193.42	661.67	397.91
% Na	39	12.59	40.92	24.27
RSC	39	−1.2	2.41	1.37
SAR	39	4.08	16.70	7.82
Na^+	39	26.4	128.8	50.26
K^+	39	2.1	5.8	3.19
Ca^{2+}	39	56	226	135.08
Mg^{2+}	39	21	66.8	35.21
Cl^-	39	29	155	54.39
SO_4^{2-}	39	22	98	40.01
CO_3^{2-}	39	1	4	2.30
HCO_3^-	39	127	397	264.36

Among cations, calcium was the most dominant cation in irrigation groundwater samples of the catchment and its concentration varies from 56 to 226 mg/l with average mean value of 135.08 mg/l. The dominance of the major anions in the study district of groundwater samples was in the following order of $HCO_3^- > Cl^- > SO_4^{2-} > CO_3^2$. Among anions, bicarbonate was the most dominant anion in irrigation groundwater samples of the catchment and its concentration varies from 127.01 to 397 mg/l with average mean value of 264.4 mg/l. All units for minimum, maximum and average concentration in Table 1 are in mg/l except EC in µS/cm, %Na in %, pH, SAR and RSC are with no unit. The abbreviation of µS/cm indicates for microSeimens per centimeter, whereas mg/l represents for mg per l and also % indicates percentage.

A correlation analysis is a method which simply exhibits how well one groundwater variable predicts the other variable. The correlation analysis establishes the relationships between physicochemical characteristics of groundwater samples, which can reveal the origin of solutes and the process that generated the observed groundwater compositions (Hamzaoui-Azaza et al. 2011; Parizi and Samani 2013). The numerical level of the relationships of groundwater physicochemical variables represented by the coefficient of correlation varies between −1 and +1 according to the statistical import of the estimated correlation matrix. A high correlation matrix coefficient close to 1 means a good positive relationship between two groundwater parameters, and its value around zero means no relationship between the two groundwater variables. In general, the results show high correlations between some pairs of groundwater parameters showing if $r > 0.7$ considered as strongly correlated, whereas r value between 0.5 and 0.7 shows moderate correlation (Kumar et al. 2006; Giridharan et al. 2008). A negative coefficient indicates that the considered variables are evolving in opposite directions. During the present study, SPSS version 20.0, the statistical software package, was used to calculate correlation matrix analysis, with the obtained results listed in Table 2.

Table 2 shows the correlation matrix result among the groundwater quality variables of the catchment, and it can be understood that from this correlation matrix EC and TDS, almost 99% have highly correlated each other. EC and TDS have above 90% perfect correlation with Ca, Na, Cl, SO4 and SAR. However, SAR has very small correlation with pH and bicarbonate (HCO3) with the value of 0.1890 and −0.035, respectively. The negative sign in the table correlation matrix of the water samples indicated that there is a very small correlation among them. The strongest significant relationships between the variables were $r > 0.70$, moderately significant relationship between the parameters, r values between 0.5 and 0.7, and $r < 0$

Table 2 Correlation matrix analysis result of the groundwater quality parameters

	pH	EC	TDS	SAR	Na	K	Ca	Mg	Cl	SO4	HCO3
pH	1										
EC	0.2489	1									
TDS	0.2489	0.999	1								
SAR	0.1890	0.993	0.9921	1							
Na	0.033	0.960	0.986	0.925	1						
K	−0.019	0.738	0.870	0.827	0.821	1					
Ca	−0.050	0.934	0.940	0.918	0.951	0.865	1				
Mg	0.020	0.892	0.864	0.876	0.719	0.869	0.928	1			
Cl	0.029	0.982	0.996	0.850	0.930	0.845	0.851	0.800	1		
SO4	0.048	0.934	0.934	0.823	0.918	0.818	0.671	0.716	0.867	1	
HCO3	−0.035	0.036	0.036	0.268	0.306	0.315	0.176	−0.026	0.612	0.413	1

negatively significant correlation among the variables that is insignificant correlation between the groundwater variables.

Suitability of groundwater quality for irrigation use

Classification of irrigation groundwater salinity hazard based on EC and TDS

The quality of groundwater is an important consideration in any assessment of salinity or alkalinity conditions in irrigation lad. Good quality of water that is good soil and water management practices can promote maximum crop yield. The suitability of water for irrigation depends upon salinity and the sodium content in relation to the amounts of calcium and magnesium or SAR (Alagbe 2006). The most influential water quality criterion on crop productivity is the salinity index, which can be computed using the electrical conductivity values (Ravikumar et al. 2011). The salts usually originate from the dissolved minerals in the groundwater or from a high saline water table (Simsek and Gunduz 2007). Crop productivity is highly affected due to salinity hazard when electrical conductivity is > 3 dS/m, and it is good if electrical conductivity is < 0.25 dS/m and also good irrigation water with a TDS value < 450 mg/l, whereas that with greater than 2000 mg/l is unsuitable for agricultural purposes (Westcott and Ayers 1984). If there is an increasing concentration of EC, there is also decreasing water intake by the plant as well as affecting productivity rate. The quality of irrigation water also depends on the quantity of total dissolved solids. If there is high accumulation of total dissolved salts in the plant root zone, salinity hazard happens, which diminishes crop production rate (Jain et al. 2011). This is because of decreasing plant growth rate as a result of decreased water uptake. Classification of groundwater quality for irrigation use based on salinity hazard was done according to the recommendation of Richards (1954), Wilcox (1955), Sadashivaiah et al. (2008) and Balachandar et al. (2010).

The groundwater that used for irrigation all the time contains computable quantities of dissolved substances, which are called salts. The salts existing in the groundwater, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. The most influential water quality guideline on crop productivity is the water salinity hazard measured by electrical conductivity and total dissolved solids (Ahmad et al. 2002). Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts. The primary effect of high EC water on crop productivity is the inability of plant to compete with ions in the soil solution for water leading to physiological drought. The higher the EC, the lesser the water available to plants, even though the soil may appear wet. Since plants can only transpire "pure" water, usable plant water in the soil solution decreases dramatically as EC increases (Kumar et al. 2014).

Table 3 shows water quality classification and recommended settings out of the analyzed water samples in the study area; based on electrical conductivity (EC) result, 17.94% of the water samples have moderately saline water class, 69.23% of the water samples have permissible water class, and 12.82% of the water samples have very high saline water class or unsuitable water classes for irrigation use. The result of TDS showed that 17.94% of the water samples have highly suitable water class, 20.51% of the water samples have moderately suitable water class, 53.84% of the water samples have permissible water class, and 7.69% of the water samples have unsuitable water classes for irrigation use.

Generally, most of the water samples in the catchment based on salinity hazard results had been permissible water class for irrigation use except in GWSN8, GWSN13, GWSN24, GWSN28 and GWSN29 water samples that have been above the desirable limit EC and TDS concentration values and unsuitable for irrigation use especially for these salinity very sensitive crops such as bean, pea lentil and vegetables. This might be because of human intervention factors

Table 3 Groundwater salinity hazard classification based on EC and TDS

Water quality variables	Class value	Water class	Salinity significance
EC (μs/cm)	< 250	Excellent	Low saline water for irrigation use
	250–750	Good	Moderate saline water
	750–2250	Doubtful	High saline water for irrigation use
	> 2250	Unsuitable	Very saline water for irrigation use
TDS (mg/l)	< 450	Excellent	No problem for all crops to grow
	450–750	Good	Moderately saline water
	750–2000	Permissible	High saline water
	> 2000	Unsuitable	Very high saline water

EC, electrical conductivity; TDS, total dissolved solid; μs/cm, microSiemens per centimeter; mg/l, milligram per liter; dS/m, deciSiemens/m

that facilitate to increase its concentration. Similarly, this result report trend analysis has been done in the Bandalamottu lead mining area, Guntur District, Andhra Pradesh, South India by Nagaraju et al. (2014) and a case study of the Tefenni plain (Burdur/Turkey) by Varol and Davraz (2015).

This similarity might be because of similar sample size used, the type of methodology used, and topographic factors, geological factor, similar human-induced activities and climatic factors.

Classification of irrigation groundwater sodium hazard based on SAR and % Na

The excess amount of sodium content in irrigation groundwater samples can affect soil permeability and soil structure that cause sodium hazard and also can decrease irrigation production rate because of reducing available water for plant growth. Irrigation water that has excess amount of sodium may immobilize other nutrient ions, particularly magnesium, calcium and potassium, which can cause shortage of these elements in plants (Sharifi and Safari Sinegani 2012). Classification of groundwater quality for irrigation use based on sodicity hazard was done according to the recommendation of Richards (1954) and Wilcox (1955).

According to Table 4 based on SAR classification, there were 32 groundwater samples classified under excellent water class, seven water samples classified as good water class, whereas based on % Na classification, there were 11 groundwater samples under excellent, 27 water samples classified as good water class and 1 water sample under permissible water class for irrigation use. Sodium adsorption ratio (SAR) is an important parameter for determining the suitability of groundwater quality for irrigation use because it is a measure of alkali/sodium hazard to crops. SAR can

Table 4 Irrigation groundwater quality sodicity hazard classification based on SAR and %Na

Water quality variables	Class	Class value	Water class	Number of water samples
SAR (eqm/l)	S1	<10	Excellent	32
	S2	10–18	Good	7
	S3	18–26	Doubtful	0
	N	>26	Unsuitable	0
%Na	S1	<20	Excellent	11
	S2	20–40	Good	27
	S3	40–60	Permissible	1
	S4	60–80	Doubtful	0
	N	>80	Unsuitable	0

S1, excellent; S2, good; S3, permissible or doubtful; S4, doubtful; *N*, not suitable or unsuitable; eqm/l, mili equivalent per liter; % percentage

indicate the degree to which irrigation water tends to enter into cation exchange reactions in the soil. Sodium replacing adsorbed calcium and magnesium is a hazard as it causes damage to the soil structure owing to dispersion of the clay particles and becomes compact and impervious (Bouderbala 2015).

The result of sodium absorption ratios (SARs) showed that 82.05% of water samples have excellent water class (S1), and 17.94% of water samples were classified under good suitable water class (S2) for irrigation use. Therefore, SAR irrigation water classification result showed that most of the water samples of the catchment fall in excellent suitable water class and accepted for irrigation use according to Richards (1954) and Wilcox (1955) irrigation water quality classification. Similarly, this report trend analysis had been done in Coimbatore District, Tamil Nadu, India, by Balachandar et al. (2010), Bhaskar Rao Kunta watershed, Nalgonda District, India, by Reddy (2013), parts of the Chandauli Varanasi region, Uttar Pradesh, India, by Singh et al. (2015), and Carsamba Plain, Turkey, by Arslan (2017). This similarity might be because of using similar methodology and sample size, similar geologic factor, topographic factor, soil type, human-induced activities, climatic factor and so on.

Sodicity hazard classification, based on %Na result, showed that 28.20% of the water samples have excellent water class, 69.23% of the water samples have good water class, and 2.56% of the water samples have permissible water class for irrigation use. There were no water samples under doubtful and unsuitable water class categories during this study. Regarding percentage sodium classification, most of the water samples in the catchment classified under good suitable water class for irrigation use, but there was no unsuitable water class for irrigation use. Similarly, this result trend analysis had been observed in Jaffna Peninsula in Sri Lanka by Sutharsiny et al. (2012). This similarity might be because of using similar methodology, sample size, geologic factor, soil type, human-induced activities, climatic factor, etc. Also dissimilarly, this report trend analysis had been done in parts of the Chandauli Varanasi region, Uttar Pradesh, India, by Singh et al. (2015). This dissimilar result might be because of using different methods, sample size, climate factor, geology, soil type, dissolution of minerals from lithological composition, and addition of chemical fertilizers.

Classification of groundwater bicarbonate hazard based on residual sodium carbonate (RSC)

Irrigation groundwater having high concentration of bicarbonates, there is a tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. Bicarbonate hazard was analyzed in terms of residual

sodium carbonate (RSC). Irrigation water with residual sodium carbonate (RSC) < 1.25 eqm/l was considered as a suitable water class for irrigation, 1.25–2.50 eqm/l RSC was classified under doubtful water class, and > 2.50 eqm/l RSC was classified as unsuitable water class for irrigation use based on the recommendation of Eaton (1950), Ramesh and Elango (2012) and Arslan (2017). RSC > 2.5 eqm/l leads to salt build up which may hinder the aeration and water movement by clogging the soil pores and lead to degradation of the physical condition of the soil. The RSC result showed that all of the water samples in the study area have < 1.25 RSC for irrigation use that is classified as a good water class for irrigation use without any restriction. In Jaffna Peninsula in Sri Lanka by Sutharsiny et al. (2012) was shown similar result trend analysis in this report. This might be because of similar method used, soil type, topography, climatic factor and sample size.

Irrigation groundwater quality classification based on total hardness

The total hardness result of the water samples ranged from 193.42 to 661.67 mg/l with average mean 397.91 mg/l. Water hardness results indicated that 15.38% of the total water sample was classified suitable for irrational use, whereas about 84.61% was classified as unsuitable water class for irrigation use (Richards 1954).

Irrigation groundwater quality classification based on specific ion toxicity problems

A toxicity problem is different from the salinity and permeability problems, in that toxicity occurs within the crop itself as a result of the uptake and accumulation of certain constituents in the irrigation water. Certain ions like chloride and sodium from water or soil accumulate in sensitive crops to concentrations high enough to cause crop damage and reduced yields. Toxicity normally results when the toxic ions are taken up by the soil water and accumulate in the leaves during water transpiration to an extent that can damage the plant. The usual toxic ions in irrigation water are chloride, sodium and boron. Chloride is one of the most important parameters in evaluating the water quality for irrigation use. High concentration of chloride indicates a higher degree of organic pollution (Yogendra and Puttaiah 2008). Classification of irrigation water based on specific ion toxicity hazard was done according to the recommendation of Ayers and Westcot (1985). The permissible limit of chloride in irrigation water was less than l00 mg/l more suitable for irrigation use and more than 100 mg/l unsuitable for irrigation use as well as severity increased as the concentration increases. The result of chloride was ranging from 29 to 155 mg/l with average mean value 54.39 mg/l. The permissible limit of sodium

in irrigation water was less than 70 mg/l more suitable for irrigation use and more than 70 mg/l unsuitable for irrigation use as well as severity increased as the concentration increased. The result of sodium was ranging from 26.43 to 128.83 mg/l with average mean value 50.3 mg/l.

Geospatial distribution modeling of groundwater quality for irrigation use

The water quality database determined from field survey and laboratory results integrated together changed into Arc GIS platform, and raster datasets were used to produce each thematic map using kriging, inverse distance weighted interpolation (IDW) and spline methods of interpolation to show the spatial distribution map of irrigation water quality. The major cation of the groundwater samples in Elala catchment from the highest to the lowest was $Ca^{2+} > Na^+ > Mg^{2+} > K^+$. Calcium was the most dominant element in Elala catchment, and its concentration varies from 56 to 226 mg/l. The cation concentration of Na^+, Mg^{2+} and K^+ in mg/l ranges between 26.4–128.8, 21–66.8 and 2.1–5.8 mg/l, respectively. The spatial distribution map of the major cations (Fig. 2) showed that their concentration distribution of the major cations increased from eastern to western part of the catchment, especially around Mekelle City there were high concentrations of sodium, potassium and magnesium distribution.

The dominance of the major anion in the study area of groundwater samples in the catchment from the highest to the lowest was $HCO_3^- > Cl^- > SO_4^{2-} > NO3^- > CO_3^2$. It was found that bicarbonate was the most dominant anion in the groundwater samples in the catchment followed by chloride. The anionic concentration of HCO_3^-, Cl^-, SO_4^{2-} and CO_3^{2-} mg/l ranges between 127.0–397.0, 29.0–154.7, 22–97.9 and 1.0–4.0 in mg/l, respectively. The spatial distribution map of the major anion in Elala catchment showed that the major anions concentration distribution increased from the upperpart toward the down part of the catchment. The central part of the catchment with high chloride concentration spatial distribution was also found (Fig. 3).

The spatial distribution map of weighted overlay model result using multi-criteria evaluation of the overall weighted value of the 12 water quality variables: EC, pH, TDS, SAR, RSC, %Na, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^{-1} and HCO_3^{-1}, is indicated in Fig. 4.

The final spatial distribution map of weighted overlay model result showed that 146 km^2 areas are highly suitable for irrigation use, 135 km^2 areas moderately suitable and 60 km^2 area unsuitable for irrigation use. Therefore, the overall weighted 12 water quality parameters of the catchment showed that the highest part of the catchment accounted for 42.8% was excellently suitable for irrigation purpose (Fig. 5).
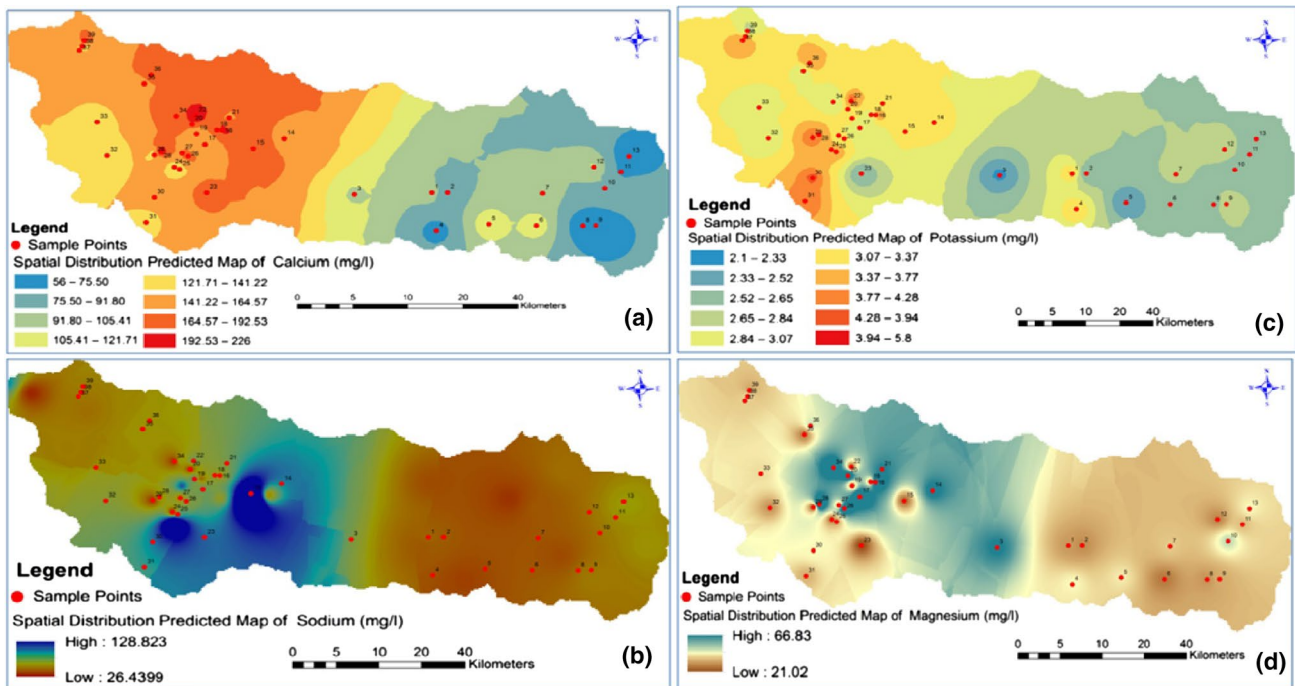
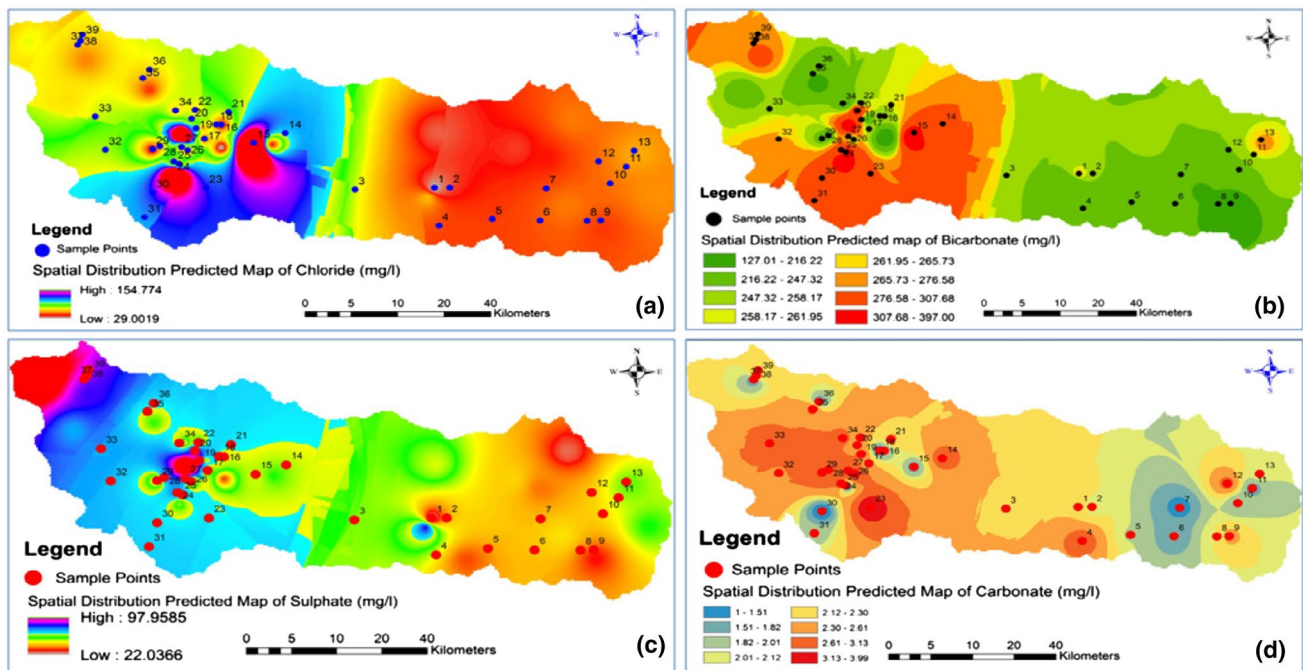**Fig. 3** Spatial distribution map of the major cation

Fig. 4 Spatial distribution map of the major anion

Irrigation water quality index (IWQI) model

Irrigation groundwater quality index classification was done based on each parameter value, according to irrigation water quality parameters proposed by the University Of California Committee Of Consultants—UCCC, and by the criteria established by Ayres and Westcot
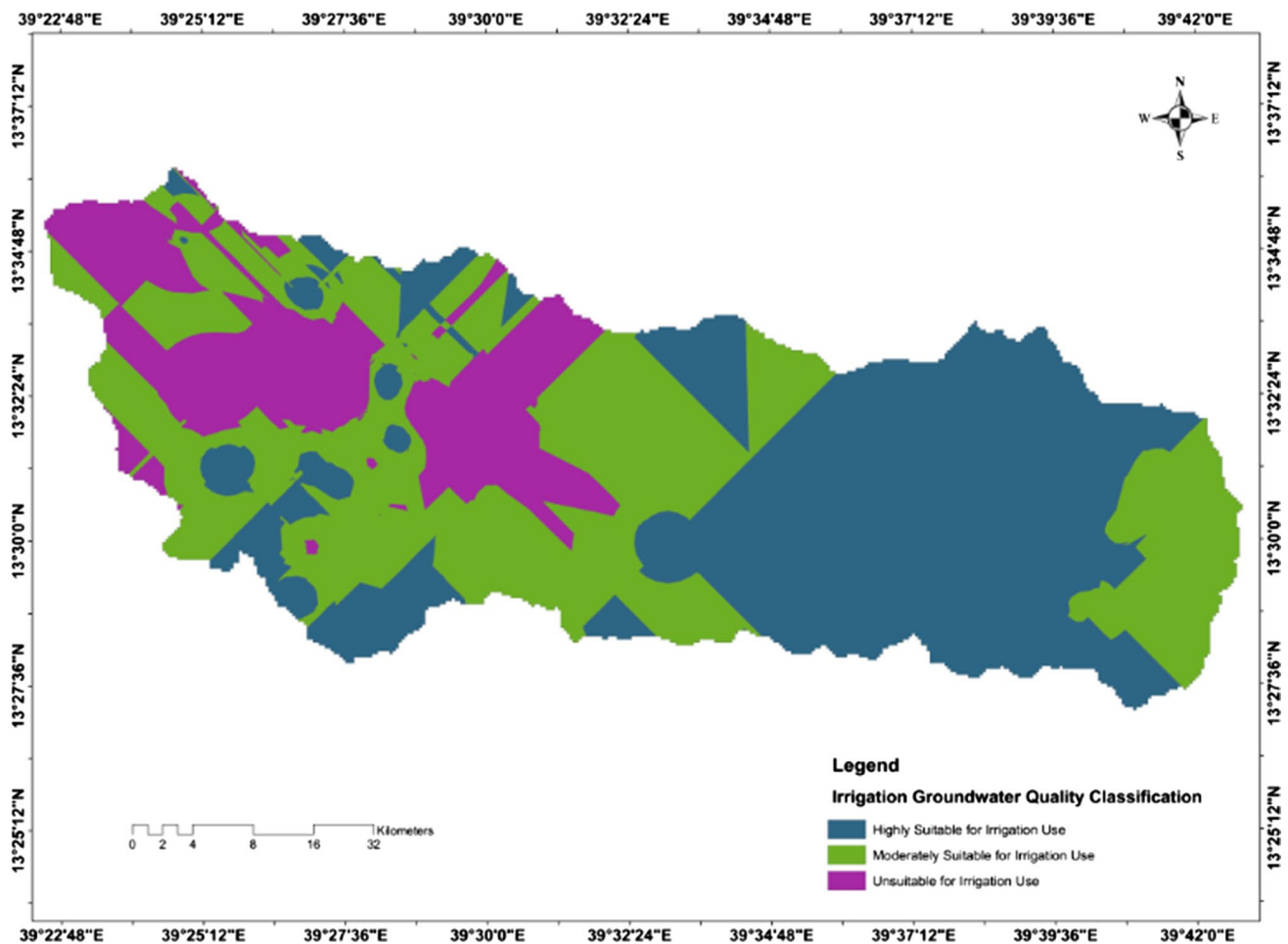
Fig. 5 Irrigation water quality classification based on weighted overlay model

(1999), Meireles et al. (2010), Omran et al. (2014) and Mohamed et al. (2017) as shown in Table 5.

Table 5 shows that recommendation setting of irrigation water quality index (IWQI) ranges from 85 to 100; almost all crops can grow without any risk of toxicity, 70–85 highly sensitive crops might be affected, 55–70 moderate tolerant crops can grow, 40–55 high tolerance crops can grow, and 0–40 this is unsuitable for all most for all crops except only plants with high salt tolerance.

Table 6 shows the calculation of water quality relative weight and quality rating value for irrigation groundwater quality index for sample number 23 (GWSN23), which was taken as an example. The overall calculated result of irrigation water quality index (IWQI) of sample number 23 was

Table 5 Classification of irrigation water quality index (IWQI)

Water quality classes	IWQI values	Restrictions	Recommendation
Plant			
Excellent	(85–100)	No	No risk of toxicity in most plants
Good	(70–85)	Low	Avoid salt sensitive plants
Poor	(55–70)	Moderate	Plants with moderate tolerance to salts may be grown
Very poor	(40–55)	High	Should be used for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na, Cl and HCO$_3$ values
Unsuitable for irrigation use	(0–40)	Severe	Only plants with high salt tolerance, except for waters with extremely low values of Na, Cl and HCO$_3$

Table 6 Water quality relative weight and quality rating values of water sample no. 23

Water quality variables	Unit	Mean measured value	Standard value	Wcv	Qrv	Qrv*Wcv
EC	μs/cm	1370.51	250–2250 1250 (mean)	0.0008	109.640	0.0877126
pH		7.55	6.5–8.5	0.117647	88.8235	10.449821
TDS	mg/l	918.24	500–2000 1250 (mean)	0.0008	73.4592	0.0587673
%Na		24.27	20–80 50 (mean)	0.02	48.54	0.9708
SAR		7.82	10–26 18 (mean)	0.055555	43.4444	2.4135561
RSC	eqm/l	1.37	1.25–2.50 1.875 (mean)	0.533333	73.0666	38.968864
Cl	mg/l	54.39	<100	0.01	54.39	0.5439
Na	mg/l	50.26	<70	0.014285	71.8	1.025663
Σ				0.75242		54.5191

$$\text{GWSN1WQI} = (\Sigma \text{Wcv*Qrv})/\Sigma \text{Wcv} = 54.5191/0.75242 = 72.45833$$

72.46. Based on the IWQI classification level and rating system, the water sample number 23 taken as an example was classified as low restriction water quality for irrigation purpose. The result of irrigation groundwater quality index (IWQI) indicated 10.26% of the water samples with no restriction, 23.08% of the water samples with low restriction, 20.51% of the water samples with moderate restriction, 15.38% of the water samples with high restriction and 30.76% of the water samples with severe restriction for irrigation use (Table 5).

Spatial distribution map of irrigation water quality index (IWQI)

Arc GIS version 10.4 with Geostatistical Analyst Tools Extension was used to produce a spatial distribution map of the irrigation water quality index (IWQI) by weighted overlay model using the integration of eight thematic water quality maps (SAR, RSC, %Na, EC, pH, TDS, Na and Cl).

Computed IWQI values are usually classified into five categories (Table 5): excellent, good, poor, very poor and unsuitable water for agricultural purposes (Omran 2012; Omran et al. 2014; Mohamed et al. 2017). Figure 6 shows the spatial distribution map of irrigation groundwater quality index (IWQI) in Elala catchment. The final result of spatial distribution map of IWQI showed that 82.87 km^2 areas were in the range of no restriction for irrigation purpose, 134.99 km^2 area was low restriction, 71.57 km^2 area was moderately restricted, 40.27 km^2 area was highly restricted, and 10.96 km^2 area was severe restrictions for irrigation use. Hence, the majority of the study area about 39.85% of the total area coverage was with low restriction for irrigation use with respect to IWQI. Finally, districts in the study area with IWQI values of less than 40 are considered to be poor quality irrigation water and are unsuitable water for irrigating agricultural fields; such type of waters could harm soil quality and agricultural yield loss.

Cross-validation and accuracy assessment

Potassium (K) was taken as an example for cross-validation of the water quality variables.

In this research project, the various semivariogram models like Gaussian, K-Bessel, J-Bessel, circular, spherical, exponential and stable were applied to tested for each water quality datasets of the catchment. Prediction performances were determined by cross-validation to determine the accuracy of the generated irrigation groundwater quality surfaces of the study area. Table 7 shows the cross-validation results for K used to determine the validity of the fitting models of the groundwater quality parameters of the catchment. All of the irrigation water quality variables were determined by cross-validation and the K (potassium) variable taken as an example for crossvalidation to represent the groundwater quality parameters of the catchment (Fig. 7). In this case of cross-validation, for K parameter the best-fitting model of semivariogram models is the exponential with a 0.00220342 standardized mean errors for K. The K's standardized mean error via exponential was closest to zero, and RMSSE values were closest to 11.0018. Similarly, this report trend analysis has been done in Darb El-Arbaein, a historic desert track running between Sudan and Egypt and passing El-Kharga Oasis by Omran (2012).

Generally, the types of kriging methods have less estimation error and more precise estimator than IDW and spline (RBF) to generate surface water by comparing their mean error predicted values and their root-mean-square error prediction of the water quality variables. Therefore, this
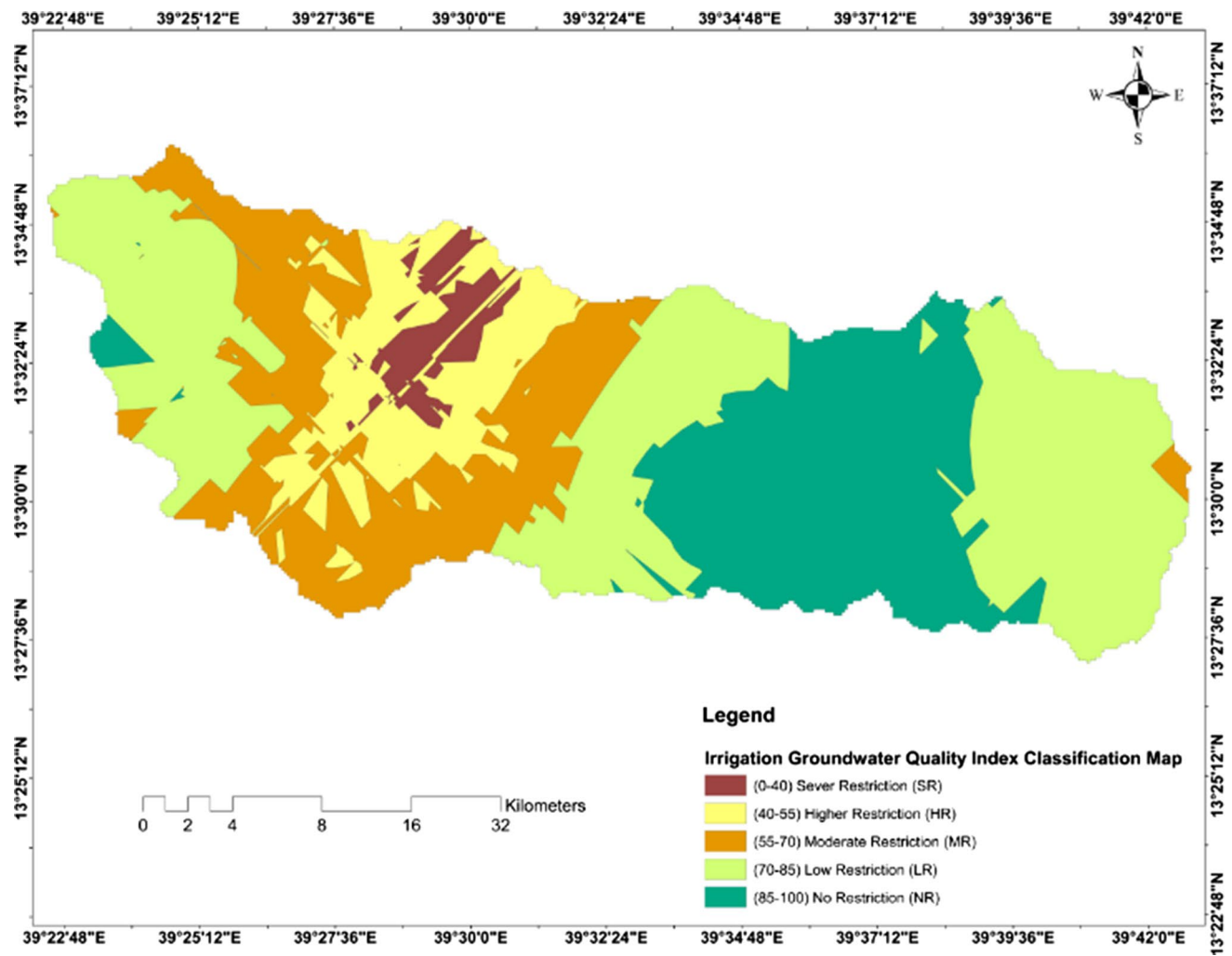
Fig. 6 Spatial distribution map of irrigation water quality index (IWQI)

Table 7 Cross-validation result for potassium parameter

Methods	Model types	Variables	Mean	Root-mean-square	Average standard error	Mean standardized	Root-mean-square standardized
Prediction errors							
Kriging	J-Bessel	K	0.0093	0.4364206	0.427858	0.01484916	1.0059
	Gaussian	K	0.00736	0.4405171	0.428833	0.02329957	1.0177
	Stable	K	0.00736	0.4405171	0.428833	0.02329957	1.0177
	Circular	K	0.01189	0.4439854	0.430302	0.01755856	1.0217
	K-Bessel	K	0.00843	0.4396229	0.429088	0.02121819	1.0159
	Spherical	K	0.01397	0.4392104	0.430829	0.00941298	1.0055
	Exponential	K	0.01724	0.4378526	0.431314	0.00220342	1.0018
IDW	–	K	0.0573	0.4557318	–	–	–
Spline (RBF)	–	K	0.0148	0.4491823	–	–	–

Fig. 7 Correlation result between measured and predicted values of potassium
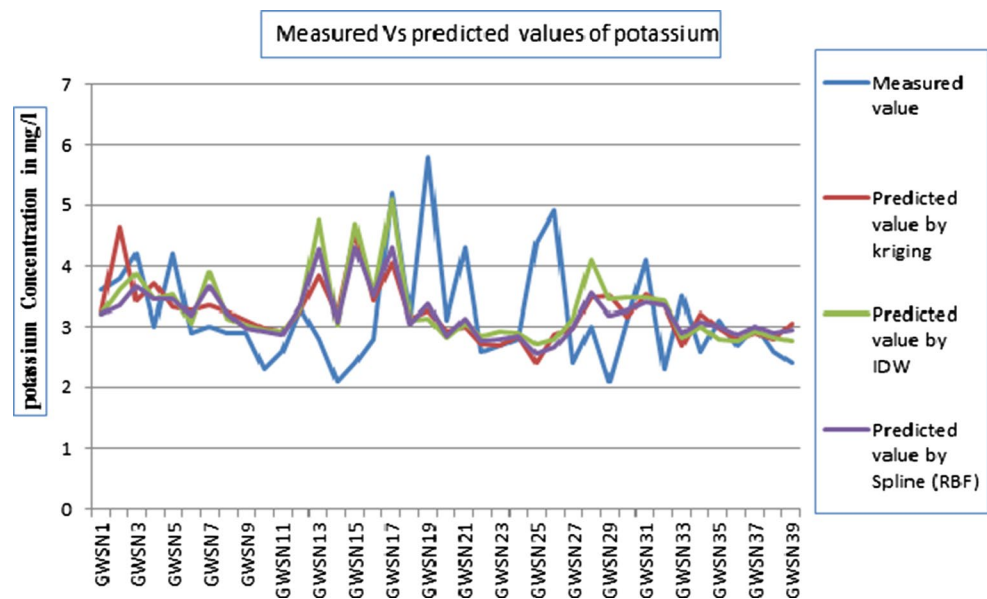
indicates that kriging method was more accurate than IDW and spline interpolation methods to generate surface water quality because kriging considers the spatial structure of the parameters, and it preserves the field value at measurement points as well as it is possible to apply log transformation and trend removal to normalize the datasets in Kriging, but not in IDW and spline (RBF) interpolation method.

The best-fitting model type of semivariogram models of potassium was an exponential model with 0.00220342 standardized mean errors that were closest to zero. Its RMSSE value was also 1.0018 that was close to 1. Kriging methods have less estimation error and more precise estimator than IDW and spline (RBF) to generate surface water by comparing their mean error predicted values and their root-mean-square error prediction of the water quality variables. Therefore, this indicated that kriging method was more accurate than IDW and spline interpolation methods to generate surface water quality because kriging considers the spatial structure of the parameters, and it preserves the field value at measurement points as well as it is possible to apply the log transformation and trend removal to normalize the datasets in kriging, but not in IDW and spline (RBF) interpolation method.

Summary and conclusion

Studying geospatial distribution modeling and determining suitability of groundwater quality for irrigation based on GIS, geospatial analysis tools and irrigation water quality index (IWQI) is one of the most key issues for sustainable green socioeconomic development, to understand groundwater quality vulnerability and to obtain reliable information about the current status of water quality over the catchment and that may also help to support as input sources of data for the growth and transformation plan (GTP II) of Ethiopia because protection of land and water resources are matters of urgent action for agricultural sustainable development, ecologically sensitive construction and sustainable socioeconomic development in the whole country Ethiopia. The overall view of the study confirms that most of the water samples have high pH, salinity hazard, hardness problem and specific ion toxicity hazards, but with no sodicity and bicarbonate hazards. The final spatial distribution maps generated by weighted overlay and IWQI model helps much easier for decision makers, water quality managers, planners, agricultural extensions and researchers in the study area. Therefore, this paper recommends that there must be adequate protection of water resources and environmental protection with a good watershed management system to achieve a full yield irrigation production rate to improve food security and to sustain it for a long period of time, to avoid the possibility of increasing environmental problems in the future generation.

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