Journal of Natural Sciences Research www.iiste.org
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.5, No.18, 2015

Impact of Urban Growth on Groundwater Levels using Remote Sensing - Case Study: Erbil City, Kurdistan Region of Iraq

Hasan Mohammed Hameed Gaylan Rasul Faqe Sherwan Sharif Qurtas Hidyat Hashemi
Geography Department of Soran University, Erbil, the Kurdistan Region of Iraq

Abstract
Remote sensing and Geographic Information Systems (GIS) have been broadly used to detect and analyze urban expansion that is one of the most significant issues facing researchers of urban issues. In the current paper, setting out to examine the applicability of remote sensing and GIS to detect urbanization and its effect on quantities of groundwater spatio-temporal data, Landsat image 5-TM and 8-OLI were utilized. The images were classified into urban and non-urban through supervised classification (maximum likelihood logarithm) to provide an urban growth map over a period of ten years. Regression analysis was utilized to identify the relationship between urbanization and groundwater level. In addition, the Markov and the CA- models were used to forecast an urban growth map. The study points out that Erbil city has experienced remarkable changes to its urban areas which have increased by 278% between 2004 and 2014. In contrast, the level of groundwater has declined by more than 54%. The prediction model result of the CA-Markov also indicated that built up areas would continue to increase by 37% to 64% between 2020 and 2025; the average of groundwater depth therefore will continue to decrease by 23% in 2025, depending on regression analysis.
Keywords: groundwater level, urbanization, remote sensing, prediction groundwater depth, regression analysis

1. Introduction

Groundwater is one of the most important sources of water for human activity which includes drinking water, agricultural and industrial sector use, and other domestic purposes. Urban population increased more than tenfold during the twentieth century with most of this increase taking place in low and middle-income countries. This trend of urbanization has an influence on the use of fresh water and affects the quantity and quality of groundwater with the changing patterns and rates of recharge (Vahid 2013; Eassa et al. 2013; Josiah, 2011; Kanagalakshmi et al 2013). Less than of 30% of the global population lived in cities before 1950. Since 2008, more than half of the world population lives in urban areas. Research indicates that, similar to increased urbanization, the worldwide population will increase by up to 60% before the year 2030 (Haque et al 2012; Ray et al 2012; Vahid 2013). For this reason, evaluation, monitoring and estimating water resources assists in the efficient and equitable distribution of water amongst competing needs (Genxu et al 2008).

Urbanization and population increase has contributed to the destruction of natural resources through surface flow increase and groundwater recharge reduction (Vahid 2013). Changes in land cover directly affects recharge distributions and reduces recharge amounts (Josiah, 2011). However, sewers and leakage from water pipelines will infiltrate this recharge. Conversely, groundwater abstraction will lead to a decrease in the groundwater levels and reduced flows from the system (Tellam et al, 2006; Tilahun et al 2009; Arunprakash et al 2014). The main issue of urbanization is the interaction between groundwater and urban expansion, in particular cities and towns that are located on shallow unconfined aquifers. Groundwater abstraction therefore, directly affects the quantity and groundwater levels. Urban expansion has at least three main problems relating to groundwater: groundwater pollution, its effect on building engineering and integrity and fluctuation in the groundwater levels (Putra & Baier 2008). There is a decline in the recharge of groundwater in some areas because of human activity. Urban expansion causes a reduction in the infiltration of groundwater because of the impermeability of catchment areas by building car parks and roads (Lerner, 1990; Foster 1990; Yun et al 2011; Campo et al 2013).

In recent years, numerous studies have investigated the potential impact of climate change and land use change on groundwater quality and quantity. Randall et al (2013) used the MIKE SHE model (‘MIKE SHE’ is an advanced integrated hydrological modeling system) to estimate how the urban groundwater table is affected by climate change. Evapotranspiration, precipitation and temperature data were used in the MIKE SHE model. The study indicated the effect of climate change on the urban groundwater table. The study of Maimone et al. (2011) used the DYNFLOW (**DYN**amic work**FLOW**) model to estimate that the future groundwater level will be more than 1.5 m of its current level if the city planned to change 40% of its permeable area to impermeable area. Jat et al (2009) indicated that the applicability of geographic information systems and remote sensing provides useful tools to deal with the spatial and temporal variability of dynamic features to investigate the effect of urban growth on quantitative and qualitative groundwater.

One of the best high performance computer-based tools is the Geographic Information System (GIS), which is considered superior to traditional approaches. It has now become essential to store, retrieve and analyze data for water resource management in groundwater studies (Ampe & Vanhamel 2012; Igboekwe 2011). GIS and remote sensing are experiencing a critical increase of use in the areas of water resources and hydrology developments (Murugiah and Venkatraman 2013). Significant spatial data management is involved in utility remote sensing technologies in order to deal with the large amount of data, necessitating an efficient system. Large and complex databases are managed efficiently by providing appropriate alternatives through the application of GIS technology. Environmental research is relying increasingly on satellite information over time (Venkateswarlu et al. 2014). Data such as multi-temporal, multi-spectral and multi-sensor information of the earth's surface is regularly provided by remote sensing technologies. Contributing to a more successful analysis, the validation and predictive ability of remote sensing data is the most powerful tool for hydrological studies and monitoring process, as remote sensing has a phenomenal ability to generate information in spatial and temporal areas (Kumari & Krishna 2013).

In the present study, an attempt has been made to examine the effect of an increase of impermeable areas (or urbanization) on groundwater levels. Groundwater levels are effected by three major criteria; land use, climate, and groundwater abstraction (Yesertener 2008); this study will examine the relationship between urbanization and groundwater levels. In addition, depending on there being a strong relationship between the urbanization area and groundwater level, this study seeks to estimate the future groundwater level.

2. Method

2.1 Study area

The study area covers the city of Erbil, situated in the North of Iraq and capital of the Kurdistan Region. It lies between the latitudes and the longitudes of 36°11′28″N and 44°0′33″E (Khalid 2014) as shown in figure 1. Physiographically, the area is comprised of a broad plain and several hills to the east (Erbil Governorate 2015) that reach 426 m higher than sea level (Ayad 2010). In 2011, the Directorate of the Kurdistan Region commissioned a census that concluded that the population of Erbil city was 826,876 inhabitants.

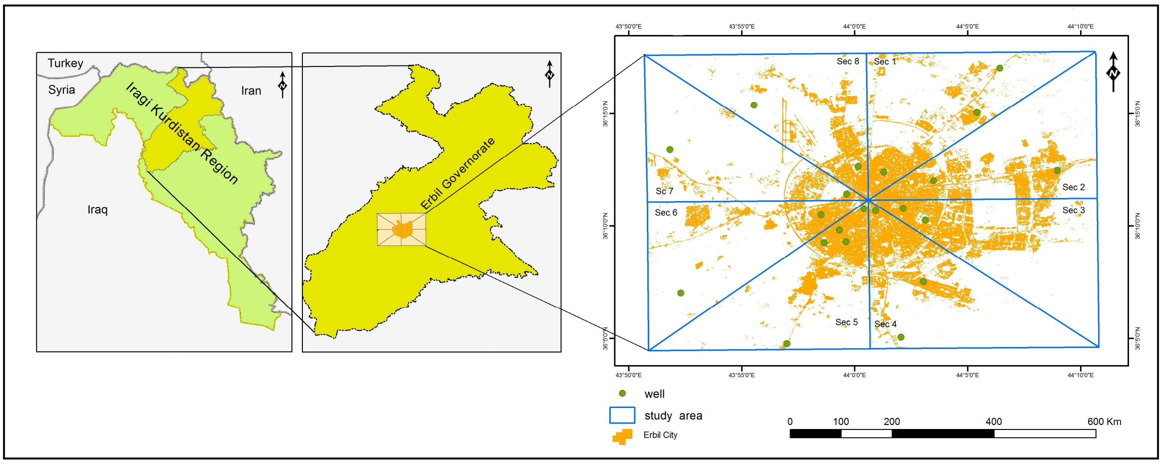


Figure 1. Shows the location of study area and distribution of sampling wells

The expansion of the basin area is bordered to the southwest by Kirkuk's anti-clinal structure and to the Northeast by the Perman Dagh anticline, which covers a wide syncline. A large syncline is separating the two anticlines, which personifies the middle of the Erbil Plain. This separates into three sections: North, Middle and South. (Bapeer et al. 2010).

The middle section is the focus of this study. The area is covered by quaternary sediments and is the result of weathering and erosion of the surrounding elevated areas. In the north and northeast part of the study area, quaternary sediments cover the Bai Hassan formation, comprised of molasses sediments. This is embodied by the alternation of clay stone and conglomerate along with siltstone and subordinate sand stone. The northwest of the study area is bordered by the Mukdadiya formation, which contains upwards fining cyclic clastic materials. (Youkhana and Sissakian 1986).

Groundwater is a major source of drinking water and a variety of other purposes in the study area, which was dependent on an unconfined aquifer. Well depth was 5 to 30 meters in 1990. As a result of the increase in the number of wells, the rate of wells' depth were increased by approximately 150 to 200 meters in 1996 (Kznee, 1997). From 2010, the study area has been dependent on the water project that supports it from the Great Zab River, which is located about 32 km to the west of the study area (Hussain 2007).

2.2 Materials:

The study employed both primary and secondary data. The primary data used in this study (Satellite images) was obtained from USGS (Gloves) in 2004 from landsat-5 TM and in 2014 from landsat-8 OLI images (path 169, row 35) with 30m spatial resolution. The demographic details are included in the collected secondary data (from the primary census carried out in the years 2004 and 2013 from the Census of the Kurdistan Region by the Directorate of Census Operations). The Groundwater Department of the Ministry of Agriculture and Water Resources in Erbil supplied the groundwater level data. The Governorate and Municipality of Erbil have provided maps such as the municipal boundaries, geographical, ward, and master plan maps.

2.3 Methodology:

This section describes the application of the main components which are applied to the city of Erbil to create the urban growth model. This includes four main stages: pre-processing, the classification of images, the accuracy assessment and model prediction in order to predict future urban growth in the city in 2020 and 2025 using Markov Chains and Cellular Automata (CA-Markov). Regression analysis was conducted to create the relationship between both urbanization and the level of groundwater overview of workflow explained in Figure 2.

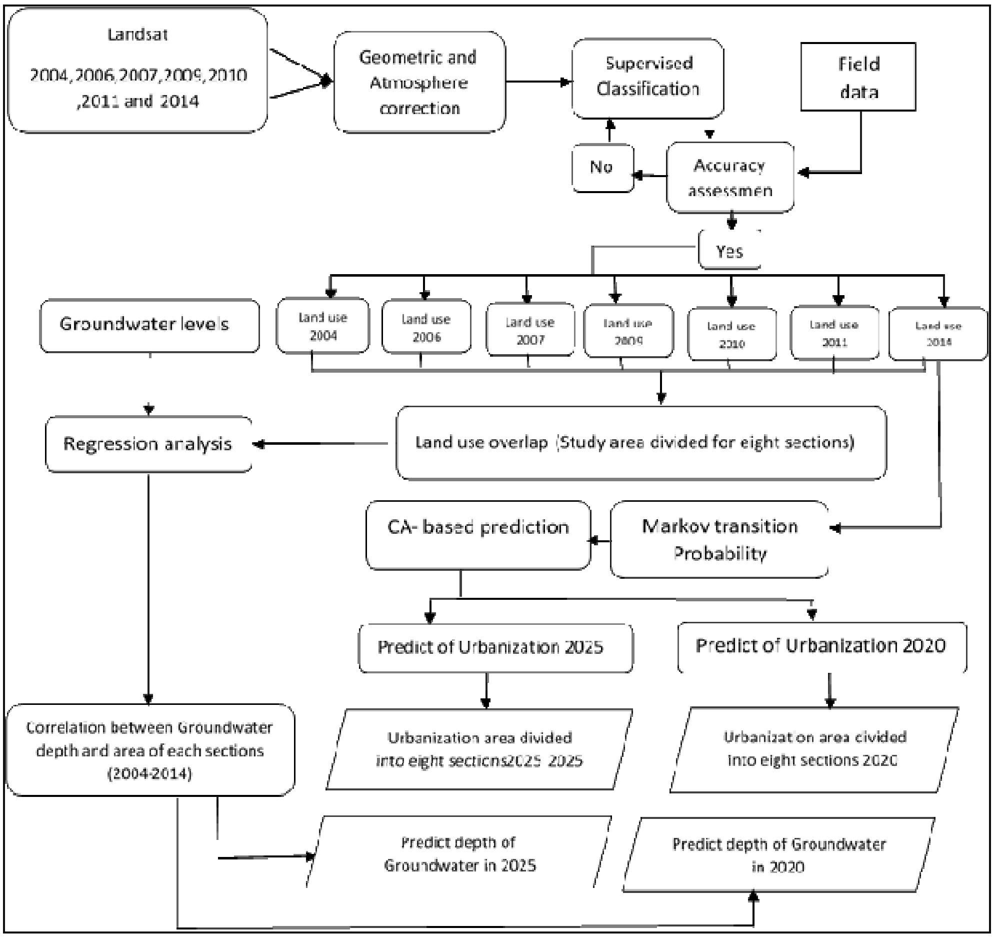


Figure 2. Flowchart illustrates the methodology.

Pre-processing: To compose geometric correction as well as atmospheric effect correction, ENVI 5.2 software was used. All satellite images were rectified and geo-referenced to a UTM coordinates zone 38N, WGS 1984. To make a subset of the images, administrative boundaries were utilized which was helpful in the analysis of the extent of Erbil municipality. The Mask technique in ArcGIS software was utilized to cut part of the image, so that the coordinates 36° 17′ 33″N 43° 50′ 43″E and 36° 04′ 37″N 44° 10′ 47″E is used to cover the study area.

2.4 Image classification and accuracy assessment:

Supervised classification was used for the mapping of land use/cover patterns. Firstly, training data was selected and then Landsat TM-5 and Landsat-8 OLI images were classified by supervised classification systems with the maximum likelihood of algorithm. The study site was classified into two areas; built-up and non-built up table 1.

Table 3. Land use categories.

Land use Category	Land use contains in class
Urban area	Resident area, Roads, Industrial, Commercial, Education area etc.
Non-Urban area	Vegetation area, Agricultural Grazing, Open land, bare land etc., Water,

The accuracy of the classification was confirmed by comparing it with other land use/cover maps that already for which a field checked was already conducted. Land cover, urban and non-urban areas, in the study area were calculated in hectares for each year in order to observe the rate of change and compare the results.

Classification of the image results from 2004-2014 were divided into eight sections by using ArcGIS10.2. These sections overlapped. Each section contains a number of wells that were taken from the study area as a sample figure 1. In order to identify the relationship between groundwater and urban expansion, regression analysis was used.

2.5 Modelling and Prediction:

Predicting the direction of future expansion of the city of Erbil was conducted by using the Markov Chain and Cellular Automata Analysis; the changes are presented in a flowchart (see figure 2). IDRISI software was utilized to develop the urban growth prediction model and to observe the spatial patterns of urban growth.

Land use/cover change models have broadly used Markov chains (Falahatkar & Soffianian 2011). Urban growth models utilizing the Markov Chain have many assumptions, the primary one being that urban growth is considered as a stochastic procedure and diverse classes are in the same situation as a chain (Weng 2002).

Markov therefore was used for obtaining the urban growth probability map for the study area and the Markov process was used to develop the probability distribution map. The Markov technique depends on comparing two images to predict the probable characteristics of that image in the future. In summary, the most successful way to predict temporal and spatial changes of land cover proved to be integrating the CA-Markov model and Markov chain (Fan 2008). In order to predict urban land use in 2020 and 2025 Cellular Automata (CA) was coupled with the Markov chain.

3. Result and Discussion

The rate of urbanization in the city of Erbil was estimated using the supervised classification method applied (Maximum likelihood approach) for 7 years: 2004, 2007, 2008, 2010, 2011 and 2014 with high precision. (Andresons et al, 1976) clarify that the minimum standard overall accuracy of land use/cover classification should be more than 85%. In this study, Accuracy assessment by Overall accuracy, Kappa coefficient for land use /cove classification of the study area were calculated as shown in table 2.

Table 4. Accuracy of land use/cover image between 2004 to 2014

Year	2004	2006	2007	2009	2010	2011	2014
Overall accuracy	94.94	96.9	92.15	94	91.2	94.9	93.1
Kappa Index	0.931	0.958	0.893	0.918	0.881	0.931	0.906

The spatial distribution expansion of Erbil's urban area is illustrated in Figure 3 for each year from 2004 to 2014.The ratio of development of urbanization in the city of Erbil is 1.8 times more than the ratio of population growth between 2004 and 2014. The urban expansion increased by 278%, while the population in the city of Erbil grew by 95% over the same period. This difference between urban expansion and population growth in the period from 2004 to 2014 signifies that the land is being developed at a faster rate which implies that land investment for urbanization has increased significantly over the last decade (for example for residential, educational, commercial, government, and industrial establishments, parks, and roads). This urbanization has led to the conversion of this land area to an impervious surface.

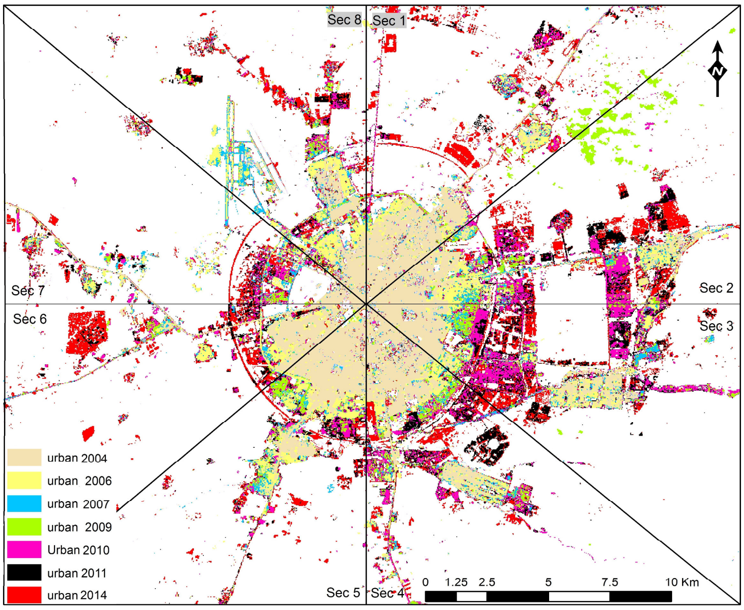


Figure 3. Shows the urban growth of Erbil city from 2004 to 2014 where each color represent the expansion of urbanization in each year.

A comparison of the rate of groundwater level depth in 2004 with the rate of groundwater depth in 2014 indicates that there has been a decline in groundwater levels in the study area. In general, there is a fall in groundwater levels in almost all of the wells in the study area. About 95% of wells have demonstrated a fall in groundwater level while only 5% of wells have demonstrated a rise in groundwater level. The results obtained from the preliminary analysis of average annual groundwater level using the raster calculator in ArcGIS can be compared in figure 4. Approximately 14% of wells have showed a fall in groundwater level within the range of zero – 20 m, approximately 24% of wells have displayed a decrease in groundwater level in the range of 20 – 40 m, and approximately 14% of wells have shown a decrease in groundwater level depth of more than 40 m . In general, the average depth of groundwater level has increased by 54% in 2014 compared with 2004.

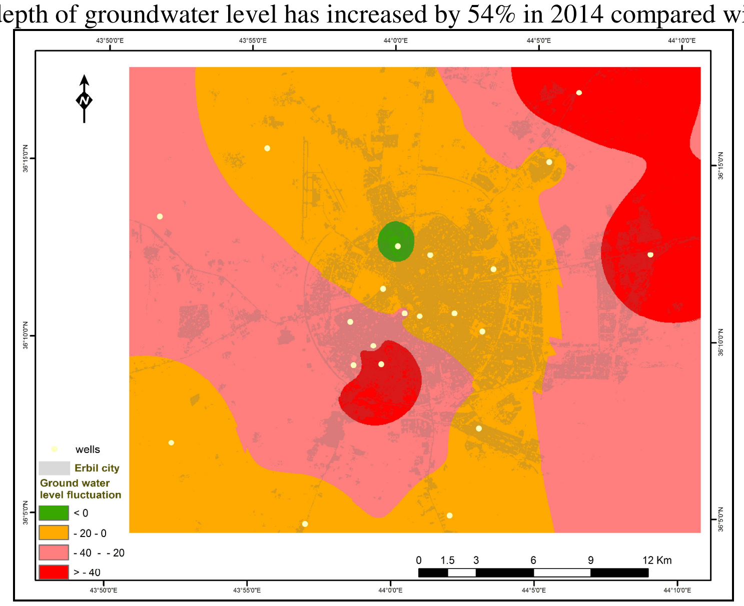


Figure 4. Comparison the average of groundwater depth in 2004 With the average of groundwater depth in 2014.

The study area was divided into eight sections as shown in Figure 5, in order to compare the increasing urbanized area with the change in groundwater level from 2004 to 2014. Simple analysis was used to find the relationship between urban growth and the fluctuation of groundwater level. Changes in the area of urbanization and groundwater level were compared using regression analysis which was then used to predict the correlation. To begin this process an area calculation of each section is necessary to find the correlation between groundwater levels that belong to its section area, as can been seen from appendix 1. From the data in Figure.4, it is apparent that the areas of Sec2 and Sec3 in the east of the study area have increased 244% in comparison with areas of Sec 6 and Sec 7. This does not mean that the urban expansion has only happened in the east of study area, but that all sections will increase over time because there are many projects which will apply in the future to other sections in the study area.

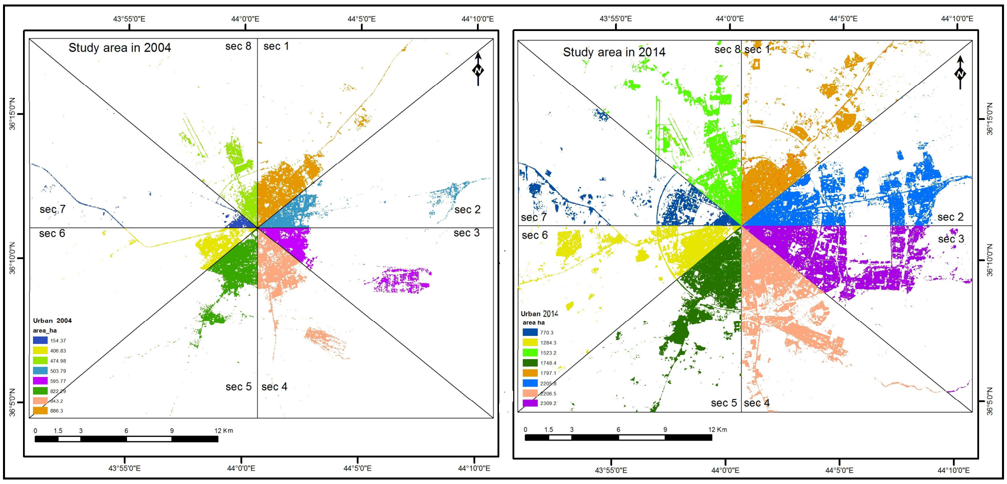


Figure 5. Presents the results obtained from the classification of urban area divided into eight sections from 2004 to 2014

Regression analysis was used to find the correlation between urban expansion and the average of groundwater depth in each section. The correlation between urbanization and groundwater level was tested on the Khabat and Badawa wells located in section 3. The result, as shown in figure 6, indicates that the correlation between groundwater level and urbanization is positive. A significant relationship exists between the urbanization areas and groundwater levels and a linear relationship between urban growth and the groundwater level was identified. The coefficient of determination (R^2) value of the Khabat well is 99%, while the coefficient of determination (R^2) value of the Badawa well is 81%. Taken together these results found in section 3 (located east-southeast of the study area), showed that there is an association between changes in built up areas and falling groundwater levels. The groundwater level rate of the Khabat and Badawa wells were 65 and 22.6 meters in 2004 respectively, while groundwater levels decreased to 71.2 and 99.8 meter in 2014. These changes in the groundwater levels can be explained by the growth of built up areas in section 3 from 595.78 hectares to 2309.2 hectares between 2004 and 2014.

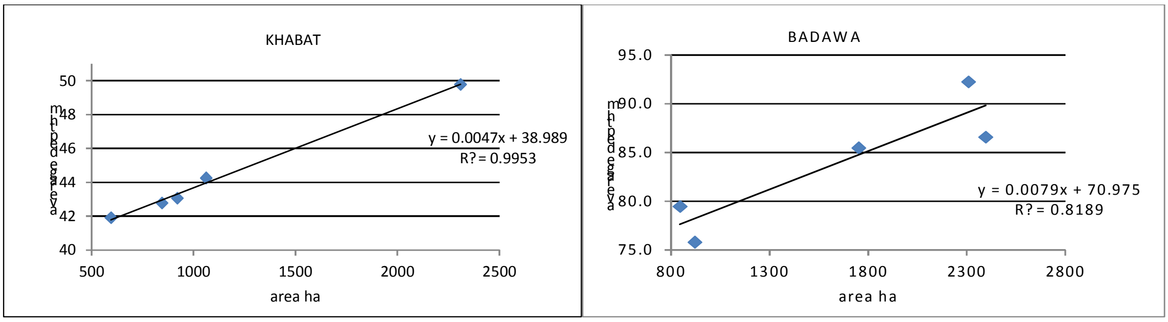


Figure 6. The relationship between urbanization and the average of groundwater depth in section 3

A significant correlation was identified between urbanization areas and groundwater levels in the other parts of the study area. Another sample of this correlation between urbanization and groundwater level is found in the south-southwest of the study area (which is located in section 5 as shown in figure 5) with the Shadi and Bahar wells. The coefficient of determination (R^2) value of the Shadi well is 93%, while the coefficient of determination (R^2) value of the Bahar well is 84% as shown in Figure 7. In addition, in 2004 the groundwater depth rate of the Shadi and Bahar wells was 35.9 and 36.9 meters, respectively, while the groundwater depth increased to 67.8 and 65.7 meters, respectively, in 2014. There was a significant, positive correlation between urban expansion and groundwater levels in all sections of the study area, as outlined in appendix 2.

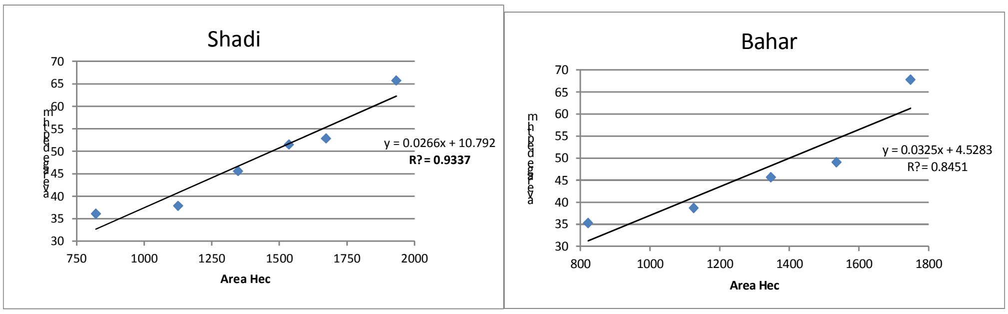


Figure 7. The relationship between urbanization and the average of groundwater depth in section 5

In recent years, the study area has been based on the water projects that provide the city of Erbil with drinking water from the Greater Zab River. The Greater Zab is located in the west of the study area; the groundwater level should be increasing because the groundwater withdrawal has been reduced, assuming all the other factors that have an impact on groundwater levels are constant. However, the groundwater level has been dropping year upon year, in spite of the water projects in the study area. A possible explanation for this might be that the recharge of rainfall will reduce in proportion to the impervious area as urban expansion changes regions from pervious to impervious. This process will directly affect the groundwater levels in the study area (Jat et al. 2009).

The study observed and averaged the groundwater levels of 19 different wells. The built up area was then taken into account to find the correlation between the data. The graph shows that there has been a gradual decrease in the rate of groundwater levels and an increase in the urbanization area between 2004 and 2014. The results, as shown in figure.8, indicate that there is a positive correlation between urbanization and groundwater levels. The coefficient of determination (R^2) value of the rate of the 19 observed is more than 80%. The groundwater table depth was between 15 and 87 meters in 2004 as compared to 19 and 158 meters in 2014, which refers to an overall decline in the groundwater table depth because of a decreased recharge and an increase in withdrawal. In general, the groundwater table has dropped in most of the study area.

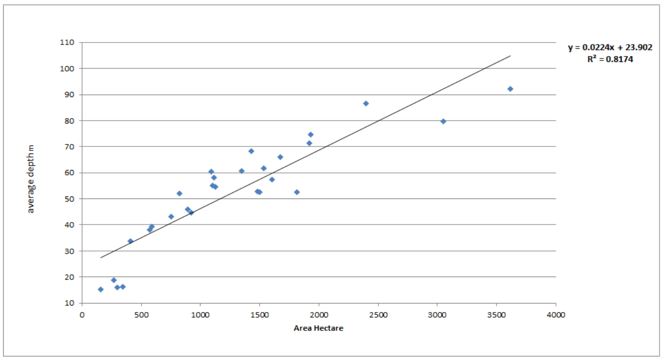


Figure 8. Presents the correlation among the 19 measurements of groundwater level and urban area from 2004 to 2014

The Cellular Automat-Markov (CA-Markov) model was used to predict urbanization changes between 2014, 2020 and 2025 based on 2004-2014 trends. Figure 9 is a map showing the distribution of predicted urban growth in 2025. Urban growth has led to an increase in built up areas in all sections. The difference in urbanization between sections was obvious between 2014, 2020 and 2025, as shown in figure 10. Urban growth has occurred mostly in sections 1, 2, 3 and 7 at 73%, 74%, 74% and 130% respectively. In comparison with urbanization areas in 2014, urban growth has identified in sections 4, 5, 6 and 8 to be 40%, 26%, 51% and 53% respectively, as shown in appendix 3. The highest rate of urban growth occurred in Sec 7, which is located west-northwest of the study area. This section contains a larger untapped area than other sections. Conversely, the lowest rate of urban growth was recorded in section 5, located in the south-southwest of the study area. This section saw the largest investment in a variety of projects (such as industrial, commercial, residential etc). Urbanized areas have expanded from the center of the city toward its exterior and surrounding areas along transportation routes. The study has confirmed the findings of (Sharp 2010) which found that urbanization leads to an increase of paved and impervious areas.

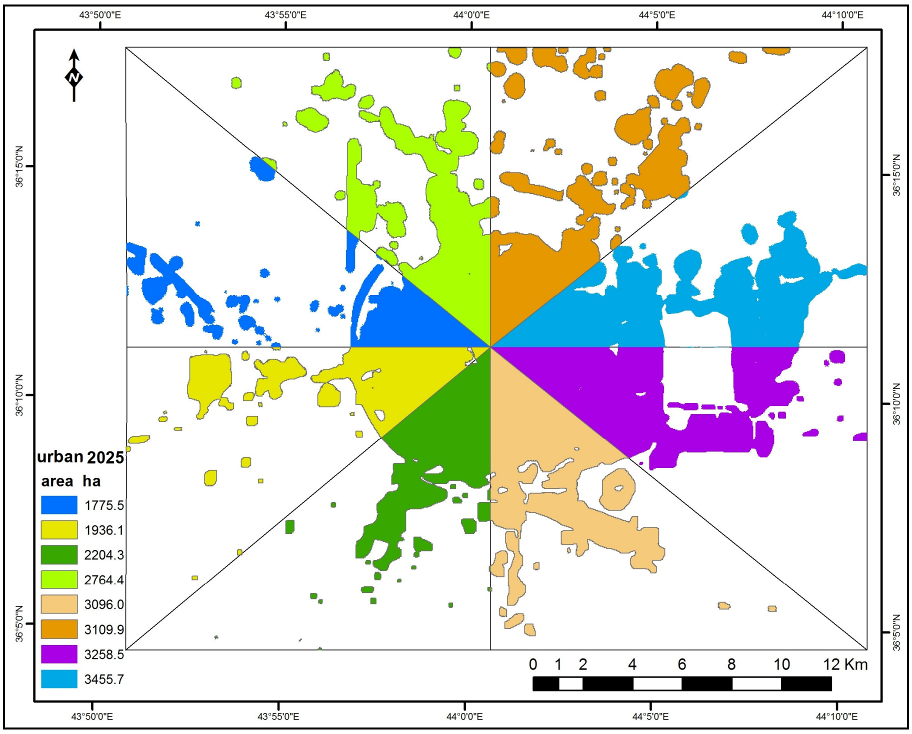


Figure 9. Spatial distribution prediction of urbanization in 2025 using CA-Markov.

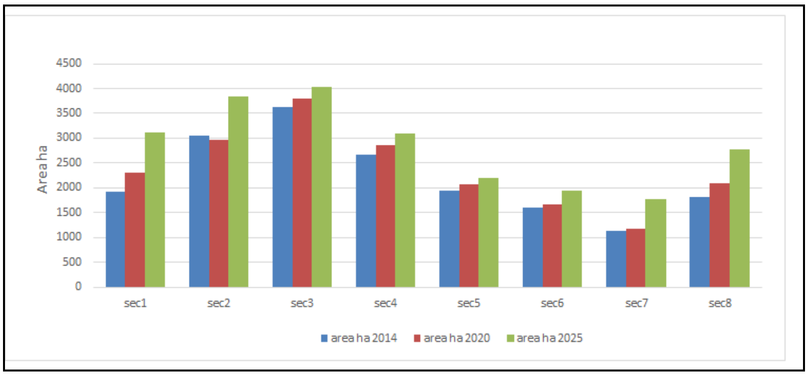


Figure 10. Shows the comparison between urban area growth from 2014 to 2020 and 2025.

There are many factors that affect groundwater levels, for example climate change, land use change, geological content, recharge, infiltration, discharge and withdrawal (Kløve 2013 et al; Clifton 2010; Mishra 2014; Qurtas 2013). This study has presented only one of the factors which contribute to the urban expansion area.

When all the constant factors that affect groundwater levels, such as climate, topography, geology, and hydrology are taken into consideration, predicting the depth of groundwater levels will depend on one factor: the urban expansion area. An estimation of groundwater levels using the regression formula of each well can be utilized. The prediction of groundwater depth has been recorded for 2020 and 2025, as can be seen from figure 11 and appendix 4. The groundwater table depth will increase approximately 12% from 2014 to 2020, while the groundwater table depth will increase around 23% from 2014 to 2025, except for the Mala Omar locality, which is located on Sec 1. The Mala Omar groundwater depth will increase in depth by around 43% from 2014 to 2020, and 88% from 2014 to 2025. The hydraulic properties of the aquifer beneath the Mala Omar area are low. However, it is located on the border of the hydrogeology basin (i.e. on the water divide of groundwater). Another possible explanation for this is that the withdrawal rate of the Mala Omar well is high because it is only source of water in the region and is used for all purposes (Qurtas 2013).

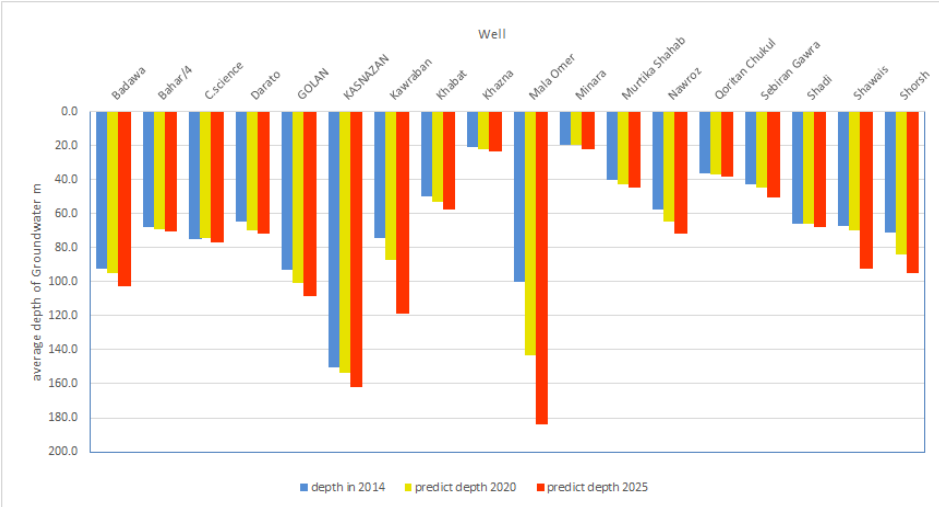


Figure 11. Comparison of groundwater table depth of 2013 with predict depth in 2020 and 2025.

The correlation between groundwater depth rates from 2014 to 2020 is 93%, while the correlation between groundwater depth rates from 2020 to 2025 is 95% as shown in appendix 5. These projected depths during the period from 2014 to 2020 and 2025 determine the minimum landing groundwater levels. Since the city of Erbil has relied on a surface water project since 2009 a rise in the groundwater level would have been normal. On the contrary, the study refers to the surprising depth of groundwater level increase from 2004 to 2014. This could be accounted for by growth and the fact that many wells are not controlled, with people using these wells for industrial, commercial and other purposes.

4. Conclusion

An integrated approach is used to evaluate the effect of urban growth on the groundwater level of the city of Erbil. Urbanization has been assessed from satellite imagery from different years. The annual rate of groundwater depth was computed with monthly data. The study area was divided into eight sections to estimate the urbanization area for each section through overlay analysis of related themes in GIS. Regression analysis was used to find the relationship between urban growth and groundwater levels. The CA-Markov model was used to estimate the urban growth in 2020 and 2025. The urbanization area was used to predict the groundwater depth in 2020 and 2025 using regression analysis. The results of this study indicate that the groundwater level has dropped around 54% from 2004 to 2014 because of increasing urbanization and the accompanying increase in the impervious area (4687.70 hectare in 2004 to 17729.35 hectare in 2014). The research has also shown that the groundwater level would fall by 6.1- 15.1 m from 2020 and 2025 (18974.7 hectare in 2020 to 22756.7 hectare in 2025). Urban growth causes changes to land cover by varying vegetation, topography, the extraction of groundwater and the increase of impervious areas. All of these affect the infiltration and recharge of the groundwater table. These alterations cause subsidence groundwater recharge as well as increasing pollution of surface groundwater through sewage systems. This data suggests that raising the groundwater level can be achieved through increasing the green area in the study area. This would lead to an increase in the recharge of groundwater in addition to avoiding the drilling of new wells and increasing control over existing wells. Constructing artificial recharge outside of the city of Erbil would also increase groundwater recharge.

5. Acknowledgment

I would like to express my very great appreciation to Dr. Pavel Spirov and Dr. Howri Mansurbeg for their valuable input and comments to enhance this paper. I would also like to thank the Groundwater Department of the Ministry of Agriculture and Water Resources in Erbil for supporting this research by providing data and basic maps of study area. Finally, I would like to thank Shna Lmc to review this paper.

References

Ampe, Eva M. & Vanhamel, Iris 2012, Impact of Urban Land-Cover Classification on Groundwater Recharge Uncertainty, IEEE Journal of selected topics in applied earth observations and remote sensing, vol. 5, no. 6, pp. 1859-1867.

Anderson, J. R. Hardy, E.E. Roach, J.T. & Witmer R.E. 1976, A land use and land cover classification system for use with remote sensor data (Vol. 964). US Government Printing Office, Washington.

Arunprakash, M., L. Giridharan, R. R. Krishnamurthy, M. Jayaprakash 2014, Impact of urbanization in groundwater of south Chennai City, Tamil Nadu, India, Environ Earth Sci 71, pp.947–957.

Ayad, M. Fadhil., 2010. Drought Mapping Using Geo-information Technology for Some Sites in the Iraqi Kurdistan Region. International Journal of Digital Earth, Volume 4, Issue 3, Taylor & Francis.

Bapeer, G.B., Surdashy, A.M. & Hassan, K.M., 2010. Infiltration Rates of Soils in Some Locations, 6(2), pp.127–137.

Campo, M. A. Martín del, M. V. Esteller, J. L. Expósito, R. Hirata 2013, Impacts of urbanization on groundwater hydrodynamics and hydrochemistry of the Toluca Valley aquifer (Mexico), Environ Monit Assess, 186:pp. 2979–2999

Clifton, Craig et al 2010, Water and Climate Change: Impacts on groundwater resources and adaptation options, published by the Water Sector Board of the Sustainable Development Network of the World Bank Group, pp 17-38.

Eassa, A.M., Mohammed, H. & Shubbar, Y., 2013. Assessment of ground water quality at Basrah , Iraq by water quality index (WQI). Abstract, (7), pp.2531–2543.

Erbil Governorate., (2015) Erbil geography. [Online available at http://www.hawlergov.org/en/page.php?id=1329120973

Falahatkar, S. & Soffianian, A., 2011. Integration of Remote Sensing data and GIS for Prediction of Land cover map. *Geomatics and,* 1(4), pp.847–864. Available at: http://www.ipublishing.co.in/jggsvol1no12010/EIJGGS2045.pdf.

Fan, F., Wang, Y., & Wang, Z., 2008. Temporal and spatial change detecting (1998–2003) and predicting of land use and land cover in Core corridor of Pearl River Delta (China) by using TM and ETM+ images. Environmental Monitoring and Assessment, 137(1-3), 127-147.

Foster, S.S.D., 1990, impacts of urbanization on groundwater, Hydrological Processes and Water Management in Urban Areas (Proceedings of the Duisberg, Symposium, April 1988). IAHS Publ. no. 198, 1990, PP 187-206.

Genxu, W. et al., 2008. Evaluation of groundwater dynamic regime with groundwater depth evaluation indexes. *Water environment research: a research publication of the Water Environment Federation*, 80(6), pp.547–560.

Gogana Venkateswarlu, G Jayasankar & B.V Saradhi, 2014. Impact Assessment of Land Use Change on Ground Water Quality Using Remote Sensing & GIS for Zone V under Municipal Corporation Hyderabad \n. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 11(1), pp.36–42. Available at: http://www.iosrjournals.org/iosr-jmce/papers/vol11-issue1/Version-5/F011153642.pdf.

Haque, Syeda Jesmin, et al., 2013. An overview of the effects of urbanization on the quantity and quality of groundwater in South Asian megacities, Limnology (2013) 14:135–145 DOI 10.1007/s10201-012-0392-6.

Hussein, SH.O. (2007). Create geographic database for the characteristics of the quality of groundwater base in the Erbil city using geographic information systems (GIS), the Ministry of higher Education, Mosel,

Igboekwe, M.U., 2011. Application of Geographic Information System (GIS) in Mapping Groundwater Quality in Uyo, Nigeria. *International Journal of Geosciences*, 02(04), pp.394–397.

Jat, M.K., Khare, D. & Garg, P.K., 2009. Urbanization and its impact on groundwater: A remote sensing and GIS-based assessment approach. *Environmentalist*, 29(1), pp.17–32.

Josiah, N., 2011. Impact of urbanization on sub-surface water quality in calabar municipality , nigeria Eni , Devalsam I .* Ekwok , Innocent Department of Geography and Regional Planning University of Calabar , Calabar , Nigeria E-mail : devimoke @ yahoo . com , Phone : 23. , 1(10), pp.167–172.

Kanagalakshmi, A. S. & S. Nagan, 2013, Effect of Urbanization on GroundwaterQuality of TirumangalamTaluk,Madurai, Nature Environment and Pollution Technology, ISSN: 0972-6268, Vol. 12, No. 2, pp. 363-366.

Khalid, N., 2014. Urban heat island in Erbil City. Student thesis series INES. http://www.lunduniversity.lu.se/lup/publication/4449039

Kløve, B., et al 2013. Climate change impacts on groundwater and dependent ecosystems. J. Hydrol. Elsevier, http://dx.doi.org/10.1016/j.jhydrol.06.037, pp:1-4

Kumari, N. & Krishna, A.P., 2013. Geospatial Techniques Recharge Site Suitability Based Assessment of Groundwater. , 2(1), pp.96–109.

Kznee, A. A. (1997). Erbil and drinking water in the past and the present, the Ministry of Education, Erbil, pp:29.

Lerner, D., 1990. Groundwater recharge in urban areas. *IAHS Publication*, (198), pp.59–66. Available at: http://www.sciencedirect.com/science/article/pii/095712729090006G.

Maimone, M. et al., 2011. Environmental Engineer: Applied Research and Practice potential impacts of extensive stormwater infiltration in philadelphia. , 14.

Mishra, Nitin et al 2014, Impact of Land Use Change on Groundwater - A Review, Advances in Water Resource and Protection (AWRP) Volume 2, pp 28-40.

Murugiah, M. & Venkatraman, P., 2013. Role of Remote Sensing and GIS in artificial recharge of the ground water aquifer in Ottapidaram taluk , Tuticorin district , South India. , 3(3), pp.405–415.

Putra, D.P.E. & Baier, K., 2008. Impact of Urbanization on Groundwater Recharge -- The Example of the Indonesian Mil lion City Yogyakarta. *UN Habitat- United Nations Settlement Programs: Fourth session of the World Urban Forum, Nanjing, China, Documentations of Germany's Contribution to a Sustainable Urban Future.*, (2).

Qurtas, Sherwan Shrif, 2013. Groundwater evaluation and Management Using Mathmatical Models for Shamamik Basin, Kurdistan Region-Iraq.

Randall, M.T. et al., 2013. Assessing urban groundwater table response to climate change and increased stormwater infiltration. *Geological Survey of Denmark and Greenland Bulletin*, (28), pp.33–36.

RAI, Suresh Chand & kumari, Preeti 2012. Assessment of groundwater contamination from land-use/cover change in rural-urban fringe of national capital terrytory of delhi (india), pp. 32-46

Sharp, J.M., 2010. The impacts of urbanization on groundwater systems and recharge. *AQUAmundi*, (may), pp.51–56.

Tellam, J. H., Rivett, M. O., & Israfilov, R. G., 2006. 2006. Towards Management and Sustainable Development of Urban Groundwater Systems. , pp.1–9.

Tilahun, Ketema & Merkel, Broder J. 2009, Estimation of groundwater recharge using a GIS-based distributed water balance model in Dire Dawa, Ethiopia, Hydrogeology Journal (2009) 17: 1443–1457, pp 1443-1457.

Vahid, G., 2013. Modeling of Ground Water Level Using Statistical Method and GIS . A Case Study : Amol-Babol Plain , Iran. , 2(3), pp.53–59.

Weng, Q., 2002. Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modelling. *Journal of environmental management*, 64(3), pp.273–284.

Yesertener, C., 2008. *Assessment of the declining groundwater levels in the Gnangara Mound*,

Youkhana, R., & Sissakian, V. (1986). Stratigraphy of Shaqlawa–Kio–Sinjar area. J Geol Soc Iraq, 19, 137.

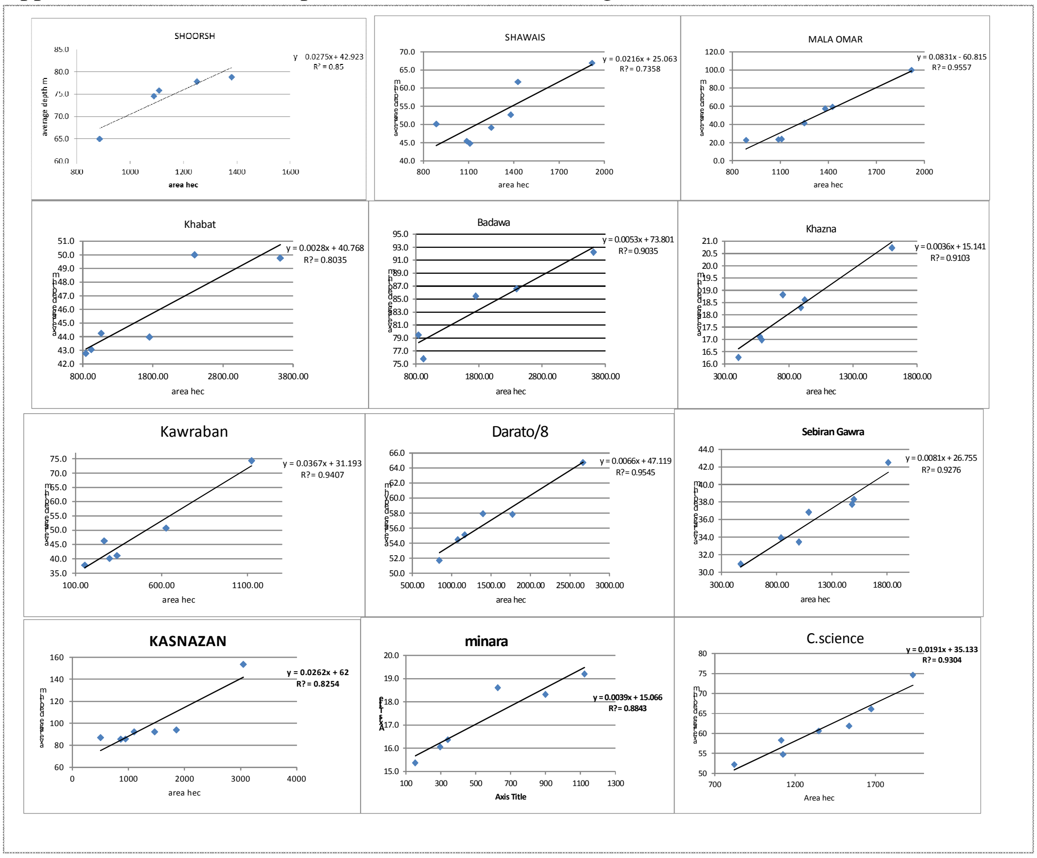
Yun, PAN., GONG Huili, ZHOU Demin, LI Xiaojuan, NAKAGOSHI Nobukazu 2011, Impact of Land Use Change on Groundwater Recharge in Guishui River Basin, China, Chin. Geogra. Sci. 2011, 21(6), pp. 734–743

Appendices

Appendix1. Average depth of groundwater level with the area in hectare for each section over 2004 to 2014

Section	well name	area ha 2004	DEPTH2004	area ha 2006	DEPTH2006	area ha 2007	DEPTH2007	area ha 2009	DEPTH2009	area ha 2010	DEPTH2010	area ha 2011	DEPTH2011	area ha 2014	DEPTH2014
3	Badawa	595.8	78.6	845.7	79.5	921.4	75.8	1062.5	84.5	1752.0	85.5	2396.2	86.6	2309.2	92.2
5	Bahar/4	822.3	36.9	1125.6	38.6	1114.0	75.8	1347.4	45.6	1536.0	49.0	1673.2	50.2	1748.4	67.8
5	C.science	822.3	52.2	1125.6	54.7	1114.0	58.2	1347.4	60.6	1536.0	61.8	1673.2	66.1	1748.4	74.6
4	Darato/8	843.3	51.7	1078.6	54.5	1165.6	55.1	1397.8	57.9	1772.0	57.8	2199.3	58.5	2206.6	64.7
2	Gulan/8	503.8	80.0	865.8	80.3	948.2	80.0	1102.3	74.2	1470.0	77.7	1859.7	77.8	2205.8	92.7
2	Kasnazan	503.8	87.0	865.8	85.6	948.2	85.7	1102.3	92.3	1470.0	92.3	1859.7	93.9	2205.8	150.3
7	Kawraban	154.4	37.8	297.6	40.1	341.0	41.2	420.0	46.3	525.0	48.9	626.3	50.8	770.3	74.3
3	Khabat /4	595.8	41.9	845.7	42.8	921.4	43.1	1062.5	44.2	1752.0	44.0	2396.2	40.0	2309.2	49.8
6	Khazna	406.8	16.3	573.5	17.1	588.5	17.0	752.9	18.8	923.0	18.6	893.5	18.3	1284.3	20.7
5	Majidawa	822.3	38.1	1125.6	38.3	1114.0	38.0	1347.4		1536.0		1673.2		1748.4	200.0
1	Mala Omer	886.4	22.6	1088.4	23.2	1108.5	23.7	1250.1	41.4	1380.0	57.3	1426.5	59.3	1797.2	99.8
7	Minara	154.4	15.4	297.6	16.1	341.0	16.4	266.7	18.7	525.0	18.3	626.3	18.6	770.3	19.2
4	Murtika Shahab	843.3	28.5	1078.6	29.0	1165.6	28.3	1397.8	31.2	1772.0	30.9	2199.3	31.1	2206.6	40.0
6	Nawroz\18	406.8	33.7	573.5	38.1	588.5	39.3	752.9	43.3	923.0	44.7	893.5	46.0	1284.3	57.4
5	Qoritan Chukul	822.3	26.7	1125.6	26.9	1114.0	26.7	1347.4	29.5	1536.0	29.2	1673.2		1748.4	36.4
4	Saadawa	843.3	11.3	1078.6	11.8	1165.6	12.1	1397.8	12.3	1772.0	12.1	2199.3	10.5	2206.6	10.6
8	Salahaddin	475.0	74.0	840.6	74.5	1002.3	66.7	1091.7	60.4	1484.0	52.8	1501.0	52.6	1523.2	62.9
8	Sebiran Gawra /6	475.0	30.9	840.6	33.9	1002.3	33.4	1091.7	36.8	1484.0	37.7	1501.0	38.3	1523.2	42.5
5	Shadi	822.3	35.9	1125.6	37.8	1114.0	75.8	1347.4	45.6	1536.0	51.5	1673.2	52.8	1748.4	65.7
1	Shawais/4	886.4	50.1	1088.4	45.4	1108.5	44.8	1250.1	49.1	1380.0	52.7	1426.5	61.7	1797.2	66.9
1	Shorsh/8	886.4	65.0	1088.4	74.5	1108.5	75.8	1250.1	77.8	1380.0	78.9	1426.5	68.3	1797.2	71.2

Appendix 2. The relationship between urbanization and groundwater in selected wells



Appendix 3. Comparison of urbanized areas in 2014 and urban expansion in 2025

section	area ha 2014	area ha 2025	area percent
sec1	1797.2	3109.9	73%
sec2	2205.8	3843.4	74%
sec3	2309.2	4026.8	74%
sec4	2206.6	3096.0	40%
sec5	1748.4	2204.3	26%
sec6	1284.3	1936.2	51%
sec7	770.3	1775.6	130%
sec8	1811.4	2764.5	53%

Appendix 4. illustrates the average depth of groundwater with urban area that belong to its section.

section	well name	well depth m	depth m 2014	area ha 2020	predict depth m 2020	area ha 2025	predict depth m 2025
sec1	Mala Omer	171	99.8	2311.9	143.1	3109.9	188.1
sec1	Shawais	134	66.9	2311.9	69.9	3109.9	92.2
sec1	Shorsh	180	71.2	2311.9	84.1	3109.9	95.2
sec2	Golan	180	92.7	2967.1	100.7	3843.4	108.7
sec2	Kasnazan	203	150.25	2967.1	153.3	3843.4	161.9
sec3	Badawa	160	92.2	3800.4	94.7	4026.8	95.1
sec3	Khabat	180	49.8	3800.4	53.0	1775.6	57.8
sec4	Darato	150	64.7	2868.2	69.5	3096.0	67.5
sec4	Murtika Shahab	200	40.0	2868.2	42.8	3096.0	44.6
sec5	Bahar/4	215	67.8	2078.8	69.3	2204.3	70.4
sec5	C.science	120	74.6	2078.8	75.6	2204.3	76.9
sec5	Qoritan Chukul	200	36.4	2078.8	37.1	2204.3	38.3
sec5	Shadi	300	65.7	2078.8	66.0	2204.3	69.2
sec6	Khazna	142	20.7	1669.6	22.4	1936.2	23.7
sec6	Nawroz	180	57.4	1669.6	64.7	1936.2	71.4
sec7	Kawraban	117	74.3	1182.4	87.2	1775.6	94.9
sec7	Minara	84	19.2	1182.4	19.6	1775.6	21.9
sec8	Sebiran Gawra	183	42.5	2096.4	44.5	2764.5	48.1

Appendix 5. Shows the correlation between groundwater depth rate from 2014 to 2020 and from 2020 to 2025