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# The Impact of Land Use and Land Cover Changes on the Underground Water Quality of the Amman, Zarqa and Balqa Regions in Jordan

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**Abstract:** The demand for water and land resources is rapidly increasing with increasing population and human activities in Jordan. Current land use activities have led to a loss of vegetation cover and a decrease in underground water quality. Remote sensing and GIS technologies and standard water quality analysis techniques were used to assess the vegetation cover and the underground water quality for three selected zones in the Amman-Zarqa basin. The objectives of this study were to determine how land use and land cover changes have affected the underground water quality of the Amman, Zarqa and Balqa regions in Jordan. Underground water quality data from selected wells for 2004 and 2010 were processed using the Getis-Ord Gi* statistic to identify the changes in the hotspots of the Amman, Zarqa and Balqa aquifer systems for the parameters of pH, nitrate and conductivity levels. These three parameters were examined for 57 wells. The results indicated that localized periodic fluctuations in groundwater contamination were creating contamination hotspots within the Amman-Zarqa basin. The results for the values of pH nitrate and conductivity revealed areas with higher than average hotspot contamination for 2004 and 2010 in the Zarqa region. The results suggested that the two major localized areas of contamination for all the parameters are centered on the western Zarqa region. This region is an area dominated by urban infrastructure and irrigated lands. We used Remote Sensing and Geographic Information Systems (GIS) to investigate the land use and land cover changes from 2004 to 2010 and linked these changes to the changes in water quality. Mahalanobis distance supervised classification was conducted on both Landsat and ASTER images to determine the extent of land use and land cover change. The study found there were clear changes in urban and vegetation land use and land cover classes between 2004 and 2010 in the study regions. The study also indicated that the land use and land cover change have a significant impact on the water quality, resulting in the increased hotspot levels of pH, nitrate and conductivity.

**Key words:** Hot spot · pH · Nitrate and conductivity · GIS · Remote sensing · Land use · Land cover · Jordan

## INTRODUCTION

A significant issue for water quality in many countries in the world is non-point source pollution [1], that is, anything that can have an indirect impact on water quality. Land use and land cover change also have an impact on the water quality and the land and air resources [2]. In Jordan there is a growing national security need exists to develop a sustainable agricultural system that maximizes water availability in line with population growth, particularly because the importation of water can be highly volatile and dependent on the stability of the states from which the imports are drawn, as exemplified in the food crisis of 1991 [3, 4].

Currently the Amman-Zarqa basin supports most of the region's demand for domestic, industrial and agricultural water supply. Wadi Es Sir, a basalt aquifer and Kurnub, sandstone aquifer are two of the most important aquifers in this basin which significantly contribute to covering this demand [5]. However the aquifers are connected and as a consequence localized contamination eventually permeates the entire aquifer system [6].

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Strong causal relationships have also been shown to exist between land use and land cover change and declining water quality [7]. There are extensive aquifers underlying the region, which have suffered historical degradation and decline in the water table as a consequence of over-exploitation and contamination from anthropomorphic activities [8, 9]. In some parts of Jordan, such as Badia, changes in land use and land cover driven by a range of demographic, socio-economic and environmental factors have been shown to have had direct impact on the water quality [10, 11]. As a consequence, the Jordanian Government has initiated policies that seek to address this decline.

Remote Sensing and Geographic Information Systems (GIS) are tools to produce accurate and timely information on the spatial distribution of land use and land cover changes over broad areas [12, 13]. GIS has been used to improve the spatial understanding of water pollution sources and hotspots [14, 15, 16]. [17] used GIS to map the spatial geochemical distribution of lead in the aquifers under the city of Karachi, which enabled the identification of high risk zones and also enabled the identification of possible sources of contamination. GIS has also been used as a strategic tool in the development of water harvesting management programs. GIS has enabled the selection of water harvesting sites for study through the real-time integration and identification of the bio-physical and socio-economic aspects of the sites available for selection [18]. Remotely sensed imagery also has many civil applications involving environmental damage evaluation, growth regulation and land use monitoring [19]. Remote sensing has been used to identify population growth, land use and land cover change using methods such as time-series, NDVI and Mahalanobis distance classification techniques. Using a process called supervised classification; the changes in land cover and land use were identified using a number of groups or clusters of cells with similar characteristics in an n-dimensional space [20].

There is a growing body of evidence that supports the use of GIS and remote sensing in water quality and resource management areas and they are increasingly becoming important tool in countries like Jordan, who are faced with continuing declines in water quality. This study utilized GIS and remote sensing to: a) map contamination hotspots in the aquifer system, b) identify land use and land cover change using Mahalanobis distance classification, which is determined to be the most accurate and useful method compared to other similar classification techniques such as the minimum distance method for this type of work [21] and c) explore the impacts of these changes on water quality in the Amman, Zarqa and Balqa regions of Jordan.

## MATERIALS AND METHODS

**Study Area:** This study focused on the three main administrative regions (or zones) of the Amman-Zarqa basin, the Amman, Zarqa and Balqa administrative regions, where the majority of urban and agricultural development has been centered (Fig. 1). These administrative regions cover an area of approximately 1945 $km^2$ located in the upland area of northwest Jordan at elevations between 500-1000m above sea level with an annual precipitation of 150 to 600 mm per year [22, 23].

**Data:** Monthly data collected of the pH; nitrate and conductivity from 57 wells for 2004 and 2010 were obtained from the Water Authority of Jordan to identify changes in the underground water quality. The 57 wells covered most of the area of the three administrative regions of Amman, Zarqa and Balqa. The wells were chosen based on the availability and completeness of the water quality data over the period of study. Samples were collected from each well for 2004 and 2010 by Department of Water Authority field workers and in accordance with the ISO/IEC 17025 standards.

The pH level was determined by the colorimetric method using an ORION EA 940 pH/ISE. The nitrate levels were determined using a Varian-USA: Cary 1E UV-Visible spectrophotometer. The conductivity was measured using a digital Orion A 150 conductivity meter. After collection, the field data was transferred to an Excel SPREADSHEET to calculate the yearly averages for 2004 and 2010. These results were then used for GIS analysis. A map of the Amman-Zarqa basin was created using Geographic Information System software (ArcGIS 9) to digitize as well as to show the location of the 57 wells that were selected across the three zones of the Amman-Zarqa basin.

Landsat Images for 2004 were obtained from the US Geological Survey (USGS), while ASTER images for 2010 were supplied by Geoimage Pty Ltd, Sydney. Two different sensors (Landsat in 2004 and ASTER in 2010) were used because no Landsat images were available for 2010. ENVI remote sensing software was used to form mosaics of the 2004 and 2010 images, after which the Mahalanobis distance supervised classification approach was used to detect and analyze the changes in land use and land cover between 2004 and 2010. Details of the satellite data used in this study are presented in Table 1.

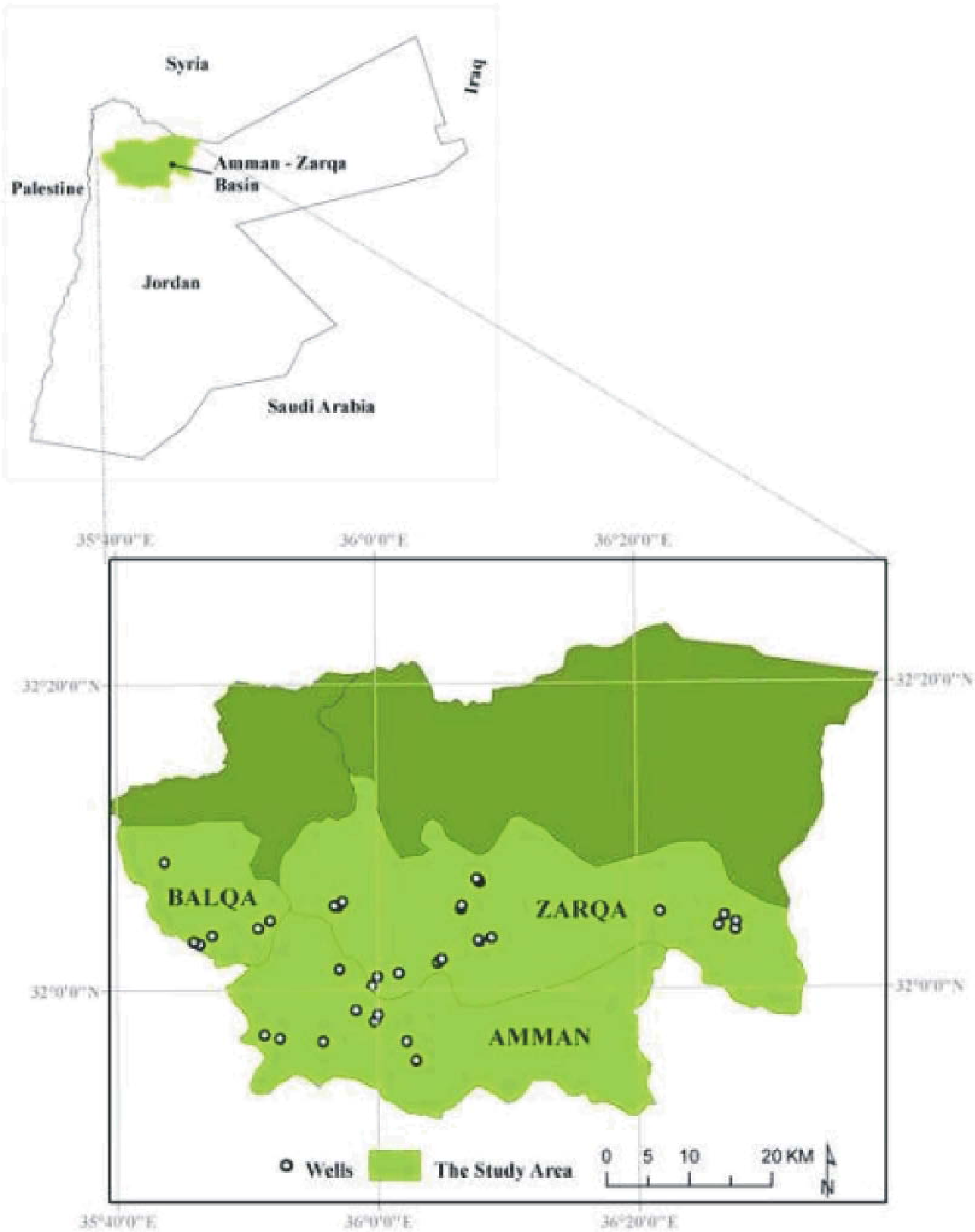


Fig. 1: Location of the study area showing the 57 wells used in this study in the Amman, Zarqa and Balqa administrative regions of the Amman-Zarqa basin in Jordan

Table 1: Details of the Landsat and ASTER data of 2004 and 2010 of the study area

| Date of Image | Satellite Sensor | Path and Row |
|---|---|---|
| 05-04-2004 | Landsat 7 ETM+ | 173-38 |
| 14-05-2004 | Landsat 7 ETM+ | 174-38 |
| 24-04-2010 | STER | 173-38 |
| 12-04-2010 | STER | 174-38 |

**Data Analysis:** Different techniques were used to identify and visualize the water quality hotspots. A number of local statistical techniques, such as geographically weighted Poisson regression (GWPR), Getis-Ord Gi*, local indicators of spatial association (LISA), multi-logistic regression, local Moran's I and Geary's index, have been developed to measure the spatial dependency to the surrounding neighbors of the sample data (e.g. wells) within a study area. Consequently, these types of statistics can easily be used to identify and visualize the hotspot areas. In this study, the Getis-Ord Gi* statistic (Equation 1) was applied to investigate the local level spatial clusters to identify and visualize the wells, where the value of the different water characteristics, e.g. conductivity, nitrate and pH, were extreme and geographically homogenous. This analysis is primarily helpful for resource allocation type problems. The analysis identifies so-called hotspots of these chemical variables, where the value of the index is extremely pronounced across the selected wells in the study area. First, the spatial relationships, which specified how the relationships between any one of the variable locations in the study area was calculated, were determined using the fixed distance band. The fixed distance band included the locations of wells inside the boundary of the study area and it excluded everything outside that boundary. Also, it was used because it was generally more suitable than the inverse distance conceptualization methods [24]. Second, the Euclidian distance was used as the distance method. The output of this analysis was a z-score and p-value for each well in our study area. The districts with high z-scores (> 2) indicated a spatial clustering of a high level of hotspots and the wells with low z-scores (< 1) indicated a spatial clustering of a low level of hotspots. Kriging was then used to generate a more efficient visualization of the hotspot distributions for the different wells in the study area. Kriging is a GIS analysis technique that creates a continuous surface map based on point data. We used an ordinary kriging method with a spherical semivariogam model. The cell size at which the raster surface was created was 250m. Kriging surfaces are effective in identifying where heavy elements are concentrated by highlighting areas (hotspots) based on the z-scores resulting from the previous stage. Many studies have used kriging to estimate or identify hotspots of heavy metal concentration or contamination. [25] studied the spatial and temporal variability of nitrate using kriging and co-kriging methods with groundwater. Their results demonstrated that both methods can be used to increase the accuracy of estimating nitrate concentration levels.

Cloud free Landsat and ASTER satellite images of the study area were evaluated for determining the changes in land cover over a temporal scale representing an approximately 6 year interval for the period between 2004 and 2010. The 2004 and 2010 Landsat and ASTER images for Amman, Zarqa and Balqa were stitched together to form a mosaic image and then applied for classification.

A number of supervised classification methods were evaluated, including parallelepiped, minimum distance, maximum likelihood and Mahalanobis. Mahalanobis distance supervised classification was found to be the most accurate method and a more useful method than the other similar classification techniques for the purposes of this study. A Mahalanobis distance supervised classification was therefore conducted in ENVI [26]. Four land use and land cover change classes (urban, vegetation, barren land and water) were used. The resulting classifications were then exported into ArcGIS 9 where the final land use and land cover change maps were produced and analyzed with the water quality and hotspot information.

The purpose of this study was to demonstrate the relationship between land use and land cover changes such as agricultural, industrial and urban area change and the hotspots of water quality. The hotspot data for 2004 and 2010 was overlaid onto the land use land cover maps of 2004 and 2010 to identify the correlation between the land use and land cover changes and the water quality changes.

## RESULTS

**Spatial and Temporal Changes of Land Use and Land Cover from 2004 to 2010:** This study indicated that there were significant changes in land use and land cover between 2004 and 2010. The results indicated that many of the vegetation, forests and other wilderness areas have been replaced with houses, farms, factories, roads and streets in the study area, especially in the Amman and Zarqa regions (Fig. 2, g and h).

Data presented in Table 2 illustrated that the changes in the land use and land cover classes from 2004 to 2010. The total area of the Amman, Zarqa and Balqa regions is approximately 1941 $km^2$. In 2004, the total area of barren land was almost 1455 $km^2$ (75%), while in 2010, this area reduced in size by12% to be approximately 1222 $km^2$ (63%). The urban area was 241$km^2$ (12.42%) in 2004 and increased in 2010 to 414$km^2$ (21.3%). The vegetation land area in 2004 was 244 $km^2$ (12.6%), while in 2010 the vegetation area increased to 305 $km^2$ (15.7%). The total loss of barren land from 2004 to 2010 was 233.6 $km^2$ (12%), which became 173$km^2$ (8.9%), of urban area and 60.9 $km^2$ (3.1%), of under vegetation area.

**Spatial and Temporal Changes of Conductivity, Nitrate and pH During 2004 and 2010:** There were notable changes in the conductivity, nitrate and pH hotspots during the study periods (2004 and 2010). For more details

Table 2: The change in the land use and land cover classes from 2004 to 2010

| Land Features | 2004 Area ($Km^2$) | 2004 Area (%) | 2010 Area ($Km^2$) | 2010 Area (%) | Difference ($Km^2$) | Difference (%) |
|---|---|---|---|---|---|---|
| Barren Land | 1455.5 | 74.1 | 1221.9 | 62.9 | 233.6 | -12.0 |
| Urban | 41 | 12.42 | 414.0 | 21.3 | 173.0 | 8.9 |
| Vegetation | 244.269 | 12.58 | 305.2 | 15.7 | 60.9 | 3.1 |
| Total | 1940.77 | 100 | 1941.1 | 100 | - | - |

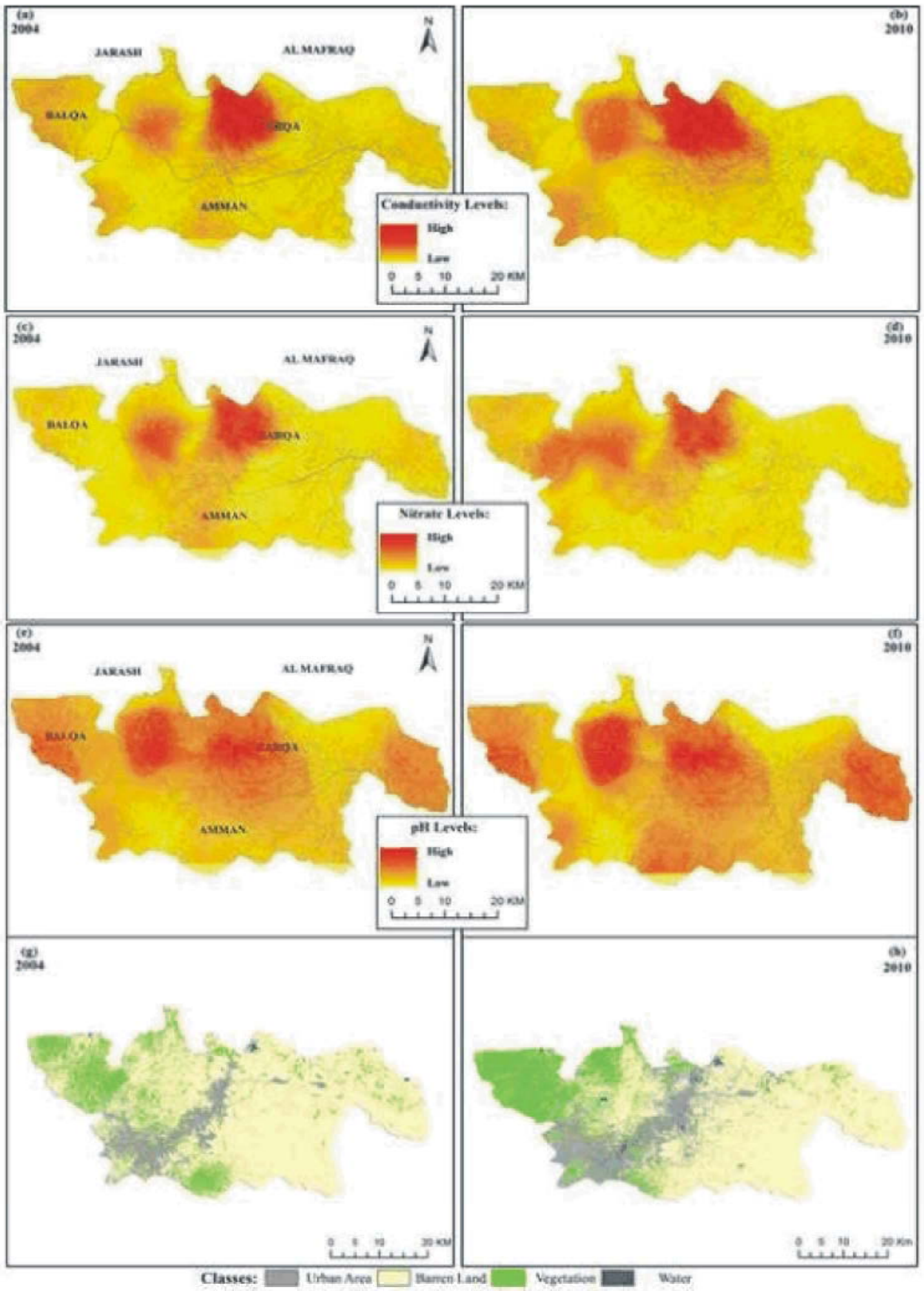


Fig. 2: Changes in conductivity, nitrate and pH hotspot levels and the land use land and cover changes between 2004 and 2010

about the hotspot analysis and modeling [15]. The high levels of conductivity in 2004 were identified in the urban and vegetation areas in the central to northern Zarqa regions, while in 2010 the high levels of conductivity increased and expanded around the area of the central to northern Zarqa (Fig. 2, a and b). The high levels of nitrate concentrations in 2004 were notable in the central and western Zarqa region, which is occupied by urban and vegetation areas, while in 2010, the high concentration of nitrate level expanded in the urban and vegetation areas that were hotspots in 2004 in the central and western Zarqa regions. In addition, in 2010 in the south east Balqa region, which is primarily a vegetation area, there is a high level of nitrate was not seen in 2004 ( Fig. 2cand d). The high level of pH concentration in 2004 were notable in the urban and vegetation areas in the central and western Zarqa region, including small parts in the Balqa region, while in 2010, the high levels of pH cover almost all the classes of areas of urban, vegetation and some parts of barren land in the central, northern and western Zarqa with small part in the southern Balqa region (Fig. 2 e and f).

## DISCUSSION

Competing land use priorities exist between the industrial, agricultural and growing regional urbanization pressures driven by population growth. The relationship between population growth and the built-up areas in the Amman, Zarqa and Balqa zones play a complex role in the declining water quality and water availability in these regions. In the Amman and Zarqa regions, a large number of people live and work in small localized districts. In addition, the Amman and Zarqa regions are designated as multi-use regions therefore, significant competition already exists between the urban, agricultural and industrial needs. These factors are contributing to the increasing pressure on the existing underground water resources and the rapid decline in water quality.

The results of this study demonstrated that the urban and vegetation areas of the Zarqa zone had high-level hotspots of conductivity, nitrate and pH. While, individuals in Jordan have a sound understanding of the complexities of water management, they do not consider the issues of supply and quality as being relevant. The identification of hotspots is an urgent issue that needs to be addressed, particularly because people are drawing their household water supplies from wells contained in the study area. This study used GIS and remote sensing technology to highlight the hotspot levels and to identify the land use and land cover charges related to the underground water quality.

In Jordan, the maximum allowable limits for conductivity, nitrate and pH in drinking water are determined by the Jordanian Institution for Standards and Metrology (JISM) According to JISM, the maximum allowable conductivity is 1000 µs/cm, the maximum nitrate level is 50 $mgL^{-1}$ and the maximum pH level is between 6.5 and 8.5.

High conductivity is related to two major problems that do not directly impact human health: first, water tastes increasingly salty after µs/cm and second, the corrosion of plumbing and appliances with each 100 µs/cm shortens the life of the appliance by one year [27]. Notwithstanding the increase in pH, all the wells remained within the parameters that are considered safe for drinking water. The safe pH range before the clinical manifestations of skin irritation and injury to mucus glands occur is pH 4-10 [28]. High nitrate levels are of significant concern, because levels above 50$mgL^{-1}$ can affect infants and levels above 100 $mgL^{-1}$, can affect those who are pregnant. The major indicator of nitrate poisoning is cyanogen due to methaemoglobinaemia [29].

From 2004 to 2010 approximately 12%, of the barren land have been changed to urban and vegetation areas in the Amman, Zarqa and Balqa regions. This change indicated that there are a growing number of urban centers in the central Amman and Zarqa regions which has led to the loss of arable land use. Land degradation and land cover changes have been widely recognized as major problems that affect the water quality in Jordan. Among the major causes of land degradation are agricultural practices, shifts in land use, removal of natural vegetation, use of machinery and agricultural chemicals, modification of hydrological systems as well as increasing populations in existing urban areas, all of which has led to an increase in water demand and a decrease in water quality and water availability.

The results of this study indicated that the increases in population and built-up areas in the Amman, Zarqa and Balqa regions, as well as the increased drawdown of water from the aquifers, has led to a decline in the water quality and water availability in these regions. Already, the supply of water in urban areas is so unreliable that many households only have access to their mains-water-supply for as little as one day a week and must to buy water from the market to meet their domestic needs and when the mains-water-supply is unavailable [30].

Increased water extraction from wells is placing pressure on the existing aquifer system and is leading to declines in water quality over the long term. Coupled with periodic droughts and ongoing seasonal use, the aquifer water levels are already declining [31].

Agricultural practices and landfill also play significant roles in the decline of underground water quality and water availability in Jordan. The recharge of water in Jordan occurs naturally by precipitation percolating through the soil into the aquifers. Many of the aquifer systems in the Zarqa region are recharged from flows in the Zarqa River. However; [32] mentioned that progressive urbanization has led to increase the surface runoff and decrease the underground water recharge. There is a lack of artificial recharge to offset declining groundwater and to provide water in times of drought. Therefore, in urban and suburban districts much of the land surface is covered by buildings and roads, that do not allow the rain to soak into the ground, thus causing water flows in a different direction and enabling the pollutants to be carried into the soil and then to the underground water bodies without being removed by infiltration. Unfortunately, this runoff causes serious harms to the underground water quality and can be a reason for the increased amount of conductivity, nitrate and pH levels in the underground water.

The large amounts of fertilizer used in Jordan to improve agricultural production have led to the infiltration of these chemicals into the aquifer system. Since 1960, fertilizer use has risen steadily from an annual average of less than 5 thousand tons per annum to over 50 thousand tons by 2000. The use of fertilizer in Jordan has been highly variable over time. The observed periodic pulse rise in the application of fertilizer is indicative of the uptake of improved agricultural farming practices and a rise in intensification. There are four distinct periods in the development of fertilizer use in Jordan during the last half century [33], which are associated with periods of increased agricultural productivity. In addition, the use and application of treated wastewater by farmers for irrigation has further increased this chemical loading. All of these factors have contributed to the significant declines in the groundwater quality across all the regions.

Other studies, [34], argued that landfill leaching is also one of the most significant issues impacting groundwater. In this process the leachate contaminants first enter the unsaturated zone before eventually being transported to the groundwater in the saturated zone [35]. In the Amman, Zarqa and Balqa regions large amounts of waste materials, discarded every year from hospitals and industrial sources, have infiltrated the soil and led to waste materials penetrating the groundwater table [15]. This waste infiltration potentially exposes the wider Amman-Zarqa basin to contamination and pollution from landfill pollution, especially because the aquifers are connected.

As population increases in the Jordanian cities, such as Amman and Zarqa, due to a consequence of not only local but also political migration and social change, the demand for food and water to cover resident's needs, also increases, along with demands to assist the country economically through the growth and development of the agricultural and industrial markets. This change in underground water level and ground water quality throughout the year are major contributing factors to the water crisis being faced in Jordan. The recent influx of over one million refugees from Syria is bound to make this situation worse.

## CONCLUSIONS

The use of Geographic Information Systems (GIS) and Remote Sensing has enabled the identification of contamination hotspots and their connection to the land cover and land use changes in the Amman, Zarqa and Balqa regions. Evidences exists in the Amman, Zarqa and Balqa regions for change in water quality parameters that are significantly above the mean well-water parameter levels, due to the increased hotspot levels in these regions and the significant change of land use and land cover from 2004 to 2010. The change in the parameter levels occur in all the variables measured of pH, nitrate and conductivity. The evidence indicates that two major localized regions of high-level hotspot, which are the regions, dominated by urban infrastructure and irrigated lands. Irrigated land leads to higher rates of contaminant infiltration, carrying farm inputs such as nitrogen as well as dissolved salts contained within the soil profile into the ground water. The combination of the lack of urban wastewater treatment facilities, the runoff of rain that comes from roofs and paved areas also (carrying pollutants such as oil, dirt and chemicals) and the presence of landfills has led to increased pollutants entering the water system and by infiltrating through the soil down into the aquifers. These findings have implications for understanding land degradation and land cover changes, which have been widely recognized as a major contributor and source of contamination within the aquifer systems in the Amman, Zarqa and Balqa regions. This research also demonstrated how the use of GIS and remote sensing can effectively enable authorities to take direct action to improve water quality and understand the origins of contaminants.

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