Article

Over-pumping groundwater in northern Jordan, the case of Irbid governorate: a conceptual model to analyze the effects of urbanization and agricultural activities on the groundwater level and salinity

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Abstract: Irbid governorate has the highest population density in Jordan and most of its water demand is supplied by groundwater. Both natural population growth and waves of migrations increased the number of its inhabitants during the last forty years. The increased number of inhabitant resulted in extending the urban and agricultural areas. Also, the demand for domestic water uses increased as a result of the increased number of inhabitant, while the extended agricultural area meant increasing the water demand for irrigation. Due to the expansion of urban areas, water was required for the construction sector. Most of the water resources needed for these sectors came and comes from groundwater resources. Nowadays, the increased water demand is putting a strain on the groundwater resources, which are currently over-exploited beyond their safe-yield. As a result of the continuous pumping, the groundwater level is decreasing rapidly and the salinity increasing gradually. This paper presents a conceptual model we have produced to measure this process through an integrated approach of remote sensing and Geographic Information Systems (GIS).

Keywords: Conceptual modeling; groundwater resources; Jordan; water demands; remote sensing; GIS

Introduction

Literature on water resources in Jordan focused on hydrological approaches and engineering solutions to water scarcity, with regional attention to the Jordan Valley, and to the Amman governorate. Extensive literature has been published on issues related to the water crisis in Jordan, which makes it impossible to fairly review within a brief literature review. In particular, Jordan is said to be among the most water scarce countries in the world, facing serious problems related to water shortages, which negatively affect its entire development [1-5]. Recent research showed that the Jordanian government has been exploring several solutions to increase the water supply in the country, from building the Wahda Dam, the Disi Canal project recently completed, and supporting the construction of the Red Sea – Dead Sea Canal [6-8]. Literature on water resources and water policies in Jordan has investigated mainly the cases of Amman governorate- where most of the population resides – and of the agricultural activities in the Jordan Valley

[9-11]. Previous research has adopted geospatial techniques for improved water management in the country [12]; Withheritrrong et al., [13] analysed estimation of the effect of soil texture on nitrate-nitrogen content in groundwater using optical remote sensing – although not for the case of Jordan -; Dogrui et al. [14] analysed groundwater modeling in support of water resources management and planning under complex climate, regulatory, and economic stresses, although not specifically in the case of Jordan; and Mohammad et al. [15] recently investigated the impact of droughts in the Yarmouk Basin, in Jordan, by monitoring the droughts through meteorological and hydrological drought indices. Nevertheless, what emerges from the review of the relevant literature is that little research has been done on the impacts of the evolving human activities – specifically of agricultural and urban activities – on the groundwater resources in the governorate of Irbid. This paper aims to make a novel contribution by presenting a conceptual model to measuring the process of human urbanization and increased agricultural activities over time according to an integrated approach of remote sensing and Geographic Information Systems (GIS) applied to the Irbid Governorate.

Study area and background information

Jordan has an area of about 89.34 Km^2 that is divided into 12 governorates, and Irbid governorate has an area of about 1.572 km^2 (Fig. 1). As a result of the tectonic events and geomorphological processes, Irbid governorate has high relief topography [16] (Fig. 2). Because of the variations of elevations, there are different rainfall patterns in the region, as showed in Figure 3, [17-18]. Irbid governorate has the second biggest population in the country, after the capital city Amman, however Irbid has the highest population density in Jordan [19].

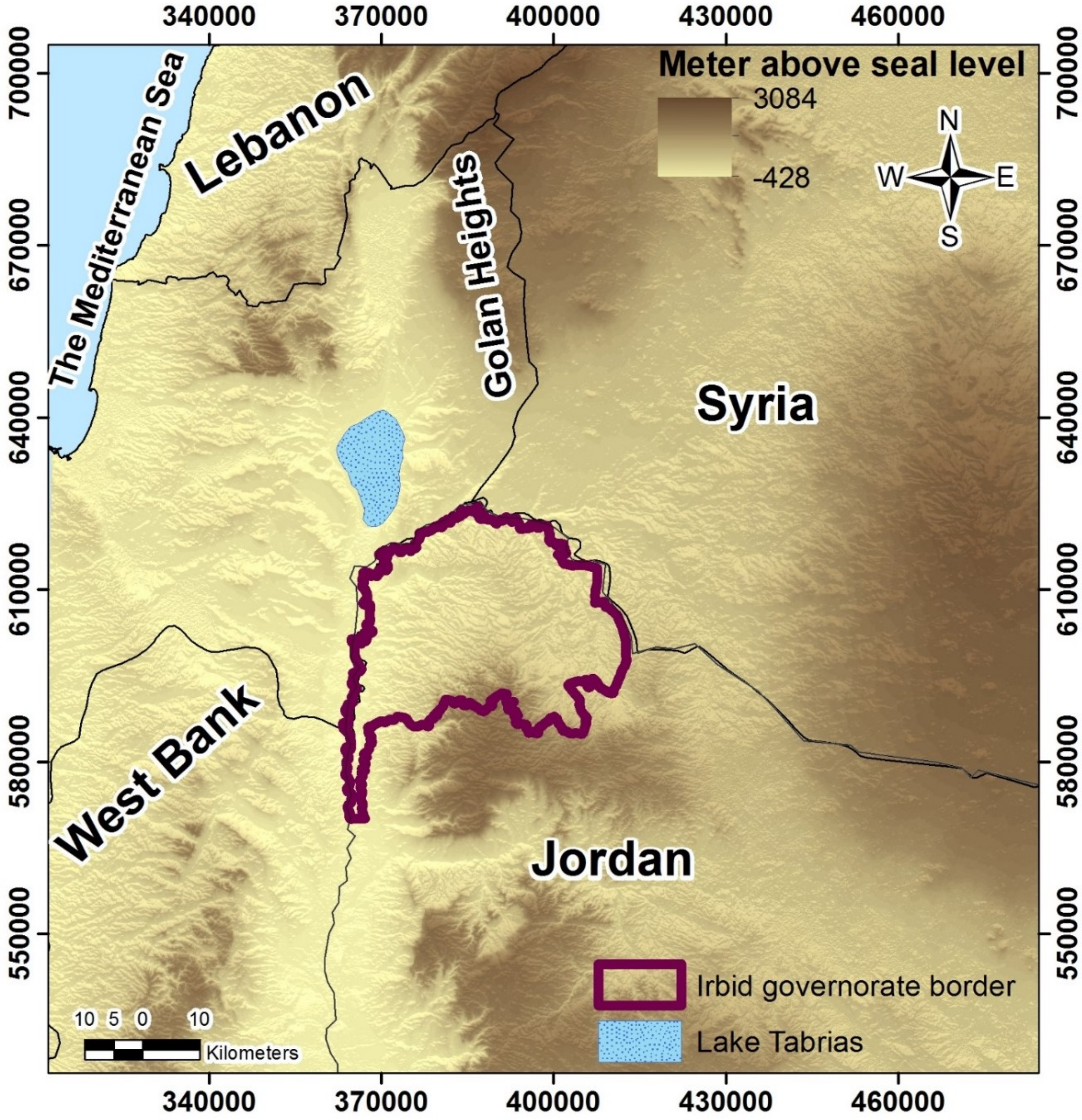


Fig. 1: Study area location so called Irbid governorate. It has a border with Syria, west bank and Israel. It has the city of Irbid that has the second biggest population in Jordan after the capital Amman.

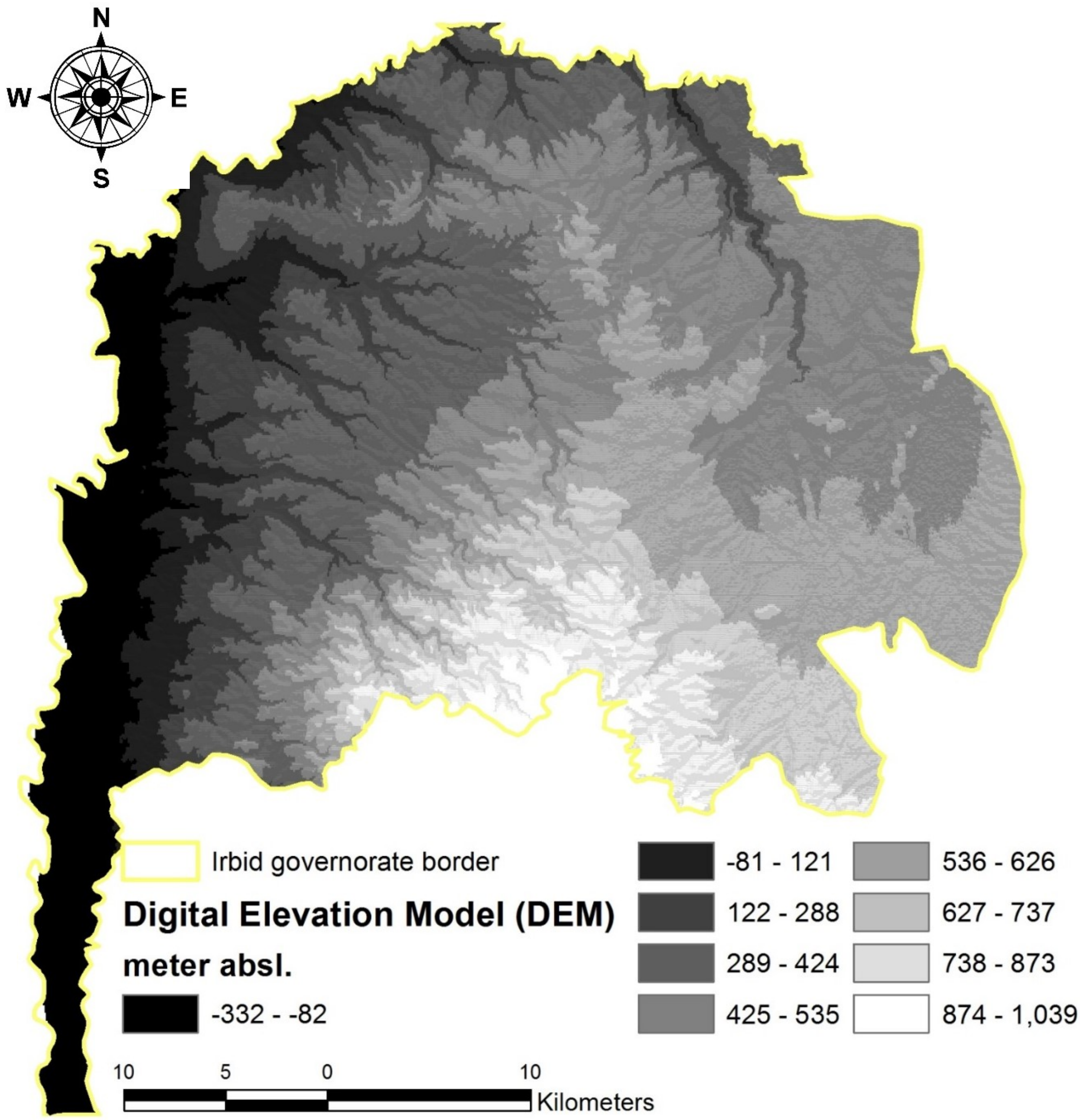


Fig. 2: The topography of the study area. The western part is the lowest elevation that is a part from the Jordan valley. The southern part has the highest elevation that is a part form Ajloun mountains.

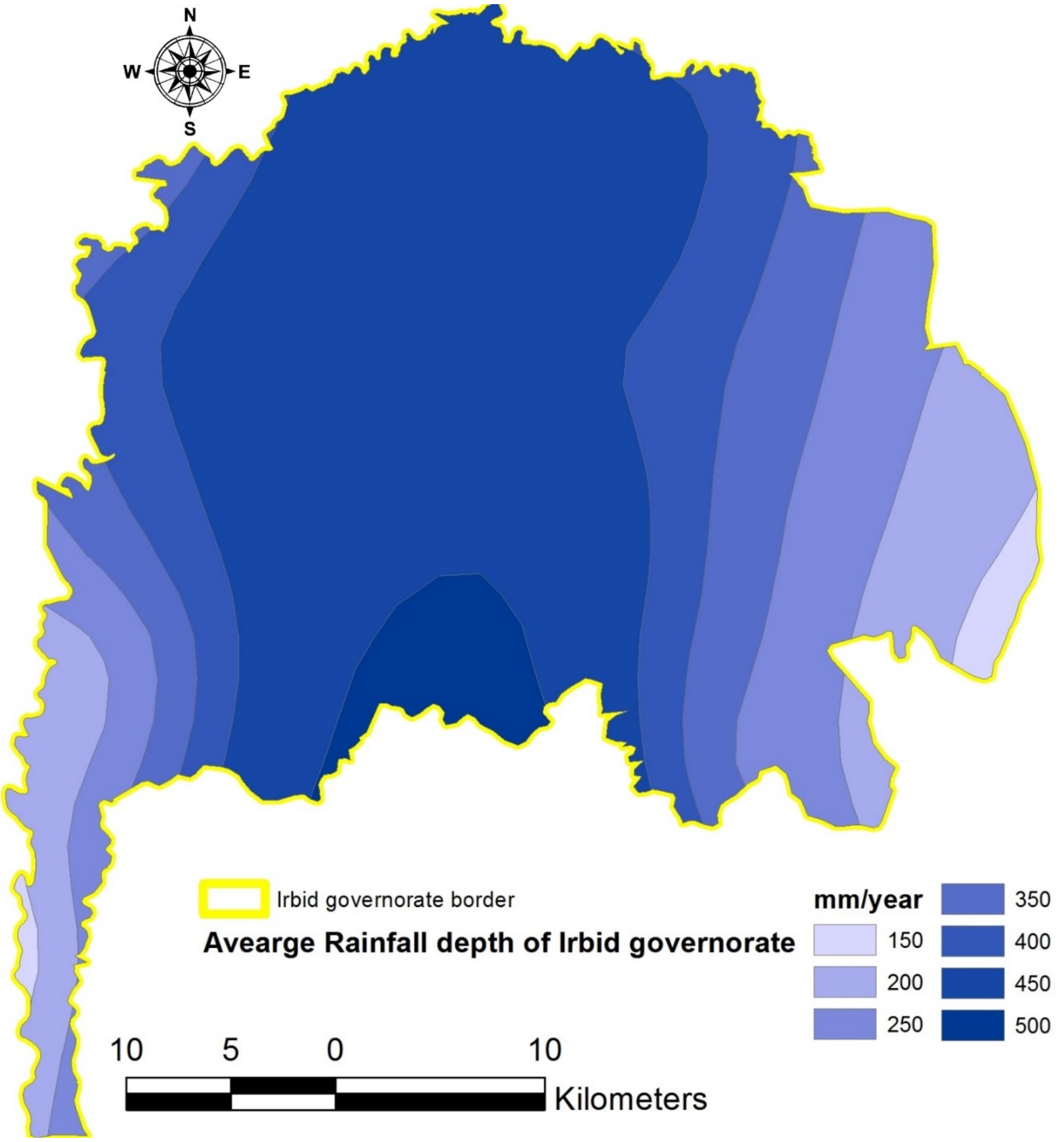


Fig. 3: Rainfall quantity spatial distributions of the study area (average of 40 years 1984 – 2014). Meteorological Department 2014 open data source. The amount of rainfall is over the highest topographical elevation at Ajloun mountains.

Irbid governorate is located in the north-western part of Jordan. Two major rivers pass through the governorate, Al Yarmouk River in the north and the Jordan River in the west; nevertheless the major source of water supply is it groundwater resources [3; 4; 15; 17]. This is because the discharges of the two mentioned rivers is limited (Al Yarmouk River 14.5 m^3/s, Jordan River 16 m^3/s) and because they are both of transboundary nature, hence Jordan needs to respect the bilateral treaties signed about the uses of these rivers [6; 15].

The groundwater of Irbid governorate comes mainly from a hydrogeological basin called Al Yarmouk. It is shared with Syria and has an area of about 1426 Km^2 [16; 20]. The basin is composed mainly from shallow unconfined unsaturated aquifers. The rock matrix of the aquifers is mainly of tertiary chalks and limestone and basaltic rocks [16]. However, alluvial deposits are found in the wadis especially in the west of the basin. The average hydraulic conductivity of the basin varies from $1x10^{-4}$ to $1x10^{-6}$ m/s. The maximum groundwater level is in the south of the study area and reach up to 1000 m absl. While the minimum the groundwater level is the eastern side of the study area and reach down to about – 239 meter absl. [6; 15]. The groundwater flow from the south to north mostly but in the eastern side of the study it moves from east to west. The average groundwater recharge is about 8% to 10% from the annual rainfall and he safe yield of the basin is estimated to be 40 Million Cubic Meter (MCM) [21].

Irbid governorate received several migrations waves during recent history [22] (Fig. 4). The first wave was in 1948 after the first Arab–Israeli war, when Palestinian refugees came to Irbid governorate. The second wave was after the Arab-Israeli Six Days War in 1967. After the war thousands of Palestinian refugees came to Jordan, settling also in the Irbid governorate. Moreover, other two migration waves came after the first and second gulf war in 1991 and 2003 respectively. Hundred thousands of Jordanians and Palestinians moved from Kuwait to Jordan following the first Gulf War. In 2011 the civil war in Syria started, and about half a million Syrian refugees came to Irbid governorate. Furthermore, Irbid governorate with 3.2% has one of the highest population growth rates in the region. Both the increased number of refugees and the natural high population growth rate play a major role for increasing the number of inhabitants rapidly in Irbid governorate [22; 19]

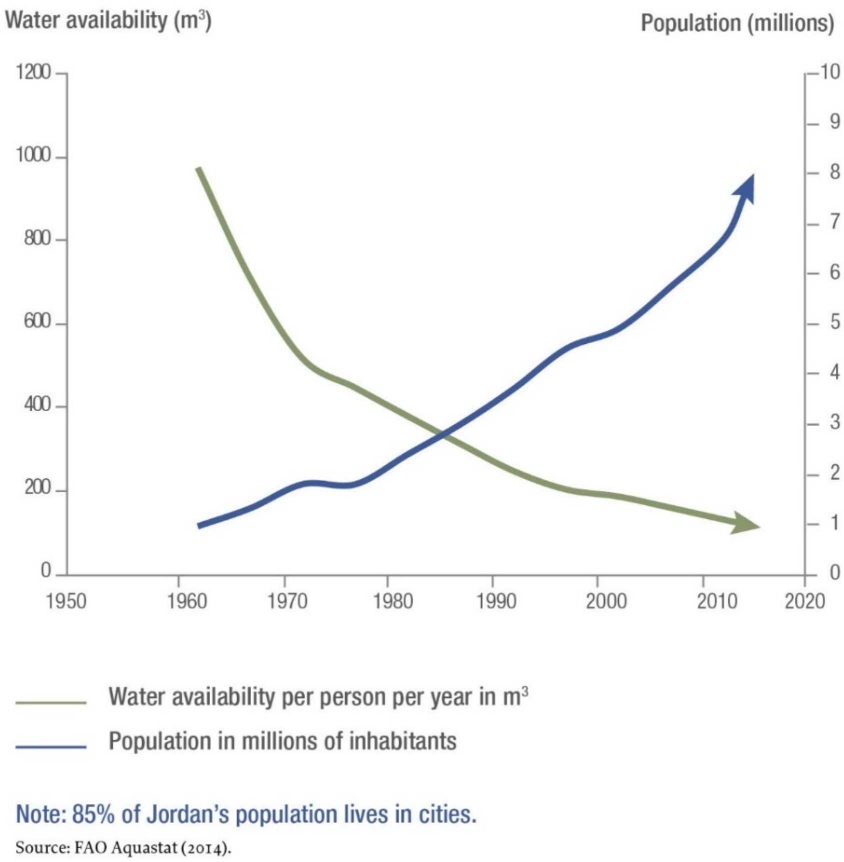


Fig. 4: The population growth in Jordan [23]. The water availability per person is decreeing while the number of the inhabitant is increasing.

The first and main reason of extension of the urban area is the increases population [24]. Naturally, the increased number of habitant and the extended urbanized area would consume more water in order to supply the drinking water and construction water respectively [25]; nevertheless, it has been shown in recent literature that most water supply in Jordan goes to the agricultural sector rather than for domestic uses [4; 10]. Nevertheless, population growth and extension of the urban area in Irbid governorate had an impact on the groundwater level and salinity. This impact was due to increasing groundwater abstraction way beyond the safe yield. This study aims at shading light on this exact relationship.

Methodology

The integrated approach Remote Sensing (RS) and the Geographic Information Systems (GIS) have been recently widely used in order to analyze, store, and display land surface data [26; 27]. However, RS could produce the land surface data of the land cover in form of satellite images, but those images have to be classified in order to generate the land cover classes [28]. The images and their classifications could be stored in form of raster, which is a major type of GIS data (geo-data). GIS is a useful tool for spatial analyzing raster data. Hence, RS and GIS are integrated in a useful approach for land surface data generating [26-29].

Landsat represents the world's longest continuously acquired collection of space-based moderate-resolution land remote sensing data. Four decades of imagery provides a unique data resource for scientists in deferent fields. These data are in form of raster data that is crucial to GIS analysis. It has capacity to provide repetitive and synoptic observations of the land surface that makes it powerful tool in giving information on how land cover changes over a span of time. We used Land sat 5 images for the years of 1984, 1994 and 2004 since it has data record for these years while for the year of 2014 Landsat 7 image was used. Any Landsat image has at least 7 spectral bands with a spatial resolution of 30 meters for Bands 1-5, and 7. For our classifications we used the visible bands that have a resolution of thirty meter and available in for all the landsat images. However, all the landsat images that were used in our study were downloaded from the landsat data access (https://landsat.usgs.gov/landsat-data-access).

ENVI 6 is an image analysis software that is used by GIS professionals, remote sensing scientists, and image analysts to extract meaningful information about the land surface class from the satellite Images [26-27]. ENVI 6 software have a many automated data analysis tools that could access spatial algorithms to rapidly, swiftly, and precisely analyze imagery, such as estimate image geostatistics, measure area and distance features and image supervised classification [26]. Therefore, we used ENVI 6 software as a remote sensing software. The objective from that was to carry out a supervised classification for Landsat images in order to understand the classes of the land surface. However, there are four major methods for supervised classification in ENVI 6 software: Maximum Likelihood, Minimum Distance, Mahalanobis Distance and Spectral Angle Mapper. The minimum distance method gave the best overall accuracy (Tab. 1) therefore we consider it for the classification. Parts of the study area has remote sensing investigations by other studies such Al-Kofahi et al 2017 [30] and Sawalhah [31] were they explained and discussed in details that approach.

However, we categorize the land surface area into only four classes, which have a major influence on the groundwater recharge, as follows: A) Soil units, B) Rock unit, C) Urban land and D) agricultural land. However, we carry out the supervised classification, for the visible bands, to generate these four land cover classes for the Landsat 7 of the time periods of 1984, 1994, 2004 and 2014. These time periods are on constancy with the time periods of the hdrogeologyical data that we would compare the land surface classes changes detections with it (Fig. 5). The validation of the classifications was according to filed work visits for the landsat image of 2014 and Google earths imageries for 2004, 1994 and 1984 landsat images.

Tab. 1: Confusion matrix table. It represents the accuracy assessment for the classifying process of landsat images.

Irbid governorate Land sat Image			Reference data: Soil units	Urban land	Agricultural land	Rock unit	Summations	Users' accuracy
2014	Classifications	Soil units	30	1	9	2	42	0.71
		Urban land	3	28	2	5	38	0.74
		Agricultural land	5	3	27	2	37	0.73
		Rock unit	2	8	2	31	43	0.72
	Summations		40	40	40	40	160	
	Producers' accuracy		0.75	0.70	0.68	0.78		0.73
2004	Classifications	Soil units	31	1	6	3	41	0.76
		Urban land	2	29	1	4	36	0.81
		Agricultural land	4	1	32	3	40	0.80
		Rock unit	3	8	1	30	42	0.71
	Summations		40	40	40	40	160	
	Producers' accuracy		0.78	0.73	0.80	0.75		0.76
1994	Classifications	Soil units	32	2	2	1	37	0.86
		Urban land	1	28	1	3	33	0.85
		Agricultural land	3	1	35	1	40	0.88
		Rock unit	6	7	1	33	47	0.70
	Summations		40	40	40	40	160	
	Producers' accuracy		0.80	0.70	0.88	0.83		0.80
1984	Classifications	Soil units	33	1	3	1	38	0.87
		Urban land	1	30	1	4	36	0.83
		Agricultural land	8	1	34	1	44	0.77
		Rock unit	1	8	1	34	44	0.77
	Summations		40	40	40	40	160	
	Producers' accuracy		0.83	0.75	0.85	0.85		0.82

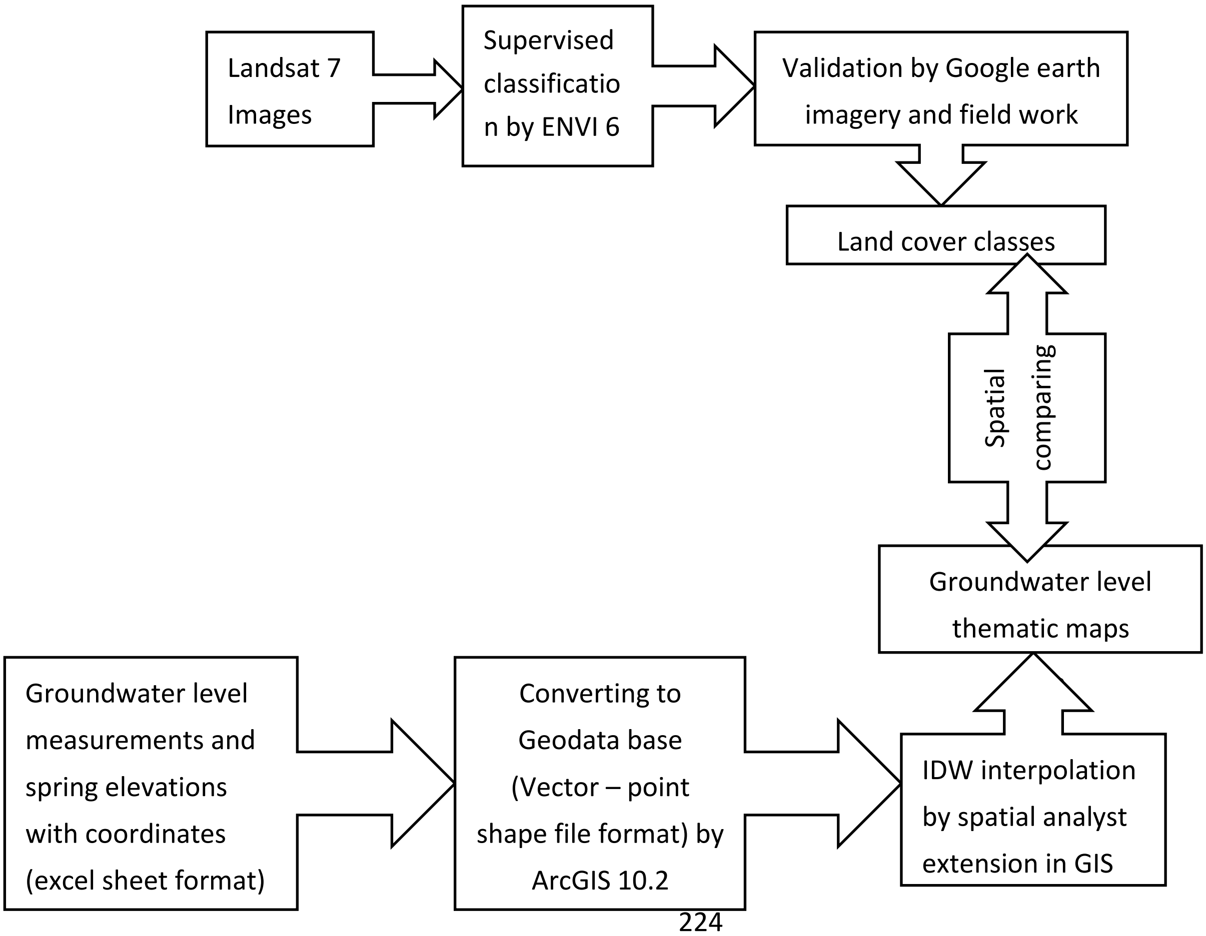


Fig. 5: A flow chart for a conceptual model of land cover – groundwater level changes detection. comparing groundwater level and land cover class. Both of the groundwater level and the land cover class are in form of raster.

The supervised classifications by minimum distance method of all our satellite images has overall accuracy greater than 70% that is applicable according to smith et al 2002 [32]. Thematic maps are one of the most common tools that could be used in order to understand the spatial distributions of specific phenomena [28]. GIS is a powerful tool to achieve that. ArcGIS 10.2 software with its spatial analyst extension is widely used currently for thematic map generating because of its useful interface [33]. Therefore, we used it to generate a thematic map for the groundwater level during time periods of the available groundwater data of Ministry of Water and Irrigation (MWI) in Jordan which are: 1984, 1994, 2004 and 2014.

However, the first step was converting the excel data of the groundwater level of the wells and spring elevations and their coordinates into a vector – points (shapefile namely) by ArcGIS 10.2. The spatial analyst extension in ArcGIS 10.3 could interpolate groundwater levels into thematic maps by the Inverse Distance Weighted (IDW) method. The IDW method includes an estimated weighted average method where the weights of the measured data points, Z(ui), i = 1, 2, …, M, is set inversely proportional to their distances, hi, from an interpolated un measured point, Z (ux). It is could be calculated as follow:

$$Z(ux) = \frac{\sum_{i=1}^{M}\left[\frac{1}{{h_i}^P} \times Z(u_i)\right]}{\sum_{i=1}^{M}\frac{1}{h_i^P}} \quad (1)$$

The values that is in gray shadow represents the overall classification accuracy.

where p > 0 is a power parameter. However, the IDW method has several advantages for interpolation such as: could calculate changes in terrain such as cliffs and faults line in addition to it could increase or decrease the number of the sample points to influence cell values [34]. Therefore, we used it as a method for interpolate the thematic maps of the groundwater levels. For that purpose we used 76 hydrogeological points (Fig. 6) that are in and around our case study. The hydrogeological points are the available wells and spring that have hydrogeological record in the ministry of water and irrigation. However, in general, because of data discontinuity/scarcity, not all the wells and springs have a full hydrogeological record [35]. We chose four time periods for interpolation. These time periods are near to the time periods of the migration waves in order to evaluate how the increasing in the inhabitant effects the groundwater level and hence the groundwater salinity. These time periods are: 19984, 1994, 2004 and 2014. They are the exact time periods of the classified Landsat 7 images in order to compare the land classes detection with the groundwater level changes.

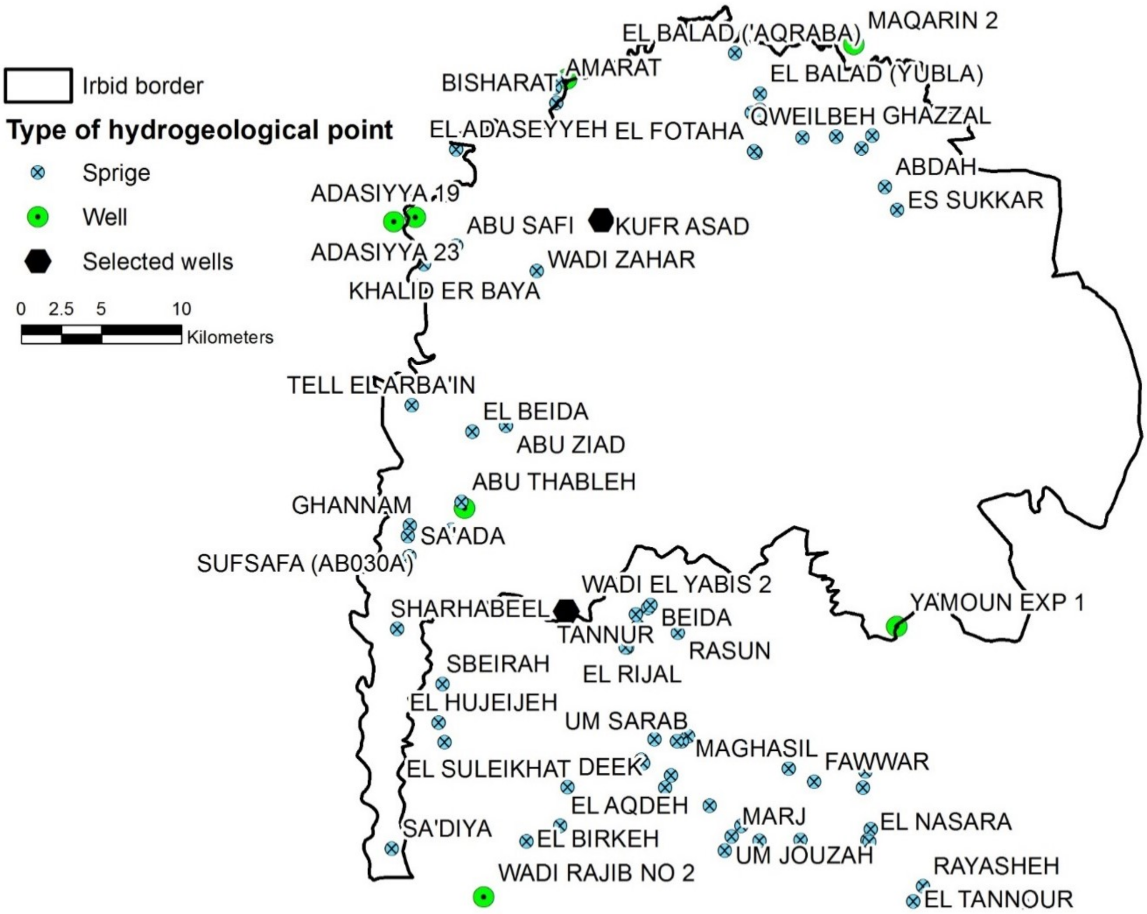


Fig. 6: Available hydrogeological points in the study area. The groundwater levels of these points were interpolated to generate a conceptual model for the groundwater level spatial changes. Not all the wells have complete data record about the water level and salinity for forty years therefor tow well only were selected to detect the changes of water level and salinity.

Results and discussion

Figure 7 shows that the land cover of Irbid governorate was changing unregularly during the last forty years. It also shows that the urbanized area was growing rapidly during the same time, as a result of the growing population [24; 19]. It also shows that the agricultural area decreased in the first ten years (1984 – 1994). This is due to the fact that youth whom were working in the agricultural sector started moving toward the main cities to take up jobs in the governmental sector, which was expanding and employing in that time period [36; 22; 19]. However, the following ten years (1994-2014) the agricultural area started to increase because the governmental sector was almost saturated, stopping expanding and hiring new people, and the people therefore preferred moving toward the agricultural jobs again [22; 19]. In this period many businessmen were investing in land and agribusinesses in this part of the country, expanding agricultural activities and job opportunities in the area [4].

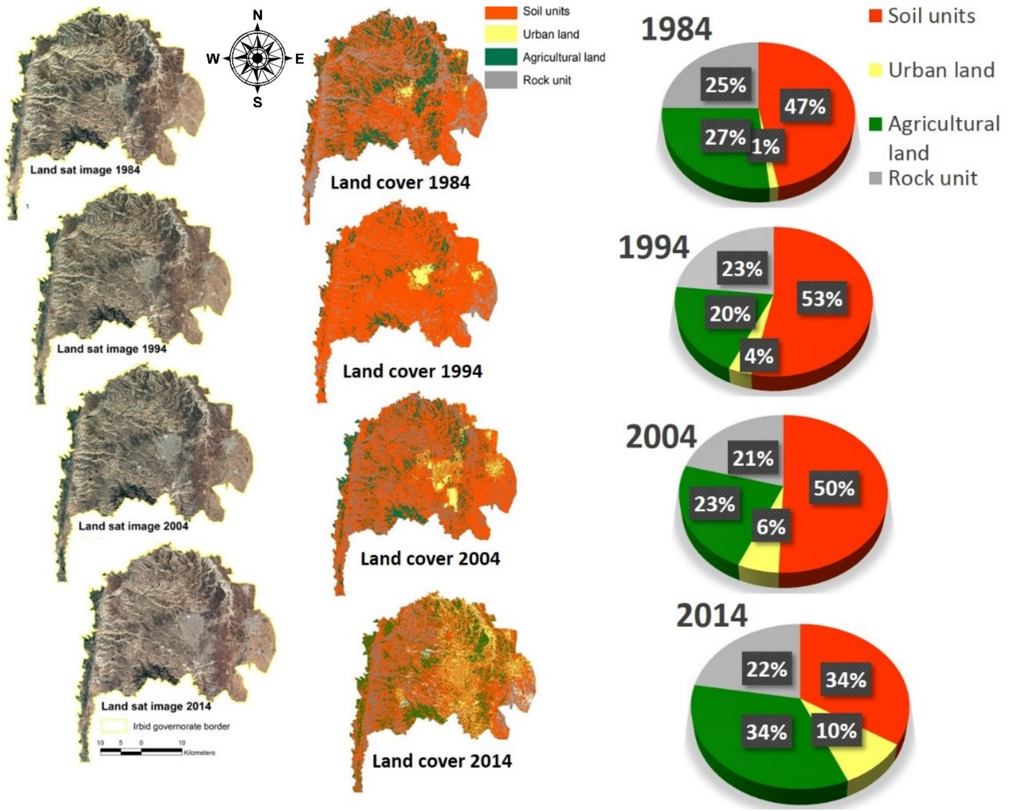


Fig. 7: Land cover changes detections of the study area. During the last forty years the urbanized area were extended rapidly. Land sat 5 images were used for the years of 1984, 1994 and 2004 while for the year of 2014 Landsat 7 image was used to generate a conceptual model for the land cover spatial changes.

From a geological perspective, the area of the soil is associated with the area of agricultural land [37]. When the area of the agricultural land decreased in the first ten year the area of the soil increased [37; 38]. Moreover, in the following thirty years people started moving back toward the agricultural activity, therefore, the agricultural land area increased [18; 19; 22].

The area of rock unit was decreasing during the first thirty years since people prefer to construct the basement of houses, which is the major part of the urbanized area, on that unit in order to reduce the cost of construction by not digging the soil [38; 39; 19]. The houses basements have to be on rock layer so they do not crack during the winter as a result of soil liquefaction [34]. However, in the last ten years the rock unit shows a slight increase up to 1% as a result of the soil erosion that increased in the last 10 years [33].

Figure 8 shows the groundwater level spatial distributions of the study area. It shows where the groundwater level changed as a result of the land cover changes during the last forty years. However, land cover effects the groundwater level in two ways: 1) Reducing the groundwater recharge by increasing the runoff water that is increasing urban area span and/or 2) Consuming more groundwater in order to meet the high demands for irrigation and drinking purposes when the agricultural land extended and the inhabitant increased respectively [40]. Both these ways impacted the spatial distributions of groundwater level on the study area but the effects were not spatially homogeneous.

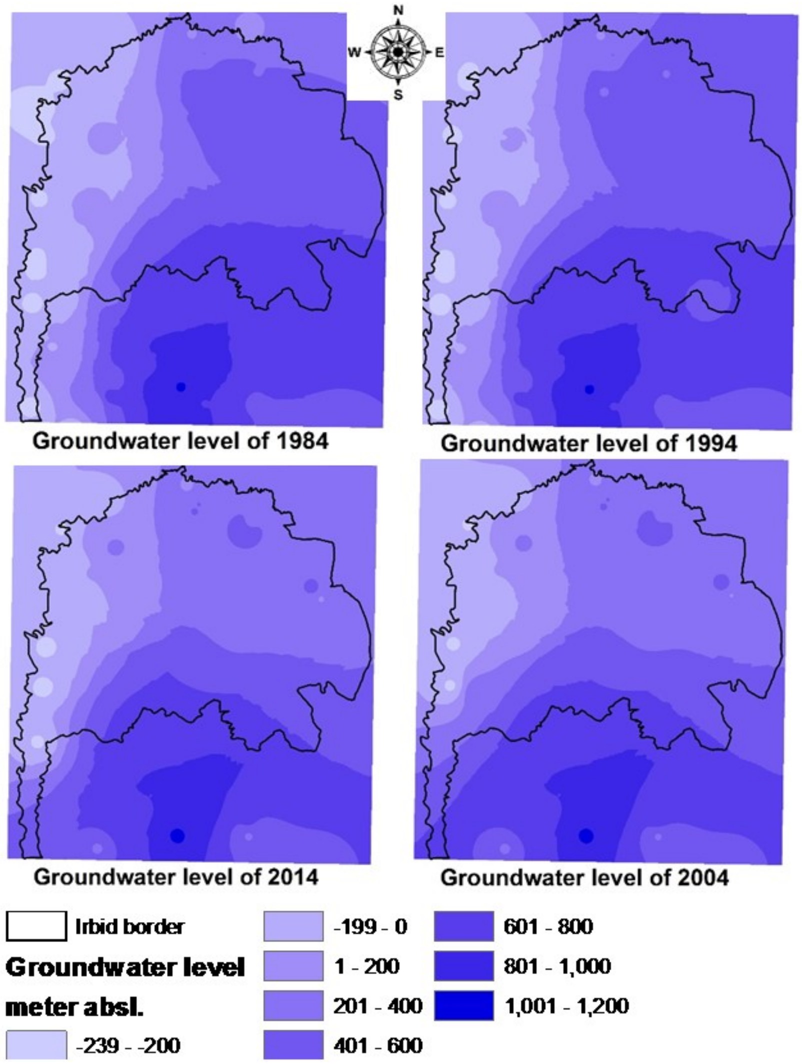


Fig. 8: The conceptual model of the groundwater level changes spatial detections of thirty years duration. In the first ten years (1984 – 1994) the groundwater level was rising in the north west of the study area. After 1994 the groundwater level decrease in the same area as a result of the extended urbanization.

From 1984 to 1994 the groundwater level increased in the north and northeast part of the study area as a result of the decrease in agricultural activities during that time period, which meant decreasing in pumped irrigated water [17]. However, in the south-eastern part of the study area a zone of groundwater over-pumping was generated as result of heavy groundwater mining to supply the increased number of inhabitants in that area, which saw a strong increase in urbanization.

From 1994 to 2004 the groundwater depletion strongly impacted the north and northwestern part of the study area as a result of the extending agricultural and urbanized area. Limestone sinkholes started to be an obvious landscape phenomenon in that area as a result of the groundwater depletion [41; 30]. However, the southern part of the study area has the highest elevation and received the highest amount of rainfall so it has the highest amount of groundwater recharge.

From 2004 to 2014 the groundwater depletion impacted the east and the southeastern part of the study area since the urbanization extended more intensively and the population increased as a result of the latest wave of migration [19; 22] (Fig. 9). Hence, it is clear that groundwater depletion is associated with the land cover detection in the study area.

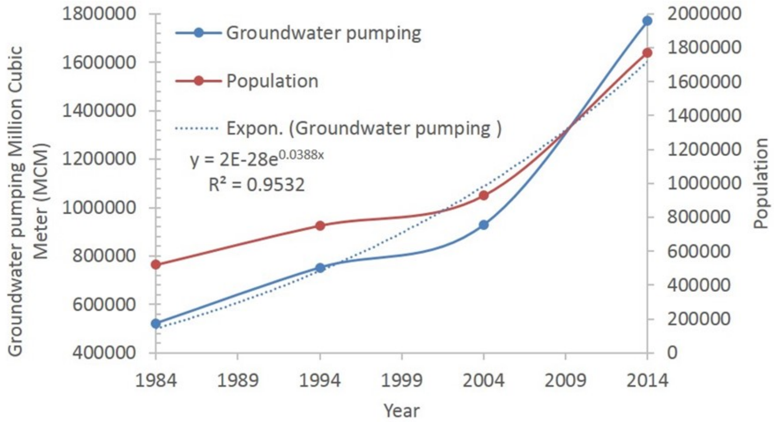
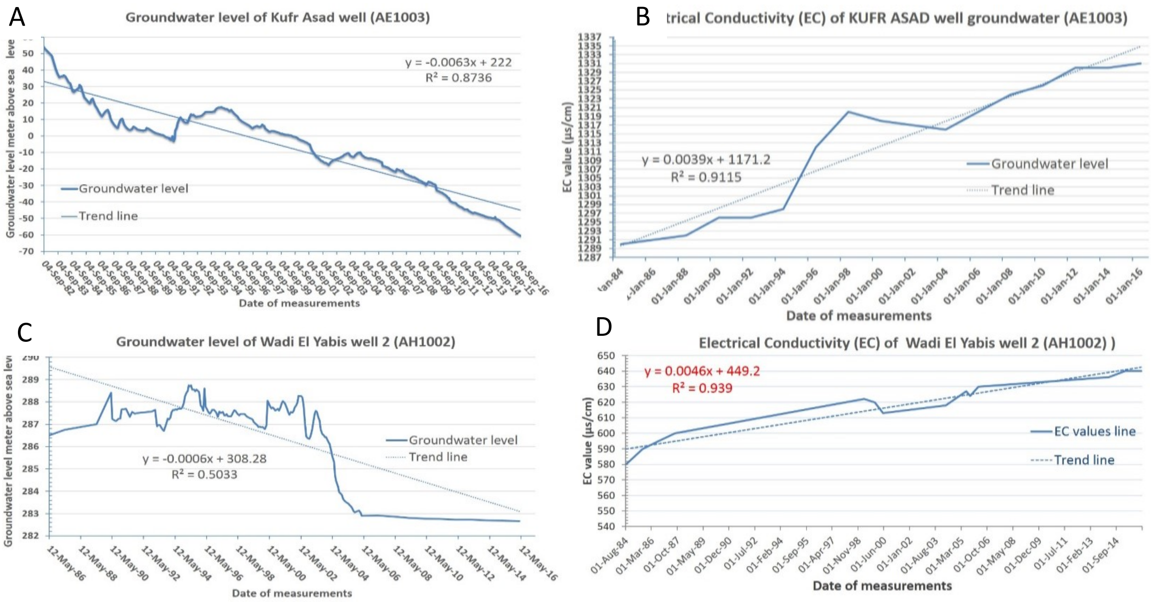


Fig. 9: Population growth and Groundwater pumping increasing in Irbid governorate. They are both in Exponential increasing.

The available hydrogeological data record of the study area received from the MWI were also examined and this study found that only two wells have data about the groundwater level and salinity for forty years. The objective of that was to correlate the decreasing level of groundwater with its increasing salinity. Previous studies confirmed that in Jordan salinity increases with groundwater level decreasing [42]. This is due to the fact that deeper waters have more retention times to accumulate dissolved salts than the higher water. Figure 10 shows that the groundwater



level in the

Fig. 10: Groundwater level changes (A and D) and groundwater salinity changes (B and C) in the two selected wells. Kufr Asad well locates in the north of the study area while Wadi El Yabis well locates in the south of the study area.

northern part of the study area decreased more rapidly than the groundwater level in the southern part and that the salinity of the groundwater in the north was increasing faster than in the south.

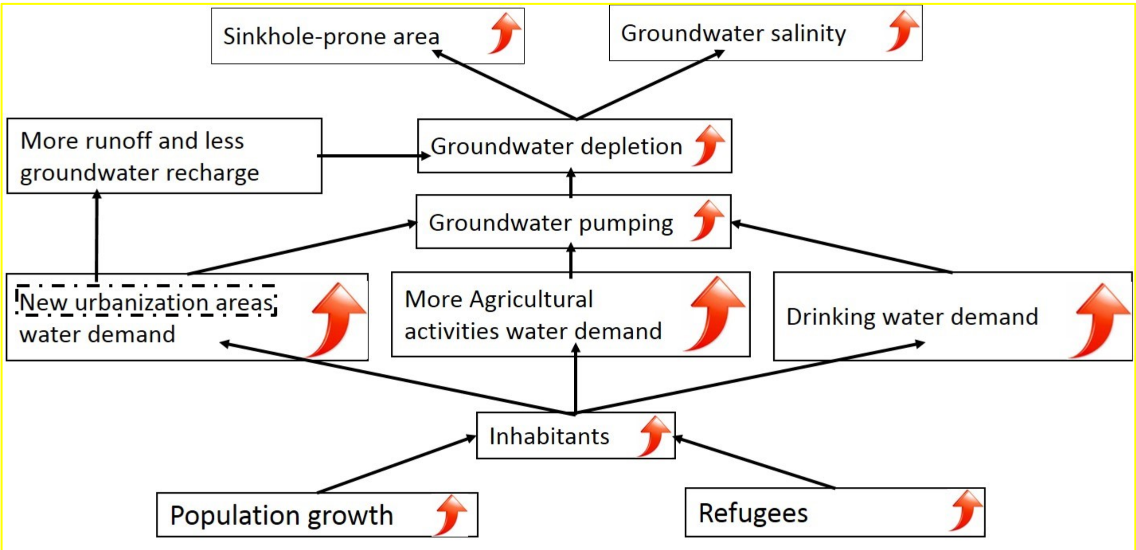


Figure 11 shows our conceptual model in form of flow chart. It indicates that the repaid increased

Fig. 11: A conceptual model for the mechanism of the increased inhabitants effects on groundwater. When the groundwater level is decreased the groundwater salinity is increased and sinkhole-prone area would increase too.

The number of inhabitants increased the groundwater demands which generate more groundwater pumping. The annual groundwater pumping is much more than the annual ground recharge therefore groundwater level decrease characterize a typical case of over-pumping. Our model indicates that that the over-pumping in our case study doesn't only increase the groundwater salinity but it creates sinkhole prone area.

Conclusions

There is a strong positive correlation between the groundwater depletion and extending urbanization and agricultural activities. Unsurprisingly, population growth is linked to extending urbanization and urban areas, as well as agricultural activities and agricultural investments. Drilling pumping wells has to consider the zonation of surface rainfall and the zonation of groundwater recharge. The area of highest amount of rainfall is usually the area of highest amount of groundwater recharge and it is more resistant and resilient to groundwater depletion. This study also found a positive correlation between the groundwater level and groundwater salinity, therefore population growth, urbanization, and agricultural activities do not threat only groundwater quantity (when over-pumped, such as in the case of northern Jordan), but also groundwater quality.

In the case of limestone aquifers, sinkholes are natural risks that impact the area of groundwater depletion zone. In the study area, sinkholes and the groundwater zones are extended rapidly and intensively where the groundwater depletion is found. Sinkholes have a direct negative impact on the urbanization areas because of its ability to destroy houses, buildings, and roads. Thus, the effects of groundwater depletion are not only negative on the water quality but also on the urban safety too.

Conceptual hydrogeological models are very important in order to conduct a sustainable management of the groundwater resources. They describe the elements of the water conflicts and prerequisite for solid numerical groundwater models. Our conceptual model for the water crisis in Irbid governorate indicates that groundwater is the major water resource and its abstraction quantities is rapidly increased in order to supply the increased number of inhabitants and their activities. However, our model indicates the abstraction rate is much more than the groundwater recharge rate, therefore the groundwater level decrease. We do recommend a numerical groundwater modelling for the study area in order to determine the optimized quantity of groundwater pumping. Furthermore, alternative water resources in the study area must be generated in order to reduce the pressure on the groundwater resource.

Acknowledgement: The authors are grateful to the Ministry of Water and Irrigation (MWI) for providing the groundwater data used in this paper.

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