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Assessment of Shallow Groundwater Quality in Zhengzhou Area Using Remote Sensing and GIS

Bassam F Al Bassam[1,2]

[1]School of Environmental Studies
China University of Geosciences
Wuhan 430074, China

[2]College of Engineering
Civil Eng. Dept. /Al Mustansirya University
Baghdad, Iraq

Abstract

The quality of groundwater in Zhengzhou area is important as many individuals depend on groundwater for drinking. A study on shallow groundwater quality assessment in Zhengzhou area, China has been done using Remote Sensing and Geographic Information System (GIS) techniques. The land use/cover classification system and remote image interpretation of characteristics were established in this process. Land types were divided into six categories: water resources, forest land, grass land, barren land, Residential areas, and crop land. Water Quality Index was also calculated for sixty three well samples in the study area to evaluate the suitability of water for human consumption. The results show that the grass land is the greatest proportion of land use/cover in the study area (37.59%), the residential area comprises 13.52%, the area of crop land occupies 22.54%, and the barren land occupies 21.81%. Water Quality Index (WQI) values revealed that the groundwater at twelve locations of the study area are Excellent quality. Twenty wells are V. good quality, and fourteen wells are Good quality, therefore can be exploited safely for human consumption. Six well samples are Fair quality, nine samples are Marginal quality, and two samples are Poor (unfit). The correlation of land use/cover with water quality indicate that the extent of water quality deterioration has a positive linear correlation with the total area of residential and crop land and a negative linear correlation with barren land areas. The analysis of the results revealed that Remote Sensing and GIS are effective tools for assessing and quantifying the impact of land use/cover on groundwater quality. Overlaying the spatial distribution of water quality on Satellite imagery is a very authenticated concept to identify the water quality problems and to correlate them with the land use/cover to interpret the reasons for deterioration of environmental quality.

الخلاصة

تعتبر نوعية المياه الجوفية في منطقة جونغ جو مهمة لان الكثير من الافراد يعتمدون عليها كمصدر للشرب. هذه الدراسة هي محاولة لتقييم نوعية المياه الجوفية في منطقة جونغ جو- الصين باستخدام تقنيات التحسس النائي و ونظم المعلومات الجغرافية (GIS) . التصنيف للغطاء الارضي من خلال التفسيرلخصائص صور الاقمار الصناعية تم اعتماده لهذا الغرض. قسمت انواع الغطاء الارضي الى ستة اصناف وهي: مصادر المياه, اراضي الغابات, اراضي الحشائش والاعشاب, الاراضي المكشوفة القاحلة, المناطق السكنية, واراضي المحاصيل الزراعية. تم ايضا حساب قيم معامل نوعية المياه (WQI) لثلاثة وستون نموذج من الابار الضحلة في منطقة الدراسة لتقييم مدى صلاحيتها للاستهلاك البشري. اظهرت النتائج بان النسبة الاكبربالمساحة للغطاء الارضي في منطقة الدراسة هي اراضي الحشائش والاعشاب (37.59%) , المناطق السكنية تشكل (13.52%) , اراضي المحاصيل الزراعية تشكل (22.54%) , والاراضي المكشوفة القاحلة وتشكل (21.81%). اوضحت قيم WQI ان المياه الجوفية في اثنا عشرموقع في منطقة الدراسة كانت ذات نوعية ممتازة, عشرون بئرا ذات نوعية مياه جيده جدا, واربعة عشر بئرا ذات نوعية مياه جيدة ويمكن استعمالها للاستخدام البشري. ستة ابار ذات نوعية مياه مقنعة, تسعة ابار ذات نوعية هامشية, وبئرين ذات نوعية مياه رديئه . اوضحت مقارنة الغطاء الارضي مع نوعية المياه الجوفية ان مدى التدهورفي نوعية المياه يتناسب طرديا مع مجموع مساحات المناطق السكنية ومساحات اراضي المحاصيل الزراعية ويتناسب عكسيا مع مساحات الاراضي المكشوفة القاحلة. اظهر تحليل النتائج ان التحسس النائي و GIS هي ادوات فعالة في تقييم وتخمين تاثير الغطاء الارضي على نوعية المياه الجوفية. من خلال عرض التوزيع المكاني لنوعية المياه الجوفية وصور الاقمار الصناعية سوية باستخدام تقنيات GIS يمكن توثيق وتعيين المشاكل في نوعية المياه الجوفية ومقارنتها مع الغطاء الارضي لتفسيراسباب التدهورفي النظام البيئي.

1. Introduction

The urban environment quality deteriorates day by day with the largest cities reaching saturation points and unable to cope with the increasing pressure on their infrastructure [1]. Groundwater is almost globally important for human consumption as well as for the support of habitat and for maintaining the quality of base flow to rivers. They are usually of excellent quality. Being naturally filtered in their passage through the ground, they are usually clear, colorless, and free from microbial contamination and require minimal treatment. Unfortunately, it seems that we can no longer take high quality groundwater for granted. A threat is now posed by an ever-increasing number of soluble chemicals from urban and industrial activities and from modern agricultural practices. Nevertheless, landslides, fires and other surface processes that increase or decrease infiltration or may expose or blanket rock and soil surface will interact with downward-moving surface water. The chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation, and for industrial and other purposes. The definition of water quality is therefore not objective, but is socially defined depending on the desired use of water. Different uses require different standards of water quality. Therefore, monitoring the quality of water is important because clean water is necessary for human health and the integrity of aquatic ecosystems [2].

The chemistry (quality) of groundwater reflects input from the atmosphere, from soil and water-rock reactions (weathering), as well as from pollutant sources such as mining, land clearance, agriculture, acid precipitation, domestic and industrial wastes. The transport of contaminants from the point of application to the groundwater system is a function of the properties of the soil-rock strata above the aquifer and the type of pollutant [3].

The World Health Organization (WHO), in its Guidelines for Drinking Water Quality, defines domestic water as the "water used for all usual domestic purposes including consumption, bathing and food preparation" [4]. In this contribution this study aims to propose a Groundwater Quality Index (GWQI) which synthesizes different available water quality data into an easily understood format.

GIS can be a powerful tool for developing solutions for water resources problems, assessing water quality, determining water availability, preventing flooding, understanding the natural environment, and managing water resources on a local or regional scale [5]. Keeping this in mind, Remote Sensing and GIS have been integrated for the assessment of the impact of land use/cover on the groundwater quality of Zhengzhou area.

2. Study area

The study area extends between the longitudes 112° 45′ 00″ E-114° 15′ 00″ E and the latitudes 34°10′00″ N-35°00′00″ N. It covers all of Zhengzhou municipality, including Zhengzhou city and its six constituent counties (Figure 1). The total area of Zhengzhou is 7,446.2 Km^2. The climate is a continental monsoon with an average annual temperature of 14.3 ºC. The mean annual precipitation of Zhengzhou is 641 mm. As a whole, the elevation of the study area decreases from southwest to northeast [6].

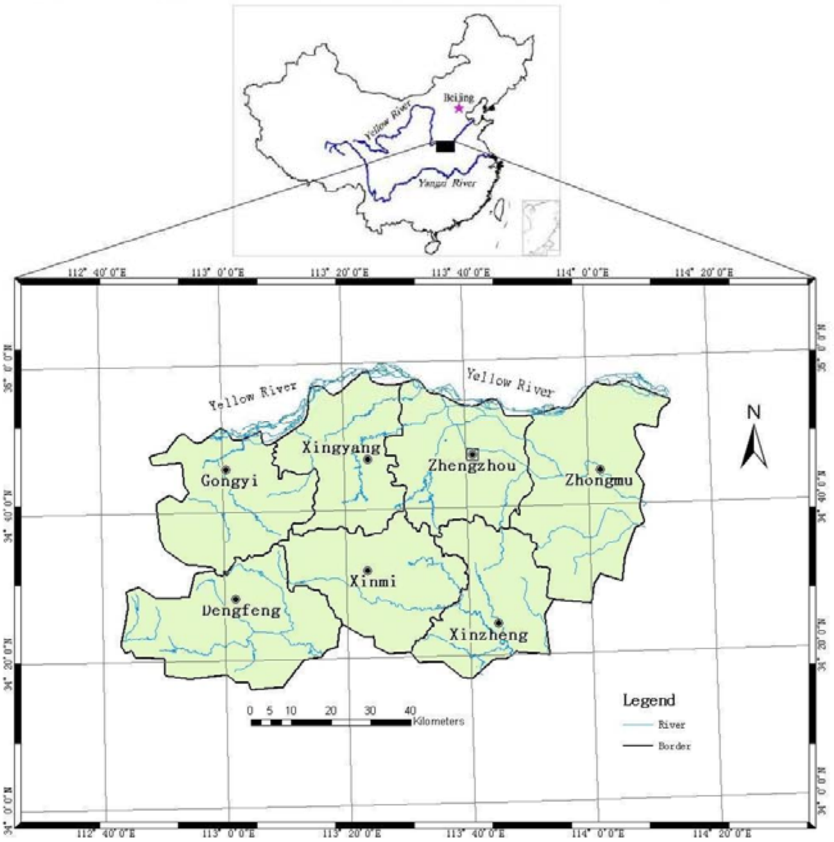

Figure 1. Location map of the study area

3. Materials and Methods

3-1 Remote Sensing Data

Remote Sensing based approaches have been followed in the present study. Landsat 7 Enhanced Thematic Mapper ETM+ image from May 10th, 2006 is utilized. The image processing techniques were implemented through ERDAS IMAGINE software. Enhancement of the remote sensing data has been applied prior to actual analysis to improve the quality of the data. Image restoration involves the correction of distortion, degradation and noise introduced during the imaging process. The radiometric and systematic geometric errors of Landsat ETM+ data have been removed by the commercial data provider, whereas the unsystematic geometric error remains in the image. The geometric errors of the Landsat ETM+ data were corrected using ground control points before the analysis of land cover. The study area which was cut from the two images covers about 7319.64 Km^2. Figure 2 shows the outcome image resulted through a color composite technique.

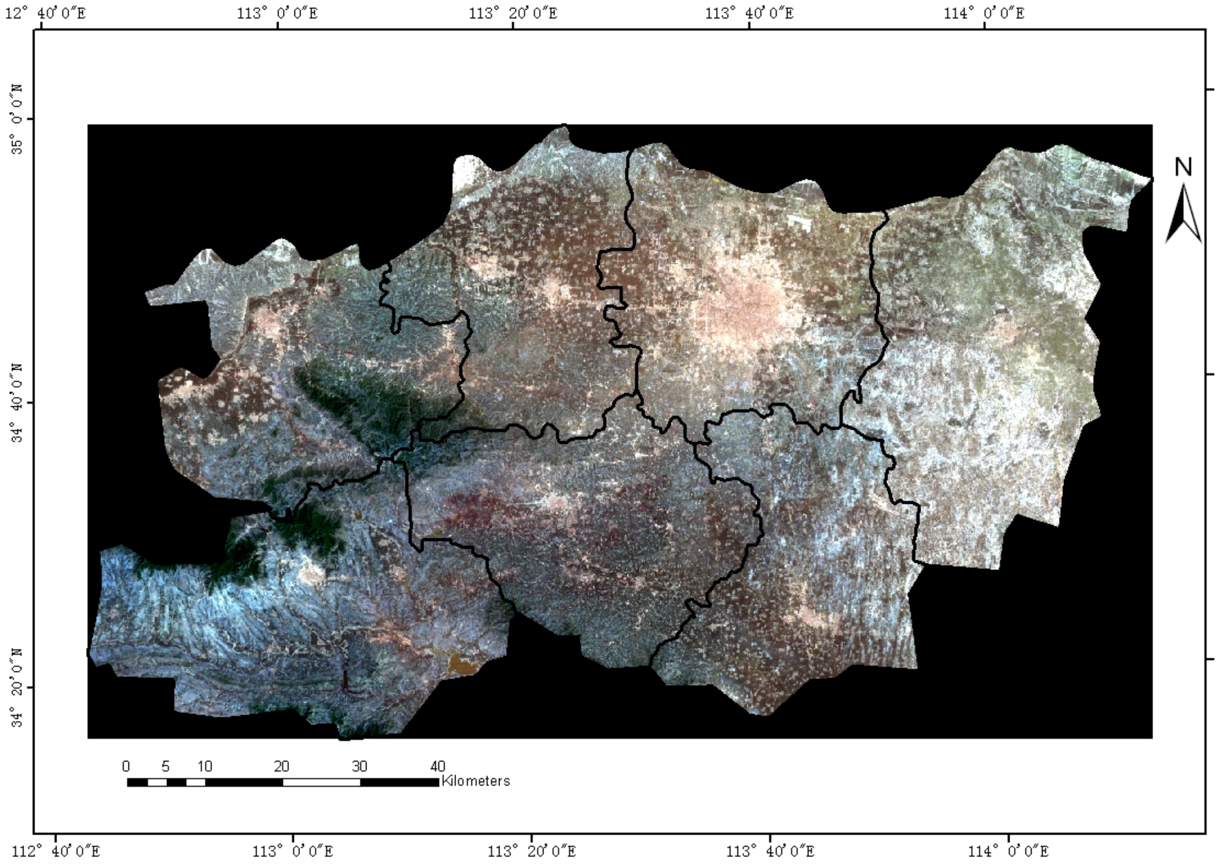

Figure 2. 2001 Color composite image RGB (321) of the study area

3-2 Land Use/Cover Classification

In order to identify the typical attributes of land use/cover types, a laminar extraction technique suggested by Al Bassam, 2007 was applied [7]. Land types were divided into six categories: Water, Forest land, Grass land, Barren land, Residential areas, and Crop land. This methodology allows full consideration of all the target features in order that the combinations of different attributes in a map are avoided.

Many functions have been created to identify each attribute in the image data. This was achieved by comprehensive use of the spectral information acquired by satellites, statistical analysis of the data, and the ground truth information in training data. Different threshold values have been tested for each attribute until the best limits were determined.

Normalized Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI), and Modified Soil-Adjustment Vegetation Index (MSAVI) were tested to detect the vegetation cover in the study area [8]. MSAVI was more effective in identifying the boundaries between the barren lands and the vegetation areas in Zhengzhou. Table 1 shows the functions which are used to extract the different attributes.

Table 1. The reference table for extraction the information of each attribute

Attribute	**Functions**
Water	(TM2+TM3+50−TM4−TM5 >0) AND (TM3 <90) AND (TM5<50) from the raw data
Forest land	(MSAVI*1000 >230) AND (DEM >500)
Crop land	(MSAVI*1000>-300) AND (MSAVI<230) AND (DEM < 200)
Residential area	(TM2>TM5) AND (TM5 >TM7) AND (100>TM7>80) AND (120>TM5>80) AND (80>TM4>60) AND (130>TM3>90) AND (110 >TM2>90) AND (TM1>110) AND (TM4-TM3<15) from raw image
Grass land	(MSAVI*1000>-600) AND (MSAVI<-300) AND (200<DEM <500)
Barren land	(MSAVI*1000>-1000) AND (MSAVI<-600) AND (300 < DEM)

Comment: TM2, TM3, TM4, TM5, TM7 are the spectrum of TM bands in the raw image; DEM=Digital Elevation Model

3-3 Hydrochemical Data Set

Water samples were taken in June 2006 from sixty-three shallow wells located in the study area. These wells were selected to represent water-quality characteristics associated with overlying land use/cover, lithology, and well depth. The depth of all the wells is less than 66 meter. The location of groundwater samples are displayed in Figure 3. The water-quality samples were analyzed at the CUG Water Quality Laboratory in Wuhan, China. Data set includes measurements of several chemical parameters of groundwater obtained by in situ measurements and laboratory analytical techniques. Eight parameters which are listed by Al Bassam et al., 2007 for drinking water quality were selected from the data set to generate the groundwater quality index [9]. Human health takes priority in choosing the standards for drinking water. These parameters (TDS, Total Hardness, Na^{+}, Mg^{2+}, SO_4^{2-}, NO_3-N, Cl^{-}, and pH) fall under the category of chemically derived contaminants that could affect its "acceptability" by consumers. pH were measured in the field. Other chemical parameters (Total Alkalinity, Arsenic, Selenium, Fluoride, Chromium, Barium, Cadmium, Lead, Mercury, Copper, Iron, Manganese, Silver, Zinc, and Nickel) were also determined and their values are within the recommended limits for domestic water quality criteria in all the wells.

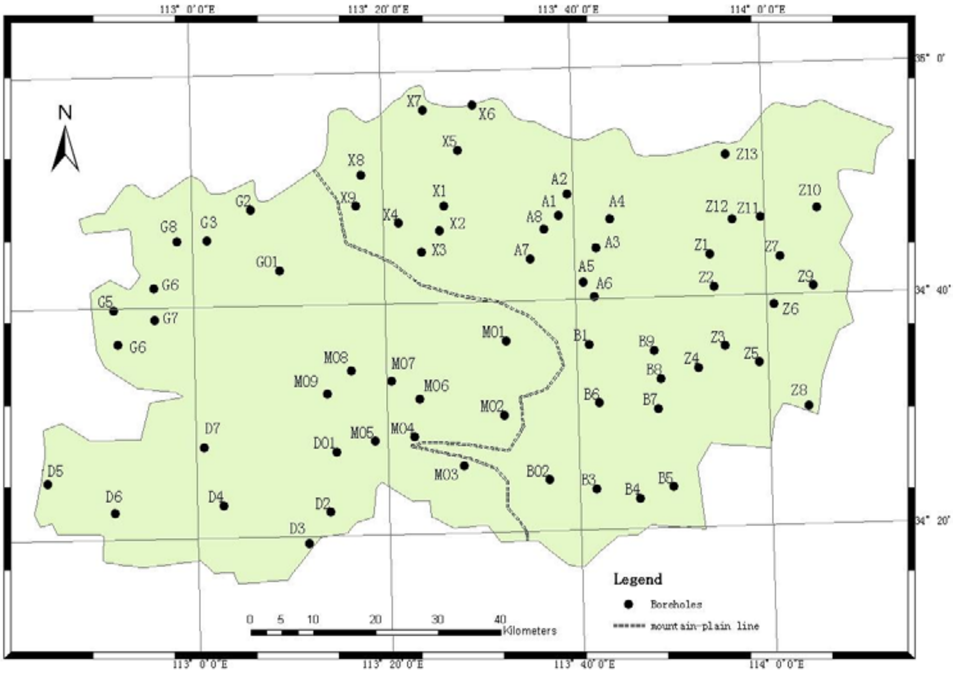

Figure 3. Location map of shallow wells in the study area

3-4 Estimation of Water Quality Index

Bahargava (1983, 1984) introduced the WQI method [10, 11]. This method was adopted because of the simplicity involved in handling small to large data for various beneficial uses. The simplified model for WQI for a beneficial use is given by:

$$WQI=[\prod_{i=1}^{N} Fi(Pi)]^{(1/N)}\times 100 \qquad (1)$$

Where N is the number of variables considered more relevant to domestic use. Fi(pi) is the sensitivity function of the ith variable which includes the effect of weighting of the ith variable for individual use. These values have been taken from figures drawn according to limited values for the variables in the water intended for domestic use (figure 4).

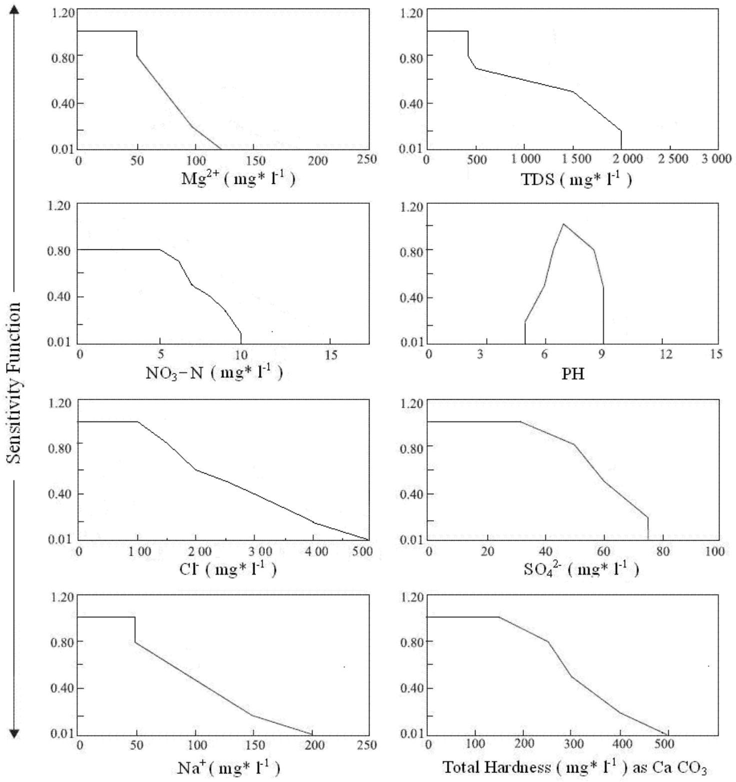

Figure 4. Relation between values of different parameters and the sensitivity function for Domestic use water.

3-5 Spatial analysis with GIS

In order to capture the spatial variation of groundwater quality in Zhengzhou area, spatial analyses with GIS were conducted employing ARCGIS software. The geographic coordinates of the wells were obtained from the hard copy maps and linked to the attribute database. The water quality data (attribute) is also linked to the sampling location (spatial) in ARCGIS and maps showing spatial distribution are constructed to easily identify the variation in water quality and in concentrations of each parameter in the groundwater at various locations of the study area using GIS software.

4. Results and Discussion

4-1 Land Use/Cover Distribution

An analysis of the nature and rate of land use change and its associated impact on groundwater quality is essential for a proper understanding of the present environmental problems [12]. In Zhengzhou area, the built-up land includes dense, medium and sparse residential areas as shown in figure 5. Table 2 and figure 6 show that the grass land is the greatest proportion (2715 km^2, 37.59%). The residential area comprises 988 km^2 (13.52%) of the total study area. The area of crop land occupies 1649.49 km^2 (22.54%). The study area comprises 1594.71 km^2 (21.81%) of the area under barren land.

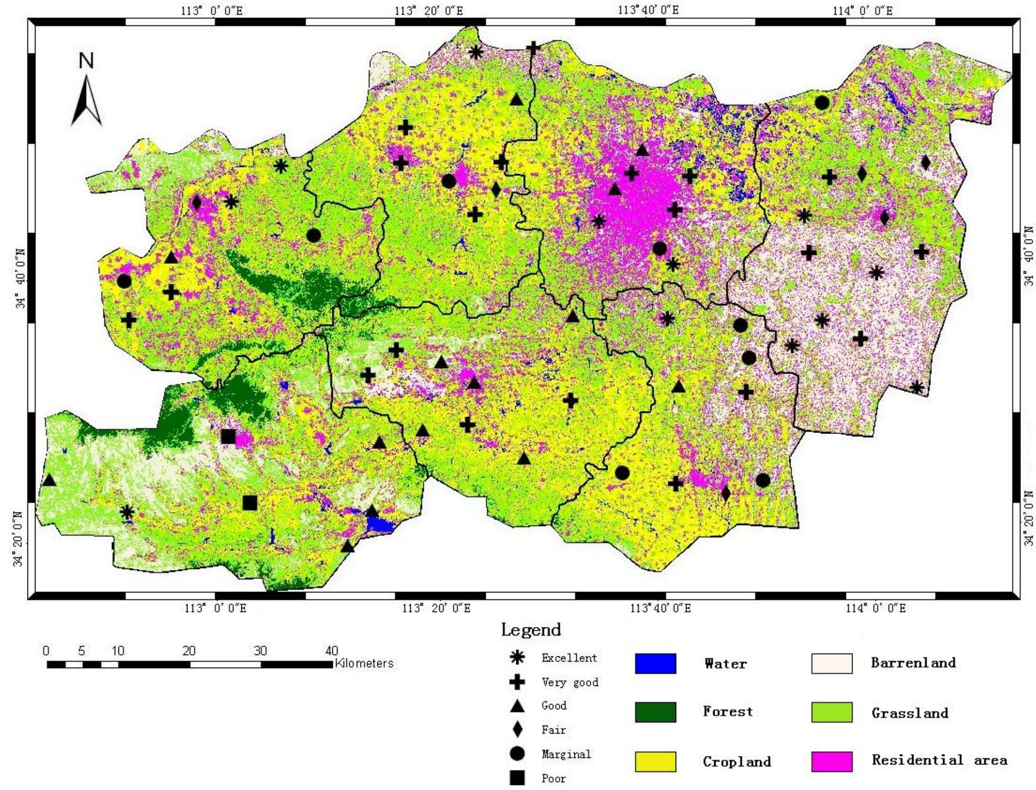

Figure 5. Locations of the wells with different water quality overlaid on Land use/cover distribution of Zhengzhou area

Table 2. The statistics of classification outcome in Zhengzhou area

Type	Area (km^2)	portion (%)
Water	113.18	1.55
Forest	214.07	2.92
Crop land	1649.49	22.54
Urban area	988.59	13.52
Grass land	2751.34	37.59
Barren land	1594.71	21.81

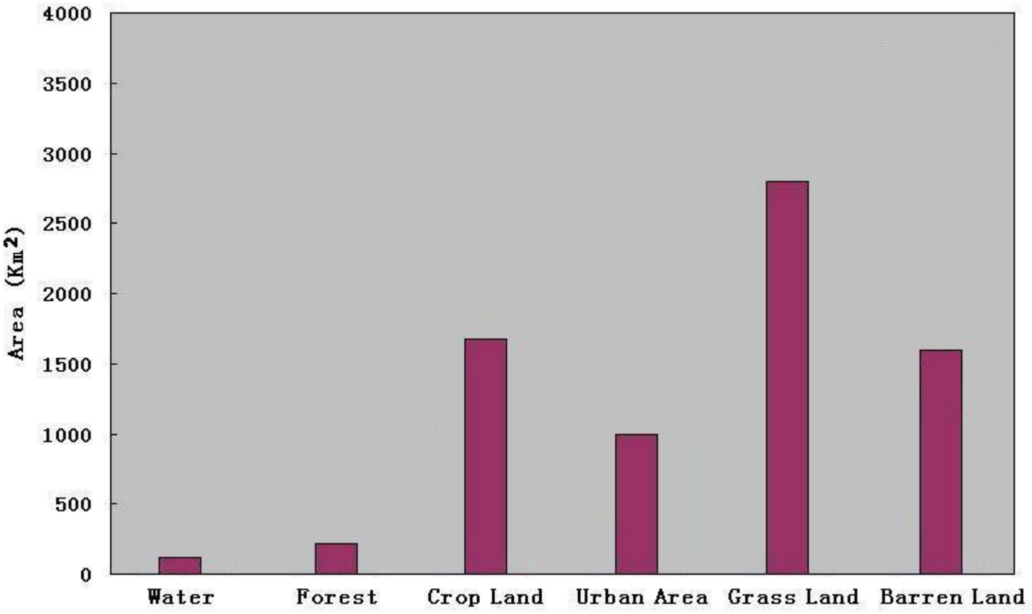

Figure 6. Land use / land cover distribution in the study area

4-2 Groundwater Quality Variation

The pH of water samples in the study area ranges between 7.21-8.54. The concentration of chloride in the whole area is within the permissible limits with maximum value of 115 mg/l. The highest concentration of Total Dissolved Solids is 822 mg/l at well D4. High TDS values in some wells are attributed to the intrusion of saltwater from Permian bed rock underlying the aquifer in Dengfeng County. It is also attributed to the leaching of salts into groundwater from surface water which flows from the mountain area. Another attribution is the presence of gypsum in coal layers in carboniferous and Permian rocks, and the dense residential and coal mining areas in Xinmi county. A high concentration of TDS was also observed at other wells near and in the residential areas which could be attributed to the solid waste dumping sites near the cities and agriculture practices. Based on TDS groundwater classification [13], all the water samples fall under the fresh type.

High concentrations of Total Hardness are found in the mountain areas in Xinmi County and other moderate range of TH values places in Gongyi and Dengfeng. These high values are attributed to the presence of limestone rocks of Cambrian, Ordovician, and Carboniferous near the surface and the common contamination due to dense residence.

Some anomalous values of Nitrate-Nitrogen are shown in Xinzheng and Dengfeng counties. The slope from the mountain area in the west towards the east and northeast could be one of the reasons for the high contents of dumped wastes and also due to agriculture practices.

4-3 Correlation of Water Quality with Land Use/Cover

Based on figure 4, WQI values for all the well samples have been calculated using equation (1). In order to classify the groundwater quality into different classes for drinking purposes, the water quality index limits which were suggested by Al Bassam et al., 2007 are adopted. The spatial distribution of different groundwater classes of Zhengzhou area is shown in figure 7. Water Quality index values revealed that the groundwater at twelve locations of the study area were Excellent quality (WQI values are greater than 95%). Twenty wells were V. good (WQI values between 85%-94.9%). Fourteen wells were Good (WQI values between 75%-84.9%). Therefore these wells can be exploited safely for human consumption. Six samples were Fair quality (WQI values between 60%-74.9%). Nine samples were Marginal (WQI values between 35%-59.9%). Two samples found to be Poor (WQI values were less than 35%) and can not be used for domestic purposes (table 3).

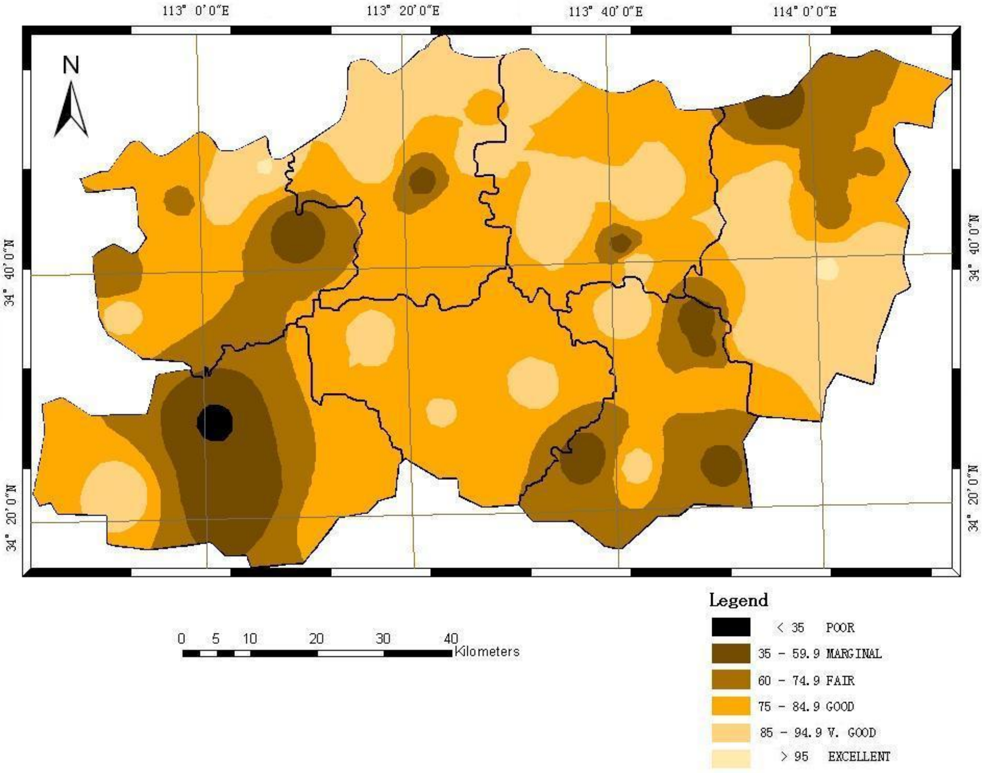

Figure 7. The spatial distribution of different groundwater classes calculated for domestic use

Table 3. Correlation of Water Quality with Land Use/cover in Zhengzhou area

WQI LU/LC	No. of Wells	Dense Residential	Medium Residential	Sparse Residential	Crop Land	Grass Land	Barren Land
I (Excellent)	12	1	0	0	3	2	6
II (V. Good)	20	3	2	2	5	1	7
III (Good)	14	3	0	1	5	1	4
IV (Fair)	6	3	0	0	1	1	1
V (Marginal)	9	2	0	0	5	1	1
VI (Poor)	2	2	0	0	0	0	0

Groundwater samples were collected from residential areas, crop land, barren land, and grass land (these are the major land use/cover classes of the study area). The crop land areas are usually associated with sparse, medium, and dense residential areas (figure 5). It has been found that 33.3% of the Excellent water quality, 60% of the V. good water quality, 64.3% of Good water quality, 66.7% of Fair water quality, and 77.8% of Marginal water quality are located at crop land and residential areas. Meanwhile two wells of Poor water quality are found at the dense residential areas. On the other hand 50% of the wells which have exhibited Excellent water quality, 35% of V. good water quality, 28.6% of Good water quality, 16% of Fair water quality, and 11.1% of Marginal water quality are located at the barren land areas (figure 8).

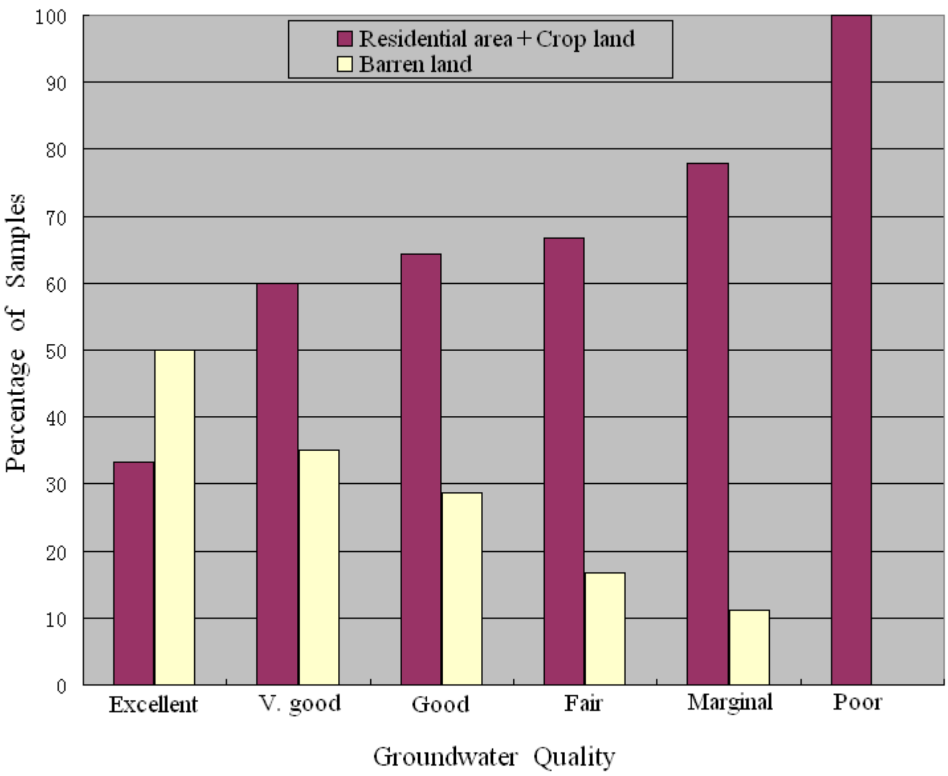

Figure 8. Correlation of land use/cover with water quality

The impact of different land cover classes on groundwater quality is a main target in this study. The correlation of land use/cover classes with water quality (table 3 and figure 8) indicates that the extent of the water quality deterioration has a positive linear correlation with the total area of residential and crop land and a negative linear correlation with barren land areas.

5. Conclusions and Recommendations

The study assessed domestic water quality of one of vital areas within North China Plain. The results show that the grass land is the greatest proportion (2715 km^2, 37.59%). The residential area comprises 988 km^2 (13.52%) of the total study area. The area of crop land occupies 1649.49 km^2 (22.54%). The Study area comprises 1594.71 km^2 (21.81%) of the area under barren land. Water Quality Index (WQI) values revealed that the groundwater at twelve locations of the study area are Excellent quality. Twenty wells are V. good, and fourteen wells are Good, therefore can be exploited safely for human consumption. Six well samples are Fair quality, nine samples are Marginal, and two samples are Poor (unfit). The results indicate that certain parameters such as Total Hardness, Nitrate-Nitrogen, and sodium are beyond the permissible limits in the area. The slope from the mountain area in the west towards the east and northeast could be one of the reasons for the high contents of dumped wastes. Residential areas and agriculture practices are also some reasons for that dump. The correlation of land use/cover with water quality indicate that the extent of water quality deterioration has a positive linear correlation with the total area of residential and crop land and a negative linear correlation with barren land areas. This indicates that the deterioration of groundwater is more influenced by the anthropogenic system than the natural system. Therefore comprehensive sewerage system for safe disposal of wastes should be developed to safeguard groundwater quality in most of the residential areas. The analysis of the results revealed that Remote Sensing and GIS are effective tools for assessing and quantifying the impact of land use/cover on groundwater quality. Overlaying the spatial distribution of water quality on Satellite imagery is a very authenticated concept to identify the water quality problems and to correlate them with the land use/cover to interpret the reasons for deterioration of environmental quality.

6. References

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