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Modelling Land Change Scenarios in the Gaza Strip and Impacts on the Environmental Elements

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TESIS DOCTORAL

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Basheer Sofyan Abuelaish

Granada, 2017

Directora de Tesis: María Teresa Camacho Olmedo

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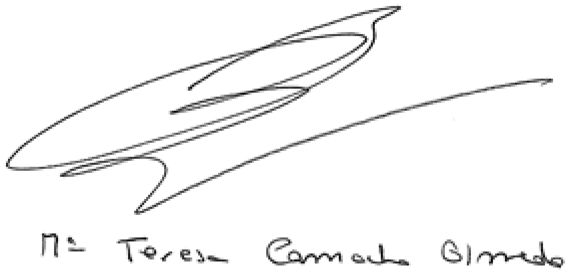


Fdo. María Teresa Camacho Olmedo

Granada a 4 de septiembre de 2017

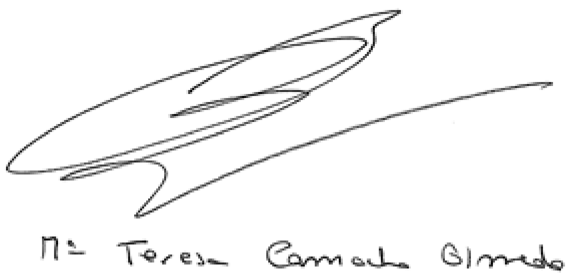
Declaration

I, Basheer Sofyan Abuelaish, and the supervisor, María Teresa Camacho Olmedo, hereby declare that this thesis for my PhD on the "Programa Oficial de Doctorado en Geografía y Desarrollo Territorial" at the University of Granada- Spain hereby submitted has not previously been submitted by me for a degree at this university or any other university, that it is my own work in design and execution and that all material contained herein has been duly acknowledged within the text and references chapter.

Phd Candidate:

Signed - Basheer Sofyan Abuelaish

Thesis supervisor:



Signed - María Teresa Camacho Olmedo

Granada, the 4th September 2017

Abstract

This submission for “Grouping of Research” or “PhD by Publications” includes four studies of land use change in the Gaza Strip (Palestine) and its impact on the environment in this region. According to the regulations of the University of Granada, a doctoral thesis can consist of “grouping of research” presented in the form of a report on the research articles published by the doctoral student in academic journals or in relevant scientific circles in their field of knowledge.

The recommendation of the Doctorate Advisory Board is that those PhD students using this format should include a minimum of three articles and a report about the impact factor of the submitted publications. I have so far produced 4 pieces of research that have either been published or are in the process. Two studies (Chapter 5 and Chapter 7) were published in the Arabian Journal of Geosciences – Journal Citation Report (JCR) 1.224. Of these, Chapter 5 was cited by one article and Chapter 7 was cited by 30 articles and one book chapter according to Google Scholar. I have also written a book chapter (Chapter 6 - in press 2018), and another article (currently under review - Chapter 8).

In line with the regulations of the University of Granada on the sections that this kind of thesis must contain, we begin by presenting a summary of the thesis. This is followed by Part I which is divided into 4 chapters: Chapter 1, which presents the background and Literature Review, concepts, and thesis structure, Chapter 2 which sets out the Hypothesis and Objectives. Chapter 3, which describes the study area, focusing on the natural features of the Gaza Strip, its population, socio-economic status, land use change in recent decades, the contribution of the Gaza Strip to climate change, transportation and the political situation. Chapter 4 explains the methodology used in the four articles.

Part II has two chapters (an article - Chapter 5 and a book chapter - Chapter 6) that set out the results and discussions of the methodology presented in Chapter 4. Part III contains two chapters: one published article (Chapter 7) and one article under review (Chapter 8). This is followed by the discussion and the overall conclusions and perspectives of the thesis. The thesis ends with two Annexes: Annex I – Impact factor and quality analysis of contributions (Chapter 7, Chapter 5. Chapter 6). Annex II - CO2 emissions in the Gaza Strip.

1. Introduction

The Gaza Strip has been a theatre of conflict for decades. Each of these conflicts has left its mark, and a significant environmental footprint has developed in the Gaza Strip over time (UNEP 2009). The population growth rate and the urban expansion it drives affect the whole region. In general, people prefer to live close to the urban facilities and infrastructures, usually found in the center of the residential areas, and to avoid the dangerous areas. The Gaza Strip has been directly involved in many wars, most recently in 2008, 2012 and 2014. The 2014 war was the most destructive in terms of buildings and infrastructure. The Israeli offensive against the Gaza Strip was launched on 8th July and continued until 26th August 2014. It left devastation all across this region, ranging from damage to complete destruction of thousands of homes. Post-war reconstruction is likely to exacerbate the normal urban growth rate, so placing a greater burden on this already congested country.

Land use and land cover in the Gaza Strip is subject to increasing pressure from population growth, which is leading to the depletion and degradation of already impacted environmental features such as water, land and natural resources. These can also have direct consequences for public health.

Understanding, predicting and analyzing land use and cover change is enormously important for future planning. One of the major factors affecting land use in the Gaza Strip is rapid population growth, one of the most significant issues in Palestinian society today. According to the Palestinian Central Bureau of Statistics (PCBS), with the recent growth rates of 3.44% in mid-2013, and 3.41% in mid 2014 (PCBS 2014) the population of the Gaza Strip will have grown to over 2.4 million by 2023. This area already has one of the highest population densities in the world with an estimated 3,956 persons/ km² in 2006. The population growth rate and the urban expansion it drives affect the whole region. This figure is even higher in the Gaza Governorate (around 6,834 persons / km²) where most of the population is concentrated. Another serious problem in Gaza is urban sprawl. The number of housing units in the Gaza Strip increased from 116,445 in 1997 to 147,437 in 2007 (PCBS 2012). Many human and natural factors have increased pressure on land use in this region, resulting in deteriorating quality and quantity of land (Abuelaish and Camacho 2016). Urbanization leads to increasing pressure on natural ecosystems (Taubenbock et al. 2012, Haas and Ban 2014) and brings with it soil, water and air pollution (Duh et al. 2006, Ren et al. 2003).

Land use and land cover change (LUCC) is a key driver of global environmental change and has important implications for many national and international policy issues (Nunes and Auge 1999; Lambin 2001) indicating that the impacts of land use and land cover change are critical to many government programmes. Documenting the rates, driving forces and consequences of change is therefore vital. Land use/land cover change is often related to land planning, food watch and urban growth (Paegelow and Camacho, 2008). In developing countries, urban sprawl is worsened by the lack of land-use planning (Jat et al. 2008; Bayramoglu and Gundogmus 2008; Han et al. 2009; Biggs et al. 2010; Lee and Choe 2011).

2. Hypothesis and Objetives

2.1. Hypothesis

The main hypothesis of this research is that the normal urban growth rate in the Gaza Strip, which results in particular from urban development and agricultural conversion, is strongly influenced by the dynamic changes in the political situation. The inherent instability of this situation makes it very difficult to assess the rate of land use and land cover change (LUCC) in the Gaza Strip. Models were therefore set up to evaluate changes in different land use and land cover data over various periods, as a function of the changes in the political situation. These models can be tested empirically to enable us to make predictions and evaluate scenarios for the future of the Gaza Strip, considering all non-urban areas as agricultural areas. Our secondary hypothesis deals with the impacts of land change on the environment. The groundwater basin is prone to receive and transmit contamination caused by human activities and land changes. This means that there are parts of the aquifer in the study area that are vulnerable to contamination. We carry out a spatial distribution analysis of the parameters and conditions under which the groundwater could be contaminated. The salinity of the groundwater seems likely to expand to most of the Gaza Strip due to high levels of fresh water extraction and high population growth.

2.2. Objetives

The research focuses on the methods and techniques for modelling and analyzing land use and cover growth. This is a complex phenomenon especially in our case study area in the Gaza Strip. Urban development involves change, growth and decline. Modelling land change scenarios must necessarily include the physical and socioeconomic dimensions of land change and its impacts on the environment.

The main objective is to find a model and easily applicable techniques to help the decision- makers and other key stakeholders in Palestine by offering different scenarios for the future planning of the Gaza Strip within the framework of the following broad objectives of this study:

- Identification and delineation of different land use and land cover categories using remote sensing data and rectified aerial photographs.

- Simulation, scenarios, modelling and prediction of land use and land cover in the Gaza Strip.
- Generation of data regarding the changes that have taken place in the area in various land use and land cover categories over different periods.
- Building a GIS database for the study areas.
- Modelling and prediction of environmental indicators such as the vulnerability of groundwater to pollution, and the salinity of the groundwater.
- Helping decision-makers take decisions on land-use management, city planning, the environmental situation and future scenarios for Gaza and its people.

3. Study Area

The Gaza Strip is a narrow area on the Mediterranean coastal plain. It is approximately 41 km long, and from 6 to 12 km wide, with a total area of 365 km². It shares a 12 km border with Egypt to the southwest and is surrounded by Israel to the east and north (the rest of the Strip - 51 km of borders), as shown in Figure 3.1. The Gaza Strip has a temperate climate, with mild winters (about 13ºC) and hot summers with frequent droughts (high 20s ºC). Average rainfall is about 300 mm a year (MOAg 2013). The terrain is flat or rolling, with dunes near the coast. In terms of topography the Gaza Strip slopes gradually downwards from east to west with the land surface elevation varying between 10 m above sea level in the west to 110 m above sea level in the east.

4. Methodology

This thesis addresses two main practical research questions. First, land change analysis, scenarios and modelling and second, land change impacts on the environment within a study of water quality in the Gaza Strip as a result of land change, increasing population and a fall in agriculture areas.

The first question addressed is that of land change analysis and modelling (Part 4.1). The results and discussions of our research on this question are set out in Chapters 5 and 6:

- Chapter 5: Scenario of land use and land cover change in the Gaza Strip using Remote Sensing and GIS model,
- Chapter 6: Urban land use change analysis and modelling: a case study of the Gaza Strip.

The second main issue, namely the impacts of land change use on the environment is analyzed from two different perspectives:

- Part 4.2 shows the methodology used in Chapter 7 in which we assess the vulnerability of the aquifer to contamination in Khan Younis Governorate, Gaza Strip—Palestine, using the DRASTIC model within GIS.
- Part 4.3 shows the methodology used in Chapter 8 in which we study the efficacy of GIS as a tool for analyzing groundwater salinity, once again looking at the Gaza Strip as a case study.

Part II: Results and Discussion. Chapter 5 and 6

Chapter 5: Abuelaish B., Camacho Olmedo MT (2016). Scenario of land use and land cover change in the Gaza Strip using Remote Sensing and GIS models. Journal: Arabian Journal of Geosciences, http://dx.doi.org/10.1007/s12517-015-2292-7

Land use and land cover change is a major global environmental change issue, and projecting changes are essential for the assessment of the environment. The population of the Gaza Strip will have grown to over 2.4 million inhabitants by 2023, and the land demands will exceed the sustainable capacity of land use by far. Land use planning is one of the most difficult issues in the Gaza Strip given that this area is too small. Continuous urban and industrial growth will place additional stress on land cover, unless appropriate integrated planning and management actions are instituted immediately. Planners need further statistics and estimation tools to achieve their vision for the future based on sound information. Therefore, this study combines the use of satellite remote sensing with geographic information systems (GISs). The spatial database is developed by using five Landsat images gathered in 1972, 1982, 1990, 2002 and 2013.

Three GIS models in Idrisi Selva software were selected to try to project the urban area in 2023: Geomod, Cellular Automata Markov (CA_Markov) and Land Change Modeler (LCM). We also used statistical estimation using the regression function to highlight the quantitative difference between the regression and the Markov chain. The three GIS models were used to simulate likely urban areas in 2023 in a single scenario.

The results showed a drastic change in land cover and the growth of the urban area from 1972 to 2013 in all three models, while the agricultural areas were converted into urban areas. These models can help land use managers and city planners to understand probable future growth and plan further developments. Urban areas are continuously increasing in time, whereas non-urban or agricultural areas are receding.

The results of the simulation showed the same quantity of urban area by 2023 in all three models according to the Markov chains, i.e. 212.3 km² (58.3% of the total area of the

Gaza Strip), although spatial differences could be observed between the forecasts made by the three models for the urban area in each of the five governorates.

The results of the past trend scenario for spatial distribution in 2023 highlighted certain differences between the three GIS models; there are similarities in the allocation of urban area, in both Geomod and CA_Markov, and there are differences in LCM, which found that urban expansion will cover 59 % of the area. The urban expansion predicted in the three models tends to be located near the urban area for 2013. This clearly makes sense given that buildings are usually constructed and money is usually invested around main roads adjacent to urban areas. Geomod also shows clear expansion near the roads in the north of the Strip in the restricted area (buffer zone driver) near the border. We observed differences in the spatial distribution of all the models in each Governorate.

The data analysis shows an increase in the urbanized area from 10.9 km^2 (1972) to 25.3 (1982), 46.9 (1990), 100.2 (2002), 166.3 (2013) and 212.3 km^2 (2023), the average area predicted by all the simulations for the whole of the Gaza Strip (around 58.8 % of the total). Urban expansion is positively correlated with population growth, such that the density of population in the Gaza Strip is also expected to increase from 4661.5 in 2013 to 6704.3 inhabitants per square kilometre in 2023. However, as most Gazans live in the cities, the actual density of population in urban areas will rise from 10,231.1 in 2013 to 11,526.4 inhabitants per square kilometre in 2023, making the Strip one of the most densely populated areas in the world. The study shows a rapid annual urban growth rate in each time period (1972–1982, 1982–1990, 1990–2002, 2002–2013 and 2013– 2023) of 1.4, 2.7, 4.4, 6, and 3.8 km^2 per year. In the absence of management and planning, agricultural land (non-urban area) cover will therefore continue to decline at an alarming rate.

Chapter 6: Abuelaish B. (2018) Urban land use change analysis and modelling: a case study of the Gaza Strip. In: Camacho Olmedo, Maria Teresa; Paegelow, Martin; Mas, Jean-François and Escobar, Francisco J (Eds.) Geomatic approaches for modeling land change scenarios. Lecture Notes in Geoinformation and Cartography LNGC series (http://www.springer.com/series/7418) Series Editors: Cartwright, W., Gartner, G., Meng, L., Peterson, M.P. ISSN: 1863-2246. Springer Verlag. Berlin, Heidelberg, New York. ISBN: 978-3-319-60800-6

The analysis of land use and land cover change is of prime importance for understanding the ecological dynamics resulting from natural and human activities, and for the assessment and prediction of environmental change. The population of the Gaza Strip

will have grown to more than 2.4 million by 2023 all of whom are forced to live within an area of some 365 km^2. This growth in population will lead to an increase in land demand, and will far exceed the sustainable land use capacity. The Gaza Strip is a relatively small area in which land use planning has not kept up with land development. Continued urban expansion and population growth in the future will place additional stress on land cover, unless appropriate integrated planning and management decisions are taken immediately. Decision-makers need further statistics and estimation tools to achieve their vision for the future of the Gaza Strip based on sound, accurate information.

This study combines the use of satellite remote sensing with geographic information systems (GISs). The spatial database was developed by using six Landsat images taken in 1972, 1982, 1990, 2002, 2013 and 2014, together with different geodatabases for those years. In order to project the urban area in 2023, we selected a GIS model in IdrisiTerrset software called the Land Change Model (LCM). This model is used to analyse land cover change, empirically modelling its relationship to explanatory variables and projecting future changes (Eastman 2012). The results showed a drastic change in land cover and the growth of the urban area between 1972 and 2014, when many agricultural areas were urbanized. This has happened in a largely unplanned, somewhat chaotic fashion, so revealing the need for land-use managers and city planners to understand future growth and plan further developments. Over this period urban areas have grown continuously, whereas non-urban (agricultural) areas have shrunk at similar rates.

The MLP Neural network was used to obtain the transition potential map for the transition from Non-Urban to Urban area, based on the real transition over the various calibration periods (1972, 1982, 1990, and 2002) to 2013, and (2002) to 2014. The high transition potential values are located around the built-up area with the biggest population density (low distance) for the five scenarios.

The study shows a comparison between six past trend scenarios. Five past trend scenarios were selected for simulation to be completed by the year 2023 using the Land Change Modeler in the IdrisiTerrset software. These different scenarios, one of which takes into account the damage incurred during the 2014 War, try to cover the possible variations in area and spatial distribution resulting from changes in land use. The first five scenarios are the Markov chains from (1972-2013), (1982-2013), (1990-2013), (2002-2013) and (2002-2014) to 2023; and the sixth one is the regression line to 2023 depending on the basic data using the Enter method, which gave areas of 202.35, 204.89, 206.95, 212.32, 204.70 and 240.79 Km^2, respectively.

The overall results of the five LCM scenarios analyse and simulate land-use changes in the Gaza Strip. The results of the past trend scenarios for spatial distribution per area in 2023 presented both differences and similarities in the allocation of urban area. We

discovered an inverse relationship between the predicted area by 2023 and the length of the calibration period, in that the longer the calibration period the smaller the growth in urban area predicted. The urban areas for 2023 predicted by the calibration periods (1972-2013), (1982-2013), (1990-2013) and (2002-2013) were 202.35 km², 204.89 km², 206.95 km² and 212.32 km². The calibration period (2002-2014), which showed an increase in urban area to 204.7 km² by 2023, is slightly exceptional due to the fact that it includes the 2014 War.

The results for calibration periods 2002-2013 and 2002-2014 have a high "goodness of fit", because they both obtained values close to the regression analysis value (240.79) used to measure statistical best fit values, while the values for the other scenarios were substantially further away from the regression analysis value.

As a percentage of the total area of the Gaza Strip, the scenarios predict that between 56.21 and 58.98% will be urbanized by 2023. The data analysis shows an increase in the urban area from 10.9 (1972) to 25.3 (1982), 46.9 (1990), 100.2 (2002), 166.3 (2013) and an average over the five scenarios of 206.24 km² in 2023, the average area predicted by the various simulations for the whole Gaza Strip (i.e. around 57.13% of the total). While the decrease in Agricultural areas (Non-Urban Area) was caused by an increase in population growth rate and a lack of management and future planning.

This study illustrates the increase in the rate of growth in urban area as a percentage of the total area of the Gaza Strip for each time period (1972-1982), (1983-1990), (1991-2002), (2003-2013), 2014 and (2015-2023), with rates of 0.40, 0.7584, 1.35, 1.83, -0.39 and 1.44% from 1972 to 2023, which implies a positive relationship with the rate of population growth.

This study tries to answer questions about the future of the Gaza Strip and the impacts on its environment. This information is useful for decision-makers and politicians, who are regularly faced with questions about the complicated situation in the Gaza Strip as a result of its weak economic resources, and the lack of donor support from countries concerned about other conflicts such as in Syria. Most of the houses destroyed during the war belong to poor people who are waiting for financial support to rebuild them. Many urban areas were destroyed during the war and their reconstruction would be harder without modelling exercises such as the one presented here.

Part III: Results and Discussion. Chapters 7 and 8

Chapter 7: AlHallaq, A.H., and Abuelaish, B. (2012) Assessment of aquifer vulnerability to contamination in Khan Younis Governorate, Gaza Strip—Palestine. using the DRASTIC model within GIS environment. Arab J Geosci 5:833–847, doi:10.1007/s12517-011-0284-9

Groundwater is a very important natural resource in Khan Younis Governorate (the study area) for water supply and development. Historically, the exploitation of aquifers in Khan Younis Governorate has been undertaken without proper concern for its environmental impact. In view of the importance of quality groundwater, it might be expected that aquifer protection to prevent groundwater quality deterioration would have received due attention. In the long term, however, protection of groundwater resources is of direct practical importance because, once pollution of groundwater has been allowed to occur, the scale and persistence of such pollution makes restoration technically difficult and costly. In order to maintain basin aquifer as a source of water for the area, it is necessary to find out whether certain locations in this groundwater basin are susceptible to receive and transmit contamination. This study aims to: (1) assess the vulnerability of the aquifer in Khan Younis Governorate to contamination, (2) discover which parts of the aquifer are most vulnerable, and (3) provide a spatial analysis of the parameters and conditions under which groundwater may become contaminated. To this end, we applied the DRASTIC model within a Geographic Information System (GIS) environment. The model uses seven environmental parameters: depth of water table, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity to evaluate aquifer vulnerability. Based on this model and by using ArcGIS 9.3 software, an attempt was made to create vulnerability maps for the study area.

According to the DRASTIC model index, the study has shown that in the western part of the study area the vulnerability to contamination ranges between high (in 26.16% of the total area) and very high (in 3.14% of the total area), due to the relatively shallow water table with moderate to high recharge potential, and permeable soils. In the eastern and south-eastern part of this Governorate, vulnerability to contamination is moderate (43.44%). In the central and the eastern part, vulnerability to contamination is low (27.24% of the total area) due to the depth of the water table. The DRASTIC Model also indicates that the highest risk of contamination of groundwater in the study area originates from the soil media.

The impact of vadose zone, depth to water level, and hydraulic conductivity offer moderate risks of contamination, while net recharge, aquifer media, and topography are low risk factors. The coefficient of variation indicates that topography makes a high contribution to variations in the vulnerability index. Depth to water level, and net recharge make moderate contributions, while the impact of the vadose zone, hydraulic conductivity, soil media, and aquifer media are the least variable parameters. The low variability of the parameters implies a smaller contribution to the variation of the vulnerability index across the study area. Moreover, the "effective" weights of the DRASTIC parameters obtained in this study exhibited some deviation from that of the "theoretical" weights. Soil media and the impact of the vadose zone were the most effective parameters in the vulnerability assessment because their mean "effective" weights were higher than their respective "theoretical" weights. The depth of the water table showed that both "effective" and "theoretical" weights were equal. The rest of the parameters exhibit lower "effective" weights compared with the "theoretical" weights. This explains the importance of soil media and vadose layers in the DRASTIC model. It is therefore important to get accurate and detailed information about these two specific parameters. The GIS technique has provided an efficient environment for analysis and is capable of handling large amounts of spatial data. In view of these results, the DRASTIC model has proved to be a useful tool that can be used by national authorities and decision makers, especially in agricultural areas in which the chemicals and pesticides most likely to contaminate groundwater resources are applied.

Chapter 8: Abuelaish B., Camacho Olmedo MT (under revision) GIS as a tool to analyze groundwater salinity: The Gaza Strip as a case study

The Gaza Strip suffers from an acute problem in terms of water quality and quantity. Groundwater is used as drinking water, for agricultural uses and in industrial processes. Salinity is increasing in groundwater in the Gaza Strip. Seawater intrusion is the main source of salinity. A chloride ion-selective is used as an indicator of salinity for the analysis and modelling of the salinity of groundwater in the Gaza Strip by 2023. Research depends on three models for prediction of the chloride concentration in groundwater: Linear regression, Multiple regression, and Forecasting for year 2023.

Groundwater is an important source of fresh water in the Gaza Strip for domestic and irrigation use. Groundwater quality is influenced by geological formation and anthropogenic activities, e.g. changes in land use, urbanization, intensive irrigated agriculture, mining activities, disposal of untreated sewage in rivers, lack of rational management, etc. (Voudouris, 2009). Groundwater contamination due to human activities may pose a severe threat for public health.

The study illustrates the chloride concentrations in the groundwater within six cross sections for 1993, 2003 and 2013. It focuses exclusively on urban areas for which purposes the non-urban areas are masked. The chloride concentration of groundwater in the whole of the Gaza Strip was classified into six classes for the years 1972, 1982, 1993, 2003 and 2013. The simulation of chloride concentrations for 1993, 2003 and 2013 (inside the urban area for 2013) demonstrates that in urban areas particularly the chloride concentration has increased clearly over the years. There is a positive relationship with the expansion of urban areas in all cross sections. Higher chloride concentrations were observed in urban areas in 2013 than in previous years in 1993 and 2002.

There are some differences in the simulated results for chloride concentrations in the three models (Forecasting Model, Linear Regression Model, and Multiple Linear Regression Model) for the year 2023, which are classified into six classes. The chloride concentration profiles show that water chloride concentration is increasing and expanding in all six cross sections.

The result for the three models showed water salinity will increase in all areas in the Gaza Strip by the year 2023. The visual analysis of the cross sections is based on the water data analysis profiles, which describe how the chloride level has continued to increase all over the Gaza Strip along the time series from 1972 to 2023. The rise in the chloride concentration is evident in the whole of the Gaza Strip in all three models. The trend of expansion from west to east due to seawater intrusion is also evident in all cross sections.

Calculation of the Root Mean Square Error (RMSE) values as predictive power shows that the Multiple Linear Regression has a value of 1631.723, followed by Forecasting with 1656.9, and then Linear Regression with 1668.3. According to RMSE, Multiple Linear Regression is therefore the best model in our study, with the Forecasting model and Linear Regression in second and third places. When the stepwise method in Multiple Linear Regression is used by SPSS, the wells are affected by all input variables at a different rate; the most effective variable is the year, around 45%, while population has a figure of 35 %, production 10 %, rainfall 10 % and water level 10%.

The data inputs and output for the chloride concentration from 1972-2013 and 2023 represent the severe changes that have taken place in the Gaza Strip. This increase in chloride concentration can be seen right across the Gaza Strip. By the year 2023 the area in the North Governorate in which the water has a chloride concentration of less than 250 mg/L and is therefore considered free of salinity will be only a small fraction (less than 10%) of the Gaza Strip.

The analysis of seawater intrusion within the cross sections shows that this problem is repeated along the coastline and spreads out from the Mediterranean Sea to the Eastern part of the Gaza Strip.

In this study, one scenario shows an increase in chloride concentration as an indicator of salinity by 2023. Another scenario involves the construction of a large desalination plant in the Gaza Strip. The EU has invested EUR 10 million during this phase which, when fully operational, will produce 6,000 m^3 of potable water daily. This will provide over 75,000 Palestinians with safe drinking water—approximately 35,000 people in Khan Younis and 40,000 people in Rafah, in the southern Gaza Strip. EU Commissioner Johannes Hahn announced an additional funding of EUR 10 Million for the second phase of the desalination plant to start in mid-June 2016, which is expected to be completed within 36 months. Then the plant will produce a total of 12,000 m^3 of safe drinkable water everyday (IMEMC, 2016). The annual increase in the amount of water required in the Gaza Strip is 2,240,437 m^3 per year from 2016 to 2023. Hence the desalination plant will reduce the shortage of drinking water. If the EU plant works as planned, it will produce 4,380,000 m^3 annually after 36 months.

Conclusions and perspectives

Conclusions

The thesis offers a better understanding of potential options for urban land use expansion by highlighting some of the key drivers behind LUCC in the Gaza Strip, for example population, socioeconomic drivers, the political situation and the Israeli occupation. It also explores the impact of urban expansion on environmental aspects such as water quality and climate change.

The following main conclusions can be drawn from this thesis:

- Around 57.13 to 58.8% % of the Gaza Strip will be urban land by 2023.
- There are differences in the spatial distribution of the urban area produced by each model (Geomod, CA_Markov and LCM).
- There is an inverse relationship between the predicted urban area for 2023 and the length of the calibration period as tested using five scenarios and the Land Change Modeler in Chapter 6.
- Urbanization in the Gaza Strip is increasing dramatically because of natural population growth. This is placing more stress on agricultural areas, causing soil erosion and impairing water quality and quantity.
- Urban sprawl has increased over time at the expense of agricultural land, above all due to an increase in population.
- An increase in agricultural land in the Gaza Strip will put pressure on natural resources and contribute to local and global climate change.

- Urban planners should take into account that in the near future the three main urban areas will merge into one, and population should be directed to vertical construction to reduce urban expansion.
- The Gaza Strip can contribute to climate change mitigation and has the potential to adapt its land cover.
- Urban expansion affects water quality and quantity, air quality, coastal zone management, and marine environment. Within cities, the nature of urban growth is an important determinant of the vulnerability of urban dwellers to environmental stress (Güneralp and Seto, 2008)
- Urban planners and decisions makers should take into account the danger of groundwater being polluted within the areas in the aquifer identified as vulnerable. Our results show that the DRASTIC model can be an effective tool for local authorities, and for the water authority responsible for managing groundwater resources.
- Groundwater salinity has extended everywhere in the Gaza Strip as a result of rapid population growth and urban expansion. Salinity is likely to continue to expand to most areas of the Gaza Strip by 2023.
- This study can help decision makers in land-use management, city planning, the environmental situation and future scenarios for Gaza.

Perspectives

This study aspires to provide a starting point for other researchers on land use and land cover changes. It recommends that future studies should pay particular attention to the following research topics in the Gaza Strip:

- Providing further assistance for environmentalists and planners to consider the impacts of urban land use development by identifying urban expansion.
- Using high resolution satellite images to produce accurate data for monitoring and analysis, scenarios, modelling and projection of LUCC and other environmental indicators for the Gaza Strip.
- Planners and decision makers should develop a strategic plan to prevent the decline of agricultural lands.
- Updating and upgrading of the LUCC GIS database within periodic data collection.
- In order to ensure sustainable urban developments, Environmental Impact Assessment (EIA) should be carried out for all future projects in the Gaza Strip, so as to reduce negative environmental impacts.

- Future research must consider all these limitations and apply an advanced modelling approach that would enable long-term forecasting.
- Future studies should focus on the impacts of land-use changes on climate change and environmental elements such as air pollution, coastal erosion related to harbours, urban heat islands, decreasing numbers of flora and fauna, land capability and productivity, etc.

References

The list of references contains bibliographic information about every source cited in the thesis. Research materials are not included in the list of references, but rather in the parts of the report dealing with the research implementation, data, and methods. The list of references is generally presented in alphabetical order according to the authors' last names, year, title of article, publisher.

Annexes (a brief description)

The annexes contain two annexes that show the quality of published research articles and the contribution of the study area to climate change:

Annex I - Impact factor and quality analysis of contributions (chapter 7, chapter 5. chapter 6).

Annex II - CO_2 emissions in the Gaza Strip.

Resumen

Según el reglamento de la Universidad de Granada, una tesis doctoral puede consistir en una "agrupación de publicaciones" y se presentará como un informe sobre los artículos de investigación publicados por el doctorando en revistas académicas o dentro de los círculos científicos relevantes en su área de conocimiento. La recomendación del Consejo Asesor de Doctorado es que aquellos estudiantes de Doctorado que utilicen este formato deben incluir un mínimo de tres artículos y un informe sobre el factor de impacto que han tenido estas publicaciones.

La presente Tesis, por agrupación de trabajos de investigación o Tesis por compendio de publicaciones, incluye cuatro estudios sobre el cambio de usos y coberturas del suelo en la Franja de Gaza (Palestina) y su impacto sobre el medio ambiente de esta región. Dos trabajos (Capítulo 5 y Capítulo 7) fueron publicados como artículos en la revista Arabian Journal of Geosciences – Journal Citation Report (JCR) 1.224. El Capítulo 5 fue citado en un artículo y el Capítulo 7 fue citado en 30 artículos y un capítulo de libro. A ellos se une un capítulo de libro en la editorial Springer (Capítulo 6), que se encuentra actualmente en prensa y cuenta ya con asignación de doi, y otro artículo (Capítulo 8), que está en proceso de revisión.

Siguiendo el reglamento de la Universidad de Granada sobre las secciones que debe tener una Tesis por compendio de publicaciones, la misma se inicia con un resumen amplio de la tesis. A continuación, la Parte I se divide en 4 capítulos: Capítulo 1, que presenta el contexto, los conceptos básicos y la estructura de la tesis; Capítulo 2, que establece la Hipótesis y los Objetivos; Capítulo 3, que describe la zona de estudio, centrándose especialmente en las características naturales de la Franja de Gaza, su demografía, su situación socioeconómica, los cambios de uso del suelo en las últimas décadas, la aportación de la Franja de Gaza al cambio climático, el transporte en esta zona y la situación política; y, finalmente, en el Capítulo 4 se explica la metodología aplicada en las cuatro aportaciones.

La segunda parte (Parte II) tiene dos capítulos (un artículo - Capítulo 5 y un capítulo de libro - Capítulo 6), que presentan los resultados y la discusión tras la aplicación de la metodología de análisis y modelado del cambio de usos y coberturas del suelo presentada en el Capítulo 4. La Parte III se compone de 2 capítulos (un artículo ya publicado - Capítulo 7 y otro artículo en proceso de revisión - Capítulo 8), que se centran en los impactos de los cambios en el uso y la cobertura del suelo sobre el medio ambiente. A estas partes le siguen las conclusiones y las perspectivas globales sobre la tesis. La tesis acaba con dos anexos: Anexo I – El factor de impacto y análisis de la calidad de las

aportaciones (Capítulo 7, Capítulo 5. Capítulo 6) y Anexo II – Emisiones de CO2 en la Franja de Gaza.

1. Introducción

La Franja de Gaza ha sido un escenario de conflicto durante décadas. Cada uno de los múltiples conflictos ha dejado su impronta en la zona, y a lo largo del tiempo se ha desarrollado una huella medioambiental importante (UNEP 2009). La tasa de crecimiento de la población y de la expansión urbana que impulsa ha afectado a la región entera. Por lo general los gazatíes prefieren vivir cerca de los servicios e infraestructuras urbanas, que normalmente se encuentran en el centro de las zonas residenciales, y prefieren evitar las zonas de peligro. La Franja de Gaza ha estado implicada directamente en muchas guerras, las últimas en 2008, 2012 y 2014. La más destructiva en cuanto a edificios e infraestructuras fue la guerra de 2014. Los israelíes lanzaron una ofensiva contra la Franja de Gaza el 8 de julio que continuó hasta el 26 de agosto de 2014. Dejó un reguero de devastación por toda la región de grados distintos, desde daños estructurales hasta la destrucción completa de miles de casas. Es probable que la reconstrucción post-bélica aumente el crecimiento urbano aún más, incrementando de esta forma la presión sobre lo que ya es una zona abarrotada.

El uso y la cobertura del suelo en la Franja de Gaza está sujeto a una creciente presión por el incremento demográfico, lo cual provoca la disminución y la degradación de elementos medioambientales que ya han sido dañados, como el agua, la tierra y los recursos naturales. Esto puede tener consecuencias directas para la salud pública.

Para la planificación futura de zonas como esta es imprescindible poder entender, predecir y analizar el uso y la cobertura del suelo. Uno de los factores más importantes que afecta a la Franja de Gaza es la rápida tasa de crecimiento demográfico, que se ha convertido en uno de los temas más acuciantes en la sociedad palestina hoy en día. Según la Oficina Central de Estadística Palestina, con las tasas de crecimiento de los últimos años, 3,44% a mediados de 2013, y 3,41% a mediados de 2014 (PCBS 2014) para el año 2023 la población de la Franja de Gaza habrá llegado a más de 2,4 millones de personas. Esta zona ya tiene una de las densidades de población más altas del mundo con una cifra estimada de 3.956 personas/ km^2 en el año 2006. Esta tasa de crecimiento demográfico y la expansión urbana que conlleva afecta a toda la región. Esta cifra es incluso más alta en la Gobernación de Gaza (unas 6.834 personas / km^2) donde se concentra la mayor parte de la población. Otro problema serio en Gaza es la expansión urbana dispersa. El número de unidades de vivienda en la Franja de Gaza aumentó desde 116,445 en 1997 hasta 147,437 en 2007 (PCBS 2012). La presión sobre el suelo en esta región se ha incrementado debido a diversos factores humanos y naturales, repercutiendo en la calidad y cantidad de suelo disponible (Abuelaish y Camacho 2016). La urbanización de zonas no urbanas ha aumentado la presión sobre los ecosistemas naturales (Taubenbock et al. 2012, Haas y Ban 2014) y trae consigo la contaminación de la tierra, el agua y el aire (Duh et al. 2006, Ren et al. 2003).

El cambio de usos y coberturas del suelo (conocido por sus siglas en inglés como LUCC) es un motor clave del cambio medioambiental a nivel mundial y tiene importantes implicaciones en las políticas nacionales e internacionales (Nunes y Auge 1999; Lambin 2001), lo cual nos indica que los impactos de estos cambios son aspectos cruciales para muchos programas gubernamentales. Por lo tanto es de vital importancia medir y documentar los niveles, motores y consecuencias de estos cambios. El LUCC se relaciona a menudo con la planificación territorial, los suministros agrícolas y el crecimiento urbano (Paegelow y Camacho, 2008). En los países en desarrollo, el problema de la expansión urbana dispersa se empeora por la falta de planificación de los usos y coberturas del suelo (Jat et al. 2008; Bayramoglu y Gundogmus 2008; Han et al. 2009; Biggs et al. 2010; Lee y Choe 2011).

2. Hipótesis y Objetivos

2.1. Hipótesis

La hipótesis principal de este estudio es que la tasa de crecimiento urbano en la Franja de Gaza, que es sobre todo el resultado del desarrollo urbano y de la reconversión agrícola, está muy influenciada por los cambios dinámicos en la situación política. La inestabilidad inherente a esta situación complica mucho cualquier intento de evaluar la tasa de cambio en el uso y la cobertura del suelo (LUCC) en la Franja de Gaza. Por lo tanto varios modelos han sido aplicados para evaluar los cambios en los datos del LUCC para distintos periodos, en función de los cambios en la situación política. Estos modelos pueden ser comprobados empíricamente para permitirnos hacer previsiones y evaluar escenarios para el futuro de la Franja de Gaza, tratando a todas las zonas no urbanas como si fueran zonas agrícolas.

Nuestra hipótesis secundaria versa sobre los impactos del LUCC sobre el medio ambiente. Las cuencas de agua subterránea son propensas a recibir y a transmitir la contaminación causada por actividades humanas y cambios en el uso del suelo. Esto quiere decir que hay partes del acuífero en la zona de estudio que son vulnerables a la contaminación. En esta tesis se realiza un análisis de la distribución espacial de los parámetros y de las condiciones en las que el agua subterránea se podría contaminar. Parece probable que la salinidad del agua subterránea se extenderá a la mayor parte de la

Franja de Gaza debido a los altos niveles de extracción de agua dulce y el crecimiento rápido de la población.

2.2. Objetivos

La investigación se centra en los métodos y técnicas utilizados para modelizar y analizar el incremento en el LUCC, como fenómeno especialmente complejo en la zona de estudio, la Franja de Gaza. Para modelar los distintos escenarios de cambio de usos de suelo es imprescindible tener en cuenta las dimensiones físicas y socioeconómicas del LUCC y sus impactos sobre el medio ambiente.

Nuestro objetivo principal es encontrar un modelo y unas técnicas fácilmente aplicables que ayuden a los actores claves en Palestina a la toma de decisiones, ofreciéndoles distintos escenarios que puedan ser útiles en la planificación futura de la Franja de Gaza. Dentro de este marco principal, los objetivos secundarios de este estudio son:

Identificación y delineación de las distintas categorías de usos y coberturas del suelo utilizando datos obtenidos con la teledetección y las ortofotos rectificadas.

- Simulación, escenarios, modelación y previsión de LUCC en la Franja de Gaza.
- Generación de datos sobre los cambios que ya han ocurrido en la zona en varias categorías de LUCC a lo largo de distintos períodos.
- Construcción de una base de datos basada en un Sistema de Información Geográfica (SIG) para las zonas de estudio.
- Modelación y predicción de indicadores medioambientales como la vulnerabilidad del agua subterránea a la contaminación y la salinidad del agua subterránea.
- Ayuda a los actores principales a tomar decisiones sobre la gestión del uso del suelo, la planificación urbana, la situación medioambiental y los escenarios futuros para la Franja de Gaza y sus ciudadanos.

3. Zona de estudio

La Franja de Gaza ocupa una franja estrecha de la llanura costera del Mediterráneo. Mide aproximadamente 41 km de largo y de 6 a 12 kilómetros de ancho, con una superficie total de 365 km². Comparte una frontera de 12 km con Egipto al suroeste, mientras que al este y al norte está rodeada por Israel (el resto de la Franja - 51 km de fronteras). La Franja de Gaza tiene un clima templado con inviernos suaves (sobre 13ºC) y veranos cálidos con frecuentes sequías (27 - 29ºC). La precipitación media es de unos 300 mm al año (MOAg 2013). El terreno es plano u ondulado con dunas de arena cerca de la costa.

En términos topográficos, la Franja de Gaza desciende gradualmente de este a oeste y la elevación sobre el mar varía desde los 110m en el este a los 10m en el oeste.

4. Metodología

La tesis aborda dos temas de estudio principales. Primero, el análisis, los escenarios y el modelado de los cambios de usos y coberturas del suelo, y segundo, los impactos de estos cambios sobre el medio ambiente, en particular el estudio de la calidad del agua en la Franja de Gaza como resultado del cambio del uso del suelo, la creciente población y la disminución de las zonas dedicadas a la agricultura.

El primer tema que se aborda es el análisis y modelado de los cambios de usos y coberturas del suelo (Sección 4.1.). Los resultados y las discusiones sobre este tema se presentan en los Capítulos 5 y 6:

- Capítulo 5: Escenario del cambio de usos y coberturas del suelo en la Franja de Gaza utilizando la Teledetección y los SIG.
- Capítulo 6: Análisis y modelado del cambio de usos de suelo urbano: estudio del caso de la Franja de Gaza.

El segundo tema principal, los impactos de los cambios en el uso y la cobertura del suelo sobre el medio ambiente, se analiza desde dos perspectivas distintas:

- La sección 4.2 presenta la metodología utilizada en el Capítulo 7 en el que evaluamos la vulnerabilidad del acuífero a la contaminación en la Gobernación de Khan Younis, Franja de Gaza—Palestina, utilizando el modelo DRASTIC dentro del SIG.
- La sección 4.3 presenta la metodología utilizada en el Capítulo 8 en el que estudiamos la eficacia de SIG como instrumento para analizar la salinidad del agua subterránea, fijándonos de nuevo en la Franja de Gaza como caso de estudio.

Parte II: Resultados y discusión. Capítulos 5 y 6

Capítulo 5: Abuelaish B., Camacho Olmedo MT (2016). Scenario of land use and land cover change in la Franja de Gaza using Remote Sensing and GIS models, Journal: Arabian Journal of Geosciences, http://dx.doi.org/10.1007/s12517-015-2292-7

LUCC es un cambio medioambiental transcendental a nivel mundial y las proyecciones de estos cambios son esenciales a la hora de realizar cualquier evaluación del medio ambiente en el futuro. Para el año 2023 la población de la Franja de Gaza habrá alcanzado más de 2.4 millones de habitantes, y la demanda de suelo excederá por mucho su capacidad sostenible. La planificación del uso del suelo es uno de los temas más complicados y polémicos en la Franja de Gaza, dado su pequeña superficie (365 km^2). El continuo crecimiento urbano e industrial redoblará la presión sobre la cobertura del suelo, a no ser que se implementen acciones apropiadas de planificación y gestión integrada de forma inmediata. Los encargados de la planificación necesitan más estadísticas y más herramientas de estimación para poder conseguir una visión de futuro basada en datos fiables. Por lo tanto este estudio combina el uso de la teledetección por satélite con sistemas de información geográfica (SIG). La base de datos espacial se desarrolla utilizando cinco imágenes Landsat recogidas en 1972, 1982, 1990, 2002 y 2013.

Seleccionamos tres modelos SIG en el software Idrisi Selva para intentar proyectar la superficie urbana total en el año 2023: Geomod, Cellular Automata Markov (CA_Markov) y Land Change Modeler (LCM). También utilizamos la estimación estadística para indicar la diferencia cuantitativa entre la regresión y la cadena Markov. Utilizamos los 3 modelos SIG para simular las probables zonas urbanas en el año 2023 en un solo escenario.

En los tres modelos los resultados muestran un cambio drástico en la cobertura del suelo y el crecimiento de la zona urbana desde 1972 a 2013 con la urbanización de zonas agrícolas. Estos modelos pueden ayudar a los responsables del uso del suelo y de la planificación de la ciudad a entender probables crecimientos futuros para así planificar mejor el desarrollo. Las zonas urbanas están creciendo de forma constante, mientras que las zonas no urbanas o agrícolas retroceden.

Los resultados de la simulación muestran la misma cantidad de zona urbana para el año 2023 en los tres modelos según las cadenas Markov, i.e. 212,3 km^2 (58,3% del área total de la Franja de Gaza), aunque se podría observar varias diferencias espaciales entre las previsiones de los tres modelos para la superficie urbana en cada una de las cinco gobernaciones.

Los resultados del escenario de tendencias pasadas para la distribución espacial en 2023 señalaron ciertas diferencias entre los tres modelos SIG; hay similitudes en la asignación de zonas urbanas entre Geomod y CA_Markov, y hay diferencias en el LCM, que estimó que la expansión urbana cubrirá un 59 % de la superficie. Los tres modelos prevén que la expansión del suelo urbano ocurrirá cerca de la zona urbana existente en el año 2013. Esto tiene sentido dado que se suelen construir edificios a lo largo de las carreteras principales adyacentes a las zonas urbanas. Geomod también muestra claramente una expansión cerca de las carreteras al norte de la Franja en la zona restringida (motor “tierra de nadie”) cerca de la frontera. Observamos diferencias en la distribución espacial de todos los modelos en cada Gobernación.

El análisis de los datos refleja un aumento en la zona urbanizada desde 10,9 km² (1972) a 25,3 (1982), 46,9 (1990), 100,2 (2002), 166,3 (2013) y 212,3 km² (2023), la extensión media prevista para el año 2023 por todas las simulaciones (alrededor de un 58.8 % de la Franja de Gaza). Hay una correlación positiva entre la expansión urbana y el crecimiento demográfico, de tal forma que se espera también que la densidad de población en la Franja aumente desde 4661,5 en 2013 hasta 6704,3 habitantes por kilómetro cuadrado en 2023. Sin embargo como la mayoría de los gazatíes viven en las ciudades, la densidad real de población en las zonas urbanas aumentará desde 10.231,1 en 2013 hasta 11.526,4 habitantes por kilómetro cuadrado en 2023, convirtiendo la Franja de Gaza en una de las zonas más densamente pobladas del mundo. El estudio muestra una tasa anual de rápido crecimiento urbano en cada periodo de tiempo (1972–1982, 1982–1990, 1990–2002, 2002–2013 y 2013– 2023) de 1,4, 2,7, 4,4, 6, y 3,8 km² por año. En ausencia de gestión y de planificación, el suelo agrícola (zonas no urbanas) seguirá bajando a un nivel alarmante.

Capítulo 6: Abuelaish B. (2018) Urban land use change analysis and modelling: a case study of the Gaza Strip. En: Camacho Olmedo, Maria Teresa; Paegelow, Martin; Mas, Jean-François y Escobar, Francisco J (Eds.) Geomatic approaches for modeling land change scenarios. Lecture Notes in Geoinformation and Cartography LNGC series (http://www.springer.com/series/7418) Series Editors: Cartwright, W., Gartner, G., Meng, L., Peterson, M.P. ISSN: 1863-2246. Springer Verlag. Berlin, Heidelberg, New York. ISBN: 978-3-319-60800-6, DOI: 10.1007/978-3-319-60801-3

El análisis del cambio de usos y coberturas del suelo es fundamental para poder comprender las dinámicas ecológicas producidas por actividades naturales y humanas, y también para la evaluación y previsión del cambio medio ambiental. Para el año 2023 la población de la Franja de Gaza habrá superado los 2,4 millones de personas, las cuales estarán obligados a vivir hacinadas dentro de un área muy limitada de unos 365 km². Este aumento poblacional producirá un incremento en la demanda de suelo que excederá por mucho la capacidad de aprovechamiento sostenible de este espacio. La Franja de Gaza es una región pequeña en que la planificación del uso del suelo ha ido siempre por detrás de un proceso de urbanización descontrolada. La expansión urbana y el incremento de población previstos para el futuro someterá a cualquier cobertura del suelo a incluso más presión, al no ser que se tomen de forma inmediata las decisiones necesarias de planificación y gestión integrada. Los responsables necesitan más datos y más herramientas de estimación para conseguir su visión del futuro de la Franja de Gaza en base a una información precisa y fiable.

Este estudio combina el uso de la teledetección con los sistemas de información geográfica (SIGs). La base de datos espacial se desarrolló con la información extraída de seis imágenes Landsat tomadas en 1972, 1982, 1990, 2002, 2013 y 2014, junto con varias bases de datos georeferenciadas para aquellos años. Para poder proyectar la superficie urbana en 2023, seleccionamos un modelo SIG en software Idrisi Terrset llamado Land Change Modeler (LCM). Este modelo se utiliza para analizar los cambios de usos y coberturas del suelo, modelando de forma empírica su relación con las variables explicativas y proyectando cambios futuros (Eastman 2012). Los resultados evidencian un cambio drástico en la cobertura del suelo y el crecimiento de la zona urbana entre 1972 y 2014, cuando muchas tierras agrícolas fueron urbanizadas. Este proceso ha tenido lugar de una manera poco planificada, a veces caótica, revelando de esta forma que los gestores territoriales y los responsables de planificación urbana necesitan entender el crecimiento futuro y planificar el desarrollo. A lo largo de este periodo las zonas urbanas han crecido de forma constante, mientras que las zonas no urbanas (agrícolas) han encogido en consonancia.

Utilizamos la red neuronal Multilayer Perceptron para obtener el mapa de potencial de transición para la transición de zona No Urbana a Urbana, en base a la transición real a lo largo de varios periodos de calibración (1972, 1982, 1990, y 2002) hasta 2013, y 2002 a 2014. Los sitios con un alto potencial de transición están ubicados alrededor de la zona ya construida con la densidad más alta de población (distancia corta) para los cinco escenarios.

Este estudio presenta una comparación entre seis escenarios basados en tendencias pasadas. De estos seis escenarios, seleccionamos cinco para realizar una simulación que acaba en el año 2023, utilizando el Land Change Modeler en el software Idrisi Terrset. Estos escenarios, uno de los cuales tiene en cuenta los daños causados durante la guerra del 2014, intentan cubrir las posibles variaciones en términos de superficie y distribución espacial que resultan de los cambios en el uso del suelo. Los cinco primeros escenarios son las cadenas Markov desde (1972-2013), (1982-2013), (1990-2013), (2002-2013) y (2002-2014) hasta 2023; y el sexto es la línea de regresión hasta 2023 en función de los datos básicos utilizando el método Enter. Estos escenarios daban superficies de 202,35, 204,89, 206,95, 212,32, 204,70 y 240,79 Km^2, respectivamente.

Los resultados globales de los cinco escenarios LCM analizan y simulan los cambios en el uso del suelo en la Franja de Gaza. Los resultados de los escenarios basados en tendencias pasadas para la distribución espacial en el año 2023 presentan tanto diferencias como similitudes en la asignación de superficie urbana. Descubrimos una relación inversa entre el área prevista para 2023 y la duración del periodo de calibración, en el sentido de que cuanto más largo fuera el periodo de calibración, más pequeño era el crecimiento previsto para la zona urbana. Las zonas urbanas previstas para el año 2023 por periodos de calibración (1972-2013), (1982-2013), (1990-2013) y (2002-2013) eran 202,35 km², 204,89 km², 206,95 km² y 212,32 km². El periodo de calibración (2002-2014), que mostró un aumento en la zona urbana a 204,7 km² para el año 2023 es un poco excepcional debido al hecho que incluye la guerra del 2014.

Los resultados para los periodos de calibración 2002-2013 y 2002-2014 tienen una alta "bondad de ajuste", porque ambos obtuvieron valores cercanos al valor obtenido del análisis de regresión (240,79) utilizado para medir los valores estadísticos de mejor ajuste (best-fit values), mientras que los valores ofrecidos por los otros escenarios distaban bastante más del valor obtenido del análisis de regresión.

A la hora de predecir el porcentaje del área total de la Franja de Gaza que estará urbanizada en el año 2023, los escenarios ofrecen cifras de entre 56,21 y 58,98%. El análisis de los datos muestra un aumento de la zona urbana desde 10,9 (1972) a 25,3 (1982), 46,9 (1990), 100,2 (2002), 166,3 (2013) y una media para los cinco escenarios de 206,24 km² en 2023, la superficie media prevista por las varias simulaciones para la Franja de Gaza entera (sobre 57,13% del total). La caída prevista en zonas agrícolas (Zonas No Urbanas) es el resultado de un aumento de la tasa de crecimiento demográfico y una falta de gestión y planificación para el futuro.

Este estudio muestra el incremento en la tasa de crecimiento de la zona urbana como porcentaje de la superficie total de la Franja de Gaza para cada periodo de tiempo (1972-1982), (1983-1990), (1991-2002), (2003-2013), 2014 y (2015-2023), con tasas de 0,40, 0,7584, 1,35, 1,83, -0,39 y 1,44% de 1972 a 2023, lo cual implica una relación positiva con la tasa de crecimiento demográfico.

Este estudio intenta responder a varias preguntas sobre el futuro de la Franja de Gaza y sus impactos sobre el medio ambiente. Esta información es útil para los gestores y los políticos, que a menudo se enfrentan a preguntas sobre la complicada situación de la Franja de Gaza, como resultado de sus recursos económicos debilitados y la falta de apoyo de países donantes preocupados por otros conflictos como el de Siria. La mayoría de las casas destruidas durante la guerra pertenecen a gente humilde que están esperando el apoyo financiero necesario para su reconstrucción. Muchas zonas urbanas fueron destruidas durante la guerra y el proceso de reconstrucción será bastante más difícil sin ejercicios de modelado como el que hemos presentado en este estudio.

Parte III: Resultados y Discusión. Capítulos 7 y 8

Capítulo 7: AlHallaq, A.H., and Abuelaish, B. (2012) Assessment of aquifer vulnerability to contamination in Khan Younis Governorate, Gaza Strip—Palestine using the DRASTIC model within GIS environment. Arab J Geosci 5:833–847, doi:10.1007/s12517-011-0284-9

El agua subterránea es un recurso natural de vital importancia en la Gobernación de Khan Younis (la zona de estudio) para el suministro de agua y el desarrollo de la zona. A lo largo de la historia los acuíferos en la Gobernación de Khan Younis han sido explotados sin preocupación alguna por el impacto medio ambiental. Dada la importancia de la calidad del agua subterránea, se podría esperar que la protección del acuífero para así evitar la degradación del agua subterránea fuese un tema prioritario. Sin embargo no ha sido así. A largo plazo la protección de los recursos de agua subterránea tiene un sentido práctico muy directo, porque una vez que se ha permitido la contaminación del agua subterránea, la escala y persistencia de esta contaminación hace que la restauración sea un proceso técnicamente difícil y costoso. Para poder mantener el acuífero como una fuente de agua para la zona, es necesario averiguar si ciertos sitios dentro de esta cuenca de agua subterránea son susceptibles de recibir y transmitir la contaminación. Este estudio pretende: (1) evaluar la vulnerabilidad del acuífero en la Gobernación de Khan Younis a la contaminación, (2) descubrir qué partes del acuífero son más vulnerables, y (3) ofrecer un análisis espacial de los parámetros y condiciones bajo los cuales el agua subterránea pueda ser contaminada. Con estos fines en mente, aplicamos el modelo DRASTIC dentro de un entorno de Sistema de Información Geográfica (GIS). El modelo utiliza siete parámetros medioambientales: profundidad del nivel freático, recarga neta, litología del acuífero, tipo de suelo, topografía, impacto de la zona no saturada y conductividad hidráulica para poder evaluar la vulnerabilidad del acuífero. En base a este modelo y utilizando el software ArcGIS 9.3, intentamos crear mapas de vulnerabilidad para la zona de estudio.

Según el índice para el modelo DRASTIC, el estudio muestra que en la parte occidental de la zona de estudio la vulnerabilidad a la contaminación varía entre alta (en un 26,16% de la superficie total) y muy alta (en un 3,14% del área total), debido a que en esta zona el nivel freático es poco profundo con un potencial de recarga entre moderado y alto, y suelos permeables. En el este y sureste de la Gobernación, la vulnerabilidad a la contaminación es moderada (43,44%). En la parte central y oriental, la vulnerabilidad a la contaminación es baja (27,24% de la superficie total) debido a la profundidad del nivel freático. El Modelo DRASTIC también señala que el riesgo más acuciante de contaminación del agua subterránea en la zona de estudio es por el tipo de suelo.

El impacto de la zona no saturada, la profundidad del nivel freático y la conductividad hidráulica ofrecen riesgos moderados de contaminación, mientras que la recarga neta, la litología del acuífero y la topografía son factores de poco riesgo. El coeficiente de variación indica que la topografía aporta mucho a las variaciones en el índice de vulnerabilidad. La profundidad del nivel freático, y la recarga neta hacen aportaciones moderadas, mientras que el impacto de la zona no saturada, la conductividad hidráulica, el tipo de suelo y la litología del acuífero son los parámetros menos variables. La baja variabilidad de los parámetros implica una menor aportación al índice de vulnerabilidad a lo largo y ancho de la zona de estudio. Además, los pesos "efectivos" de los parámetros DRASTIC obtenidos en este estudio mostraban alguna desviación de los pesos "teóricos". El tipo de suelo y el impacto de la zona no saturada eran los parámetros más efectivos en la evaluación de vulnerabilidad porque sus pesos "efectivos" medios eran más altos que sus respectivos pesos "teóricos". Para la profundidad del nivel freático los pesos "efectivos" y "teóricos" eran iguales, mientras que el resto de los parámetros exhibían pesos "efectivos" más bajos que sus correspondientes pesos "teóricos". Esto explica la importancia del tipo de suelo y del impacto de la zona no saturada en el modelo DRASTIC. Por lo tanto es importante conseguir información precisa y detallada sobre esto dos parámetros específicos. La técnica SIG ofrece un entorno eficiente para el análisis y es capaz de manejar grandes cantidades de datos espaciales. Los resultados muestran que el modelo DRASTIC ha sido una herramienta útil que podría ser aprovechado tanto por las autoridades como por los tomadores de decisiones, sobre todo en las zonas agrícolas donde se aplican los productos químicos y pesticidas más propensos a contaminar los recursos de agua subterránea.

Capítulo 8: Abuelaish B., Camacho Olmedo MT (under review) GIS as a tool to analyze groundwater salinity: the Gaza Strip as a case study

La Franja de Gaza sufre un problema agudo en cuanto a la calidad y cantidad de sus aguas. El agua subterránea se utiliza para beber, para usos agrícolas y también para procesos industriales. La salinidad del agua subterránea en la Franja de Gaza va en aumento. La causa principal de este problema es la intrusión de agua salada del mar. Se utiliza un electrodo selectivo de iones de cloruro como indicador de la salinidad para el análisis y modelado de la salinidad del agua subterránea en la Franja de Gaza para el año 2023. Nuestra investigación se basa en tres modelos para la previsión de la concentración del cloruro en el agua subterránea: Regresión lineal, Regresión Múltiple y Previsión para el año 2023.

En la Franja de Gaza las aguas subterráneas son una fuente importante de agua dulce para usos domésticos y para riego. La calidad del agua subterránea depende de la formación geológica y también de las actividades antropogénicas, por ejemplo, cambios en los usos del suelo, urbanización, la agricultura intensiva irrigada, actividades de minería, los vertidos en los ríos de aguas residuales no tratados, la falta de gestión racional, etc. (Voudouris, 2009). La contaminación del agua subterránea debido a las actividades humanas supone un grave riesgo para la salud pública.

Este estudio ilustra las concentraciones de cloruro en el agua subterránea dentro de seis transectos para 1993, 2003 y 2013. Analiza exclusivamente las zonas urbanas y con este fin se eliminan las zonas no urbanas. La concentración de cloruro en el agua subterránea en toda la Franja de Gaza se clasificó en seis clases para los años 1972, 1982, 1993, 2003 y 2013. La simulación de las concentraciones de cloruro para 1993, 2003 y 2013 (dentro de la zona urbana para 2013) demuestra que la concentración de cloruro ha aumentado claramente a lo largo de los años sobre todo en las zonas urbanas. En todos los transectos hay una correlación positiva con la expansión de las zonas urbanas. Se detectaron concentraciones de cloruro más altas en las zonas urbanas en el año 2013 que en los años anteriores (1993 y 2002).

Hay algunas diferencias entre los tres modelos (Regresión Lineal, Regresión Lineal Múltiple y Previsión) en los resultados simulados para las concentraciones de cloruro previstas para el año 2023, que se clasifican en seis clases. Los perfiles de concentración de cloruro muestran que la concentración de cloruro en el agua está aumentando y expandiendo en todos los transectos.

El resultado para los tres modelos demuestra que la salinidad del agua aumentará en todas las zonas de la Franja de Gaza para el año 2023. El análisis visual de los transectos se basa en los perfiles del análisis de los datos sobre el agua, que describen como el nivel de cloruro ha seguido subiendo en toda la Franja de Gaza a lo largo de dos distintos periodos de tiempo entre 1972 y 2023. La subida en la concentración de cloruro es evidente en toda la Franja de Gaza en los tres modelos. La tendencia de expansión de oeste a este debido a la entrada de agua salada del mar también se ve claramente en todos los transectos.

El cálculo de los valores de la Raíz del Error Cuadrático Medio (RECM) como potencia predictiva muestra que la Regresión Lineal Múltiple tiene un valor de 1631,723, seguido por Previsión con 1656,9, y Regresión Lineal con 1668,3. Por lo tanto, según la RECM, la Regresión Lineal Múltiple es el mejor modelo de nuestro estudio, seguido por el Modelo de Previsión y el Modelo de Regresión Lineal en segunda y tercera posición. Cuando se utiliza el método paso a paso (stepwise) en la Regresión Lineal Múltiple en SPSS, los pozos están afectados de forma más o menos intensa por todas las variables introducidas; la variable más efectiva es el año, con una cifra de aproximadamente 45%, mientras que la cifra para población es de 35%, producción 10%, precipitación 10% y nivel de agua 10%.

Los datos introducidos y obtenidos para la concentración de cloruro desde 1972-2013 hasta 2023 representan los cambios muy severos ocurridos en la Franja de Gaza. Este aumento en la concentración de cloruro es evidente en toda la Franja de Gaza. Para el año 2023 la parte de la Gobernación del Norte en lo cual la concentración de cloruro está por debajo de 250 mg/L y por lo tanto se considera libre de salinidad será sólo una pequeña fracción (menos de un 10%) de la Franja de Gaza.

El análisis de la intrusión de agua del mar dentro de los transectos muestra que este problema se repite a lo largo del litoral y se extiende desde el Mar Mediterráneo hasta la parte oriental de la Franja de Gaza.

En este estudio, un escenario muestra un aumento en la concentración de cloruro como indicador de la salinidad en el año 2023. Otro escenario contempla la construcción de una gran planta desaladora en la Franja de Gaza. La UE ha invertido 10 millones de euros durante esta fase y en cuanto la planta esté en pleno funcionamiento, producirá 6.000 m^3 de agua potable cada día, suministrando agua potable fiable a más de 75.000 palestinos —aproximadamente 35.000 personas en Khan Younis y 40.000 personas en Rafah, en la parte sur de la Franja de Gaza. El comisario europeo Johannes Hahn anunció financiación adicional de 10 millones de euros para la segunda fase del proyecto que comenzaba a mediados de junio de 2016, y se espera que se complete en 36 meses. Entonces la planta producirá un total de 12.000 m^3 de agua potable segura cada día (IMEMC, 2016). El aumento anual en la demanda de agua en la Franja de Gaza es de 2.240.437 m^3 por año desde 2016 a 2023. Por lo tanto la planta desaladora financiada por la UE ayudará a reducir la escasez de agua potable. Si la planta funciona según lo previsto, producirá unos 4.380.000 m3 por año después de 36 meses.

Conclusiones y perspectivas

Conclusiones

La tesis identifica los motores clave detrás del LUCC en la Franja de Gaza, y de esa forma ofrece una mejor comprensión de las distintas opciones para la expansión del suelo urbano. Estos motores incluyen la población, aspectos socioeconómicos, la situación política y la ocupación israelí. También explora el impacto de la expansión urbana sobre aspectos medioambientales tales como la calidad del agua y el cambio climático.

De la tesis se puede llegar a las siguientes conclusiones principales:

- Alrededor del 57.13 al 58.8% de la Franja de Gaza será suelo urbano en el año 2023.
- Hay diferencias entre la distribución espacial de la zona urbana producida por cada modelo (Geomod, CA_Markov y LCM).

- Hay una relación inversa entre la superficie urbana prevista para 2023 y la duración del periodo de calibración, un hecho comprobado utilizando cinco escenarios y el Land Change Modeler en el Capítulo 6.
- La urbanización de la Franja de Gaza está aumentando de forma acelerada debido al crecimiento natural de la población. Este hecho aumenta la presión sobre las zonas agrícolas, lo cual provoca la erosión del suelo y empeora la calidad y la cantidad del agua.
- La expansión urbana dispersa se ha incrementado a través del tiempo en detrimento del suelo agrícola, debido sobre todo al aumento en la población.
- Un aumento en el suelo agrícola en la Franja de Gaza aumentaría la presión sobre los recursos naturales y contribuiría al cambio climático a nivel local y mundial.
- Los responsables de la planificación urbana deberían tener en cuenta que las tres mayores zonas urbanas se van a fundir en una en un futuro próximo cercano, y que la población debería alojarse cada vez más en construcciones verticales para así reducir la expansión urbana.
- La Franja de Gaza puede hacer su parte para mitigar el cambio climático y tiene la capacidad para adaptar la cobertura del suelo en su territorio.
- La expansión urbana afecta a la calidad y a la cantidad del agua disponible, a la calidad del aire, a la gestión de la zona costera y al medio ambiente marino. Dentro de la ciudades, la forma en que crecen las ciudades es un factor determinante en la vulnerabilidad de los habitantes de las ciudades al estrés medioambiental (Güneralp y Seto, 2008)
- Los responsables de la planificación urbana y otros actores que toman decisiones en este ámbito deben tener en cuenta el riesgo de contaminación del agua subterránea en aquellas zonas del acuífero identificadas como vulnerables. Nuestros resultados demuestran que el modelo DRASTIC model puede ser una herramienta útil para las autoridades locales y para la entidad responsable de la gestión de las aguas subterráneas.
- La salinidad del agua subterránea ha incrementado en toda la Franja de Gaza debido al crecimiento demográfico acelerado y la expansión urbana que conlleva. Es probable que este problema de salinidad seguirá extendiéndose y en el año 2023 afectará a la gran mayoría de las zonas de la Franja de Gaza.
- Este estudio puede ser de ayuda para las personas que tienen que tomar decisiones en ámbitos como el uso del suelo, la planificación urbana, la situación medioambiental y los escenarios futuros para Gaza.

Perspectivas

Este estudio pretende ser un punto de partida para otros investigadores en el ámbito del cambio de usos y coberturas del suelo. Recomendamos que los estudios futuros sobre la Franja de Gaza se centren sobre todo en los siguientes temas de investigación:

- La identificación de las zonas más propensas a la expansión urbana, para ofrecer más ayuda a los gestores del medio ambiente y de la planificación que quieren evaluar los impactos de este fenómeno.
- Utilizar imágenes de satélite de alta resolución para obtener datos muy precisos para el seguimiento y análisis, los escenarios, el modelado y la proyección de LUCC y otros indicadores medio ambientales para la Franja de Gaza.
- Los responsables de la planificación urbana y otros actores clave deberían formular un plan estratégico para evitar el declive de las tierras agrícolas.
- Actualización y mejora de la base de datos LUCC SIG como parte de la recogida periódica de datos.
- Para poder asegurar desarrollos urbanos sostenibles, una Evaluación del Impacto Ambiental (EIA) debería ser obligatoria en todos los proyectos futuros en la Franja de Gaza, para así reducir los impactos medio ambientales negativos.
- En el futuro, la investigación debe tener en cuenta todas estas limitaciones y aplicar un planteamiento avanzado de modelado que permitirá previsiones a largo plazo.
- Estudios futuros deberían intentar identificar los impactos de los cambios de usos y coberturas del suelo sobre el cambio climático y otros aspectos medio ambientales como la contaminación del aire, la erosión costera relacionada con los puertos, las islas de calor en las ciudades, la caída en la flora y fauna, en la capacidad y productividad de la tierra, etc.

Bibliografía

La lista de referencias contiene la información bibliográfica sobre cada fuente citada en esta tesis. Los materiales de investigación no están incluidos en la lista de referencias, pero sí aparecen en las secciones que tratan sobre los datos, fuentes y métodos de la investigación. La lista de referencias se presenta por orden alfabético del apellido del autor, año, título del artículo y editorial.

Anexos

El Anexo I incluye un análisis del Factor de impacto y la calidad de las aportaciones (Capítulo 7, Capítulo 5. Capítulo 6).

El Anexo II analiza la aportación de la Franja de Gaza al cambio climático (emisiones de CO_2).

PART I. Theoretical Introduction and Methods

1. Introduction

1.1. Background and Literature Review

The Gaza Strip has been a theatre of conflict for decades. Each of these conflicts has left its mark, and a significant environmental footprint has developed in the Gaza Strip over time (UNEP, 2009).

Land use and land cover in the Gaza Strip is subject to increasing pressure from population growth, depletion and degradation of the available environmental resources such as water, land, flora and fauna, with their associated environmental and health impacts.

Understanding, predicting and analysing land use and cover change is enormously important for future planning. One of the major factors affecting land use in the Gaza Strip is rapid population growth, one of the most significant issues in Palestinian society today. According to the Palestinian Central Bureau of Statistics (PCBS), with the recent growth rates of 3.44% in mid-2013, and 3.41% in mid 2014 (PCBS 2014) the population of the Gaza Strip will have grown to over 2.4 million by 2023. This area already has one of the highest population densities in the world with an estimated 3,956 people/km² in 2006. The population growth rate and the urban expansion it drives affect the whole region. This figure is even higher in the Gaza Governorate (around 6,834 people/km²) where most of the population is concentrated. Another serious problem in Gaza is urban sprawl. The number of housing units in the Gaza Strip increased from 116,445 in 1997 to 147,437 in 2007 (PCBS 2012). Many human and natural factors have increased pressure on land use in this region, resulting in deteriorating quality and quantity of land (Abuelaish and Camacho 2016). Urbanization leads to increasing pressure on natural ecosystems (Taubenbock et al. 2012, Haas and Ban 2014) and brings with it soil, water and air pollution (Duh et al. 2006, Ren et al. 2003).

Land use and land cover change (LUCC) is a key driver of global environmental change and has important implications for many national and international policy issues (Nunes and Auge 1999; Lambin 2001). Research into the impacts, driving forces and rates of land use and land cover change can therefore provide crucial information for government planners and policy-makers. Land use/land cover change is often related to land planning, food production and urban growth (Paegelow and Camacho, 2008). In developing countries, urban sprawl has been exacerbated by the lack of land-use planning (Jat et al. 2008; Bayramoglu and Gundogmus 2008; Han et al. 2009; Biggs et al. 2010; Lee and Choe 2011).

One important method of understanding ecological dynamics, such as natural and human disturbances, ecological succession and recovery from previous disturbances, is the analysis of changing land cover patterns (Turner, 1990). Satellite imagery provides an excellent source of data for performing structural studies of a landscape. Simple measurements of pattern, such as the number, size and shape of patches, can indicate more about the functionality of a land cover type than the total area of cover alone (Forman, 1995). When fragmentation statistics are compared over time, they are useful in describing the type of land cover change and indicating the resulting impact on the surrounding habitat. The areas of land cover change between images can also be compared with landscape characteristics to determine whether change is more likely to occur in the presence of certain environmental and human induced factors. This level of classification detail offers opportunities for analysing land cover change patterns at a structural scale (Matt et al 2003).

Several monitoring techniques, such as Remote Sensing, are very useful for gathering the data required for land use change assessment, urban planning, urban sprawl and other environmental issues. Land use changes must be monitored at suitable intervals in order to update the knowledge required to support decision-making. Monitoring of land use and land cover requires the support of two parameters: spatial resolution and temporal frequencies (Curran, 1985; Janssen, 1993; Hualou et al. 2007).

Remote sensing and GIS are increasingly being used in combination spatial analysis. GIS databases are used to improve the extraction of relevant information from remote sensing imagery, whereas remote sensing data provide periodic pictures of geometric and thematic characteristics of terrain objects, improving our ability to detect changes and update GIS databases (Janssen, 1993).

A combination of remote sensing, GIS and visualization techniques was applied to demonstrate the potential for realistic computer visualizations depicting the dynamic nature of forested environments. Scientific visualizations are a useful support tool to help environmental and forest managers take decisions. They can also be used in landscape ecology to relay the findings of studies. While visualization software and methods have already been developed to recreate natural landscapes, little has been done to investigate the potential for illustrating land cover change through temporal data acquired from the real world (Matt et al., 2003).

Fung (1990) indicated the importance of the techniques and methods for using satellite imageries as data sources which have been developed and successfully applied for land-use classification and change detection in various environments including rural, urban, and urban fringes. Satellite-based remote sensing technology cannot yet be used to monitor land use at the level of accuracy required by developers, engineers and planners. Turner et al. (2003) showed how remote sensing can be applied in biodiversity monitoring through direct and indirect approaches based on individual organisms and through reliance on environmental parameters as proxies. Therefore, satellite remote sensing data is widely applied throughout the world for land use/land cover change detection and monitoring with the aid of technological improvement that provides high resolution images.

There are three satellite imagery systems which could supply the required data, namely the Land sat Multi-Spectral Scanner (MSS), the Land sat Thematic Mapper (TM) and the Land sat Enhanced Thematic Mapper (ETM). While satellite imagery is a flexible form of data for electronic processing, Tudor et al (1998) indicated its two practical difficulties. Firstly, the need for reasonably cloud-free coverage means that a set of images spanning several seasons may be required. A second difficulty arises as a consequence of the first. The boundaries between neighbouring scenes can be difficult to match, if they are captured at different times of the year and under different atmospheric conditions.

Previous studies related to GIS, Remote sensing, Land changes and their impacts in the Gaza Strip include:

- Alghamri Rami J. H., August 2009, Study of the Impact of Land Use and over Pumping on Nitrate Concentration in Groundwater by Using Modelling Approach Case Study: Khan Younis Governorate- Gaza Strip, this work tried to study the nitrate concentration in groundwater. A coupled flow and transport model using a three-dimensional, finite difference simulation model (VMODFLOW Pro.) was applied to simulate the southern part of the Gaza coastal aquifer.
- Badwan Al-Moataz Billah, 2010, Master thesis, “GIS Based System for Evaluating Groundwater Quality in the Gaza Strip”.The researcher produced an application as a prototype developed, using Microsoft Visual Basic, from map objects and map files generated using the ARCInfo Software, which has a geographic database for monitoring chloride as an indicator of water quality with respect to the current situation. This is useful for both managers and decision-makers.
- AbuAmra Saleh, 2010, Master thesis, “Applications of Geographic Information Systems in Land Use. This study produced many accurate digital, computerized maps linked with databases for the City of Deir Ale Balah, which were hard to create using GIS techniques. The study concluded by describing the patterns of

land use in the city. It also described the different functions in detail. The study also presented a special model of spatial analysis for recreational services (green areas) using ArcGIS9.3software and standards of urban planning methods in selecting sites for services.

- AbuJaiab Suhaeb, 2012, Further Urban Development in the Governorate of Khan Younis in the Light of Maintaining the Environmental resources using GIS and RS. Master thesis, The Islamic University - Gaza.
- Ashour Ehab K., Alnajar Husam, May2012, Modelling of Orchards Irrigation Demand under Vulnerable Climate Change and the Sequencing Effect of Soil Salinization in Gaza Strip. Master Thesis. The Islamic University Gaza.
- UNEP.2002, Desk Study on the Environment in the Occupied Palestinian Territories. This study discussed all environmental issues, analysing land cover change in the southern and northern parts of the Gaza Strip as a result of Israeli settlement and GIS implementation by town councils. The results show that there is a shortage of data, that the hardware, software and other systems used by Town Councils are weak, and that, according to the employees, there is a lack of support from top management; while the governments can make policy decisions to build GIS from the perspective of decision-makers.
- Habboub Mohammed, 2013, Spatio-Temporal Analysis of the Dead Sea Area using Remote Sensing and GIS-Based Model: Markov - Cellular Automata. In this research fourteen satellite imageries from 1972 to 2010 were collected in addition to 2011-ASTGTM-DEM. The Dead Sea is shrinking by 2.5 km^2/yr while the water level decreases by 0.7 m/yr. This means that the volume is dropping by 0.33 km^3/yr.

1.2. Concepts

*Land cover*is defined as the layer of soils and biomass, including natural vegetation, crops and human structures that cover the land surface. *Land use* refers to the purposes for which humans exploit the land-cover (Fresco, 1994). According to FAO (2000), land cover can be defined as “the observed bio-physical cover on the Earth’s surface”. When considering land cover in a very pure and strict sense it should be only used to describe vegetation and man-made features. Consequently, areas where the surface consists of bare rock or bare soil can only be described as land itself rather than as land cover. It is also debatable whether water surfaces are real land cover. However, in practice, the scientific community usually describes these areas under the term land cover (FAO, 2000). Land use was defined by the FAO (2000) as “characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it”. Definition of land use in this way establishes a direct link between land cover and the actions of people in their environment. Lambin et al. (2006) refer to land use as "the purposes for which humans exploit land cover. It involves both the manner in which biophysical attributes of the land are manipulated and the intent underlying that manipulation, i.e., the purpose for which the land is used". Hence, land use is always determined by the "arrangements, activities and inputs people undertake on a certain land-cover type to produce, change or maintain it" (Di Geregorio and Jansen, 2000)

Land-cover change is the complete replacement of one cover type by another, while *land-use changes* also include the modification of land-cover types, e.g., intensification of agricultural use, without changing its overall classification (Turner II *et al., 1993).*

Land-use changes, mostly driven by human activities, result in global environmental change (Riebsame et al. 1994; Vitousek et al. 1997; Houghton, 1994; Tinker, 1997). Individual human activities that lead to land-use changes can meet locally defined needs and goals, but when aggregated may have an impact on the regional and global environment (Turner II, 1994; Ojima *et al.*, 1994). They may affect biodiversity, water and radiation budgets, trace gas emissions and other processes that, cumulatively, affect global climate and biosphere (Intergovernmental Panel on Climate Change, 1997).

Land-use change is directly linked to the theme of transition to a sustainable world. This transition requires an improved understanding of the trajectories of land-use change that invoke positive or negative human environment relationships (Turner II et.al. 1987; Holling et.al.1 996). Land-cover and land-use change is only one component of the global environmental changes currently underway, and is superseded by fossil fuel consumption in terms of its impact on atmospheric warming (Steffen et al., 2001). Land use/cover change is a complex process which is caused by the mutual interactions between environmental and social factors at different spatial and temporal scales (Valbuena et al. 2008; Rindfuss et al. 2004).

There are many *driving factors* (driving forces), normally related to time, that can help us understand land changes, spatial distribution and the future land use situation.

Land use models are used to explore the effects of possible future changes in driving factors on land use, especially given that land use/cover change is a driver for many environmental issues and climate change. One example is the expansion of urban land use, which is a serious challenge for decision makers in many developing countries. A capability to simulate/forecast land use and land cover change based on specific policies and constraints can be important for making informed decisions (Rasuly et.al., 2010).

Land use and cover change can be caused by multiple driving forces that control certain environmental, social and economic variables, while these driving forces can contain any factor which influences human activities, including local culture, economic and financial matters, environmental circumstances (i.e. greenness, land quality, terrain situation, water availability and accessibility to recreation) (Arsanjani, 2012). Human activities, climate change, environmental alterations and meteorological variability are dynamic variables for changes over time. These are time-dependent drivers (e.g. proximity to existing development or infrastructure) and are recalculated over time during the course of a prediction (Eastman, 2016).

Drivers act as indicators for leading and measuring land use changes and can be used to assess a range of planning issues in the Gaza Strip, such as total land area, agricultural land, land covered by urban development, water quality, environmentally sensitive areas, and population density. These indicators can be adapted according to the practical experience gained during their implementation in order to meet our needs and fit our situation in the Gaza Strip.

The ability to predict land changes depends on understanding the past drivers of land use and land cover change.*Predictions*are based on the historical land use and cover change data that has occurred primarily in response to population growth, infrastructure, socio-economics, physical features and the political situation.

Models are simplifications of reality; they are theoretical abstractions that represent systems in such a way that essential features crucial to the theory and its application are identified and highlighted (Batty, 2009). Modelling can be defined within the context of geographic information systems (GISs), as occurs whenever GIS operations attempt to emulate processing in the real world, at one point in time or over an extended period (Goodchild 2005, Paegelow et al. 2013). GIS models go beyond simply evaluating the future and are used to assess different scenarios, on the basis of the historical data retrieved from multiple resources.

A *scenario* can be defined as a description of an assumed future state of affairs (Kuhlman, 2007), while scenarios can be built by making a number of assumptions about the future and entering them into a model.Scenarios have emerged as useful tools to explore uncertain futures in ecological and anthropogenic systems (Sleeter et al. 2012). Scenarios typically lack quantified probabilities (Nakicenovic and Swart 2000 and Swart et al. 2004), functioning instead as alternative narratives or storylines that capture important elements about the future (Nakicenovic and Swart 2000, Peterson et al. 2003, Swart et al. 2004). Alcamo et al. (2008) define scenarios as “descriptions of how the future may unfold based on ‘if-then’ propositions.” Scenarios provide a structured framework for the exploration of alternative future pathways, and are used to assist in the understanding of possible future developments in complex systems that typically have high levels of scientific uncertainty (Nakicenovic and Swart 2000, Raskin et al. 1998). Plausible scenarios generally require knowledge of how drivers of change have acted to influence historical and current conditions (Sleeter et al. 2012). The past trends scenarios should be consulted for each driving force to assess the most likely developments. Hence the driving force has a weight value (effect) on land change.

Environmental pollution is “the contamination of the physical and biological components of the earth/atmosphere system to such an extent that normal environmental processes are adversely affected” (Kemp, 1998). Pollution is “the introduction of contaminants into the environment that cause harm or discomfort to humans or other living organisms, or that damage the environment”. These contaminants can come “in the form of chemical substances, or energy such as noise, heat or light”. “Pollutants can be naturally occurring substances or energies, but are considered contaminants when in excess of natural levels.” (Wikipedia, n.d.). The three main types of environmental pollution are; Air pollution, Water pollution and Soil pollution.

Groundwater is the main source of drinking water in the Gaza Strip and extraction from the coastal aquifer has greatly increased over time. This has led to severe problems with both the quality and quantity of water. One example is nitrate contamination produce above all by the use of pesticides and leachate of waste water into the aquifer. Salinity has increased due to high water extraction and seawater intrusion into the aquifer.

Vulnerability is a relative, unquantifiable, and non-dimensional property that could be either intrinsic or specific (Vrba and Zaporozec, 1994). Assessment of aquifer vulnerability can help identify zones that are more easily polluted than others. Vulnerability analysis can thus provide valuable information for individuals working to prevent further degeneration of the environment (Mendoza and Barmen 2006). Groundwater vulnerability can be defined as a measure of the degree of protection offered by natural and manmade factors to prevent groundwater from being affected by surface pollution. Intrinsic aquifer vulnerability takes into consideration the geological and hydrogeological characterization of the area, regardless of the properties of the pollutant or the nature of contamination (Zwahlen, 2004). Since the concept of groundwater vulnerability to contamination was first discussed (Margat, 1968), several approaches have been adopted for performing aquifer vulnerability analysis, such as GOD (Foster, 1987), DRASTIC (Aller et al., 1987), AVI (Van Stempvoort et al., 1993), and SINTACS (Civita 1994). DRASTIC is a popular approach for mapping aquifer vulnerability in several regions (Sener et al., 2009; Massone et al., 2010; Lathamani et al., 2015).

Seawater intrusion is the migration of seawater into freshwater aquifers under the influence of groundwater development. (Freeze and Cherry, 1979). Groundwater pumping can reduce freshwater within flow of seawater towards coastal aquifer areas and cause saltwater to be drawn towards the freshwater zones of the aquifer.

1.3. Thesis Structure

The research conducted during the preparation of this thesis focused on theory, methodology and application. These form the core of the three main parts of the thesis, which is completed with various Annexes.

Part I is the Theoretical Introduction describing also the Methods used in the thesis and includes four chapters:

- Chapter 1 is the Introduction. It presents the background to this question and a review of the literature, concepts relating to land change, the vulnerability of ground water to pollution and water salinity, and the structure of the thesis.
- Chapter 2 presents the objectives and hypothesis of the thesis.
- Chapter 3 presents the study area including land changes as a result of the increase in population, socio-economic status, and the political situation, all drivers of change.
- Chapter 4 presents the methodology applied in the thesis, and the models used in parts II and III within the required data analysis and data processing, the modelling requirements and scenarios for the case study area.

Parts II and III are the Results and Discussion.

Part II focuses on the Analysis, Simulation and Scenarios of Land Change, and is divided into two chapters:

- Chapter 5 presents “Scenario of land use and land cover change in the Gaza Strip using remote sensing and GIS models”.
- Chapter 6 presents “Urban land use change analysis and modelling: a case study of the Gaza Strip”

Part III explores the impacts of land change on the environment in two chapters:

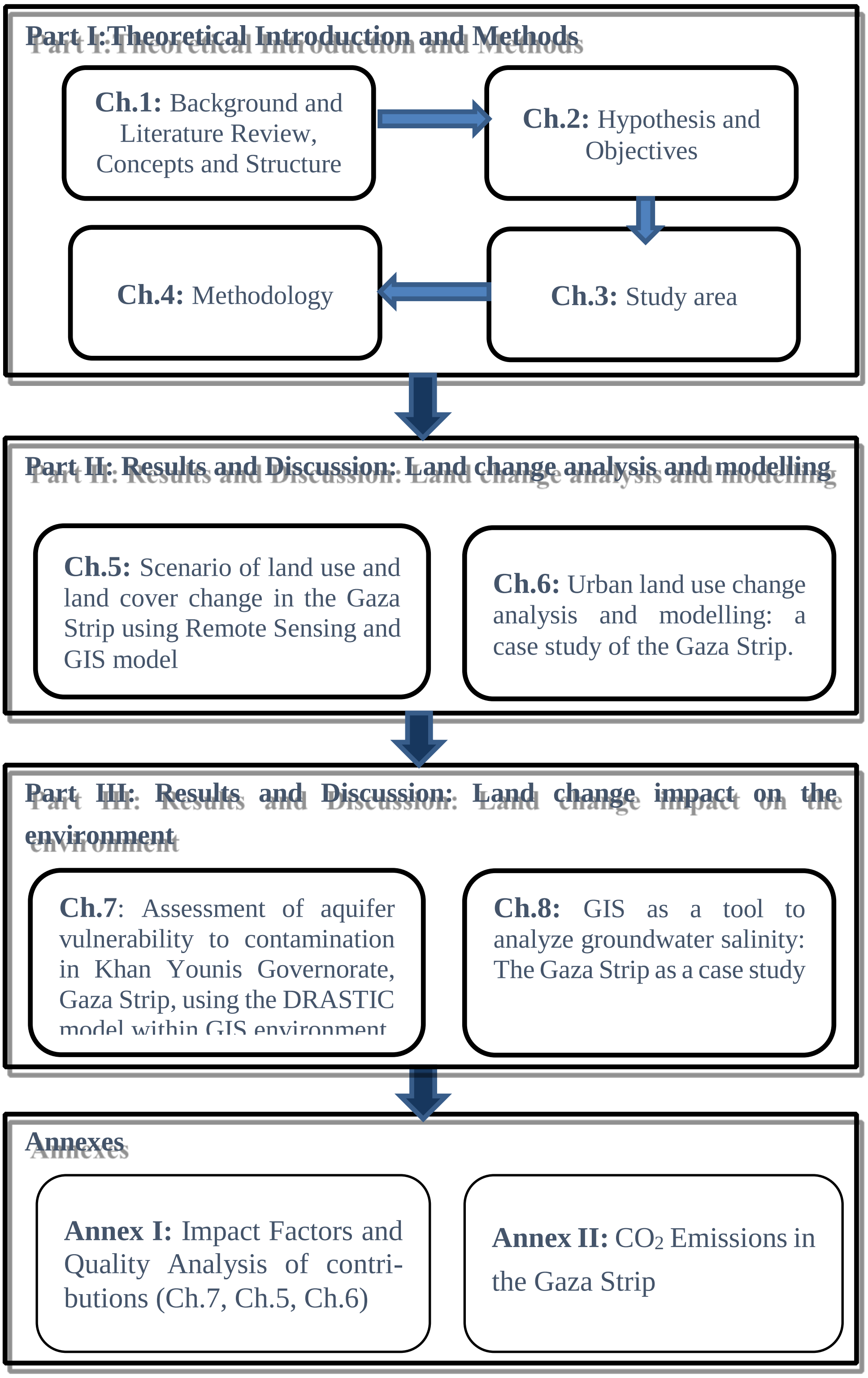
- Chapter 7 presents “Assessment of aquifer vulnerability to contamination in Khan Younis Governorate, Gaza Strip—Palestine, using the DRASTIC model within a GIS environment”
- Chapter 8 presents “GIS as a tool to analyze groundwater salinity: The Gaza Strip as a case study”.

The thesis ends with two annexes:

- Annex I presents the impact factor and the quality and knowledge contributions (Chapter 7, Chapter 5 and Chapter 6)
- Annex II - CO_2 Emissions in the Gaza Strip

The structure of the thesis is displayed in a flowchart (Figure 1.1), which summarizes the eight chapters (and the Annexes) that make up this study and the relationships between them.

Figure 1.1. The structure of the thesis



2. Hypothesis and Objectives

2.1. Hypothesis

The principal hypothesis of this research is that the normal urban growth rate in the Gaza Strip, which results in particular from urban development and agricultural conversion, is strongly influenced by the dynamic changes in the political situation. The inherent instability of this situation makes it very difficult to assess the rate of land use and land cover change (LUCC) in the Gaza Strip. Models were therefore set up to evaluate changes in different land use and land cover data over various periods, as a function of the changes in the political situation. These models can be tested empirically to enable us to make predictions and evaluate scenarios for the future of the Gaza Strip, considering all non-urban areas as agricultural areas.

Our secondary hypothesis deals with the impacts of land change on the environment. The groundwater basin is prone to receive and transmit contamination caused by human activities and land changes. This means that there are parts of the aquifer in the study area that are vulnerable to contamination. We carry out a spatial distribution analysis of the parameters and conditions under which the groundwater could be contaminated. The salinity of the groundwater seems likely to expand to most of the Gaza Strip due to high levels of fresh water extraction and high population growth.

2.2. Objectives

The research focuses on the methods and techniques for modelling and analyzing land use and cover growth. This is a complex phenomenon especially in our case study area in the Gaza Strip. Urban development involves change, growth and decline. Modelling land change scenarios must necessarily include the physical and socioeconomic dimensions of land change and its impacts on the environment.

The main objective is to find a model and an easily applicable technique to help decision makers and key stakeholders in Palestine to apply different scenarios for future planning of the Gaza Strip, within the framework of the following broad objectives of this study:

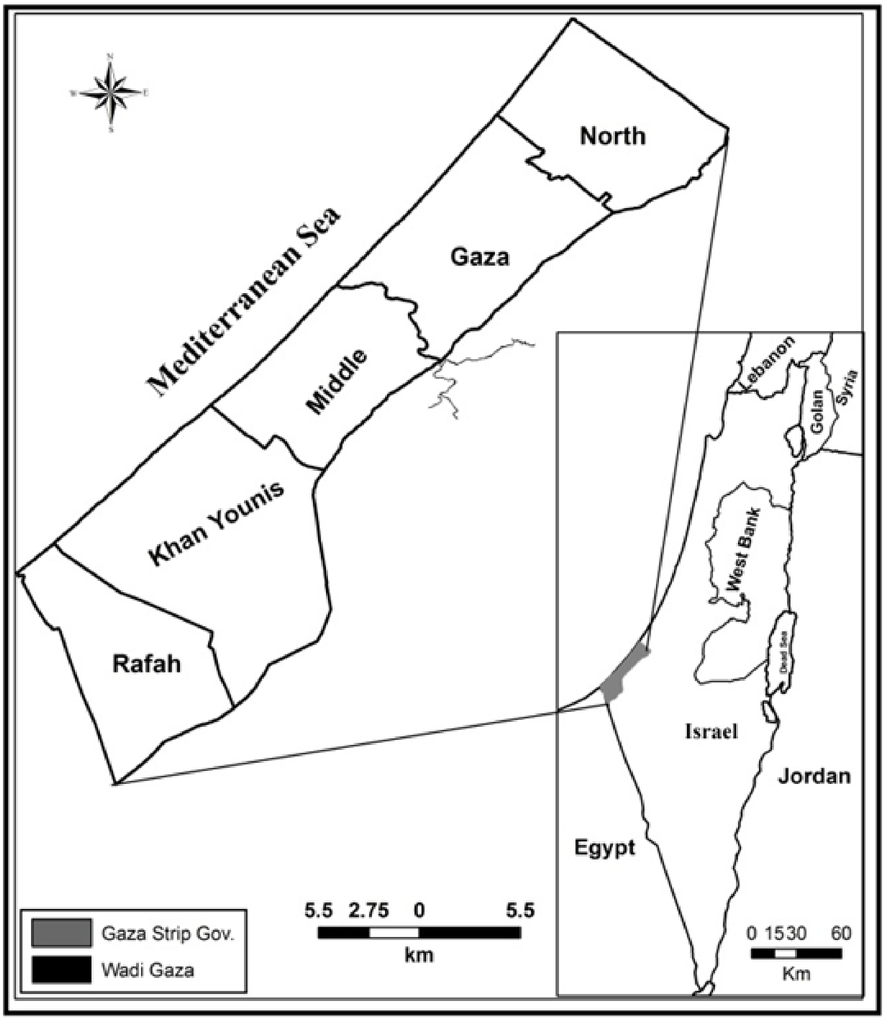
- Identification and delineation of different land use and land cover categories using remote sensing data and rectified aerial photographs.
- Simulation, scenarios, modelling and prediction of land use and land cover in the Gaza Strip.

- Generation of data regarding the changes that have taken place in the area in various land use and land cover categories over different periods.
- Building a GIS database for the study areas.
- Modelling and prediction of environmental indicators such as the vulnerability of groundwater to pollution, and the salinity of the groundwater.
- Helping decision-makers take decisions on land-use management, city planning, the environmental situation and future scenarios for Gaza and its people.

3. Study Area

The Gaza Strip is a narrow area on the Mediterranean coastal plain. It is approximately 41 km long, and from 6 to 12 km wide, with a total area of 365 km². It shares a 12 km border with Egypt to the southwest and is surrounded by Israel to the east and north (the rest of the Strip – a 51 km border), as shown in Figure 3.1. The Gaza Strip has a temperate climate, with mild winters (about 13ºC) and hot summers with frequent droughts (high 20s ºC). Average rainfall is about 300 mm a year (MOAg 2013). The terrain is flat or rolling, with dunes near the coast. In terms of topography the Gaza Strip slopes gradually downwards from east to west with the land surface elevation varying between 10 m above sea level in the west to 110 m above sea level in the east.

Figure 3.1. Location on the Gaza Strip.



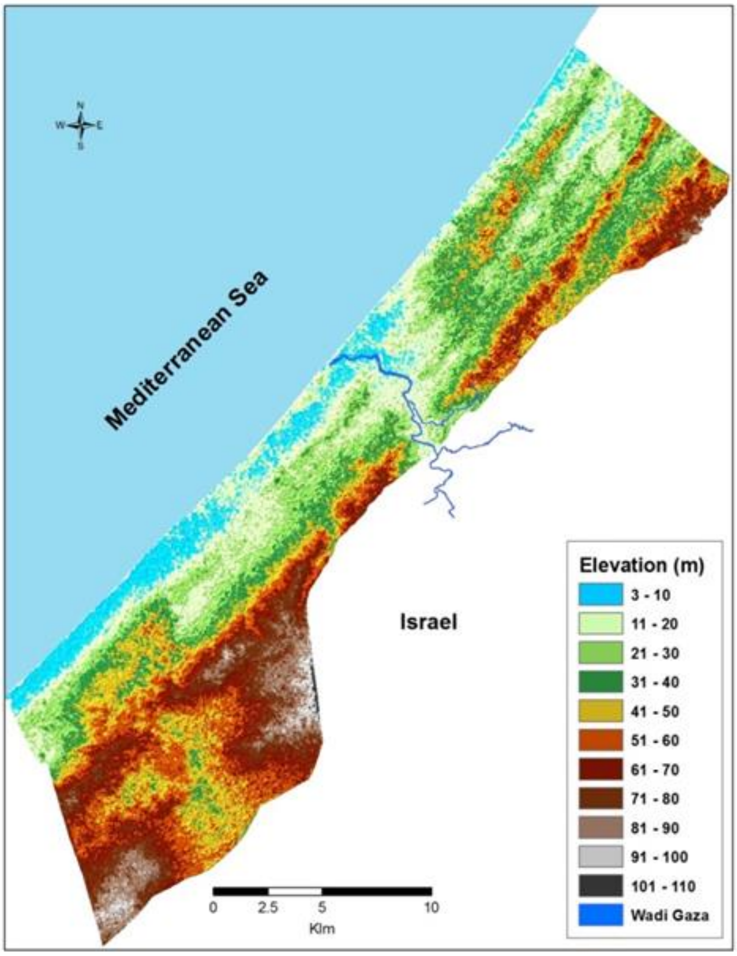
Source: by student depending on (MOPIC, 1996)

3.1. Features of the Gaza Strip

3.1.1. Topography

The terrain of the Gaza Strip is flat to rolling, with sand dunes near the coast. The highest point is 105 meters above sea level. Figure 3.2 shows the decreasing elevation along the coast as we cross the Strip from north-east to south-west.

Figure 3.2. Topographic map of the Gaza Strip.



Source: (MOPIC, 1996)

In topographic terms the Gaza Strip has three main distinguishing features: the coastal zone and sand dunes, the Wadi Gaza, and the Kurkar hills

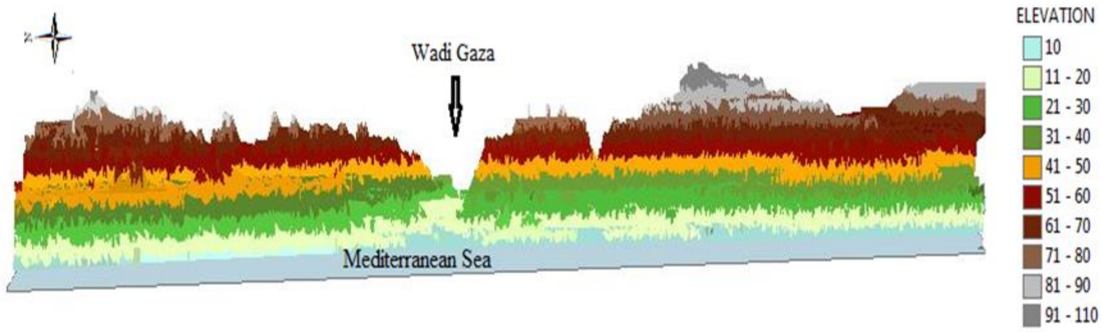
The topography of the Gaza Strip is defined by three ridges (known locally as the Kurkar ridges), depressions, dry streambeds and shifting sand dunes as illustrated in Figures 3.2 and 3.3. The ridges and depressions generally run NE-SW parallel to the coastline. The surface elevation ranges from mean sea level to approximately 110 m above mean sea level. The depressions, which contain alluvial deposits, are approximately 20 - 40 m above mean sea level.

3.1.2. Coastal zone and sand dunes

The coastal zone of the Gaza Strip is about 40 km long and has an area of approximately 74 km², with a variety of different human activities. It includes wide sand dune areas in the south and the north of the Gaza Strip, the coastal kurkar cliffs running north from the middle coastal zone for about 5.6 km, non-urban areas, and part of the Wadi Gaza river valley, as shown in Figure 3.3.

The coastal area has a straight, sandy shore. The near-coast continental shelf slopes downwards with a gradient of 1:100. The irregular, rocky seabed of the coastal shelf at a depth of 100 m is 28 km wide in the south and 14 km wide in the north. The seabed drops quickly beyond a depth of 100 m. Its sediments consist mainly of sand (25 m deep), with muddy places near the Wadi Gaza (Sogreah, 1996).

Figure 3.3. 3D Topography Map of the Gaza Strip.



Source: *by student depending on data contour maps(MOPIC, 1996)*

Generally, there have been fewer opportunities in the coastal zone for the construction of towns and for agriculture than on the Kurkar ridges and the adjacent plains and valleys in the central and eastern parts of Gaza. This is because of the fertility of the land and the historic importance of security in the highlands of the Kurkar ridges (Camp Dresser et. al., 1999)

3.1.3. Wadi Gaza

The Wadi Gaza (valley) is about 105 km long. It starts in the Negev hills and the southern heights of Hebron and runs from the Truce Line in Eastern Gaza to the coast where it flows into the Mediterranean Sea, in the centre of the Gaza Strip.

The section of the Wadi Gaza that passes through the Gaza Strip is around 10 km long, and it varies in width from place to place, widening near the mouth where it is about 100m wide. The maximum elevation of the Wadi near the Truce Line is about 30 meters above sea level, from which it descends to the Mediterranean Sea. (MedWetCoast, 2002)

Wadi Gaza is considered one of the most important coastal wetlands in the Eastern Mediterranean Basin, in that it is very rich in biological diversity (both flora and fauna). The wadi is also a stopover point on the migratory routes from north to south and from south to north. In addition, as it is the biggest wetland in Gaza (and indeed in Palestine) and has a special, outstanding landscape, it could potentially become a recreational area attracting people from different areas. (UNESCO, 2012).

3.1.4. Kurkar hills (Calcareous sandstone)

The topography of the Gaza Strip is dominated by the three Kurkar ridges. The coastal ridge is up to 50 meters above MSL and extends along to the coast near Dier-Albalah city in the western part of the Strip. The Al-Montar and Beit Hanoun ridges run along the middle and eastern parts of the Strip as can be seen in Figure 3.3. These ridges belong to the Pliocene-Pleistocene Kurkar Group and are composed of marine and continental calcareous sandstone (Frechen et al., 2004; Galili et al., 2007). Deep depressions with alluvial deposits separate the ridges at 20 to 40 m above MSL. (Ubeid, 2011)

In the southern part of the Gaza Strip, these ridges tend to be covered by sand dunes. There are three main types of soil in the Gaza Strip: sandy soil, clayey soil, and loess soil (Ubeid, 2011; 2014). The sandy soil is found along the coastline and middle parts of the Gaza Strip in the form of sand dunes. The clayey soil is found along the north-eastern part of the Gaza Strip. The loess soil is found around the Wadi Gaza (Ubeid, 2014).

3.2. The Population

3.2.1. Population Distribution

In 1948, the Gaza Strip had a population of less than 100,000 people (Ennab 1994), however by 2007, it had risen sharply to around 1.4 million (Census, 2007). The total population in 2014 was estimated to be in excess of 1.79 million and, at the end of 2015, about 1.82 million inhabitants, distributed across five Governorates (PCBS[a] 2015), of whom almost 1.3 million were UN-registered refugees. Gaza City, which is the biggest governorate, has some 625,824 inhabitants. The other two main governorates are Khan Younis and Rafah in the southern part of the Gaza Strip, which have 341,393 and 225,538 inhabitants, respectively. There is also the Northern Governorate, with a population of about 362,772, and the Middle Governorate, which has 264,455 inhabitants. The smallest governorate in terms of area is the Middle Governorate, with 55.19 km^2. This is followed by Rafah (60.19 km²), the Northern Governorate (60.66 km²), and Gaza (72.44 km²). The largest governorate is Khan Younis with an area of 111.61 km², as shown in Figure 3.1.

Agriculture is the economic mainstay of the employed population, and nearly three quarters of the land area is under cultivation. On the Gaza coastal plain the original Saharo-Sindian flora has been almost completely replaced by farmland and buildings. Gaza has six main vegetation zones: the littoral zone along the coast, the stabilized dunes and blown-out dune valleys, the Kurkar, alluvial and grumosolic soils in the northern part, the loessial plains in the east, and three wadi (valley) areas (UNEP 2006).

3.2.2. Population components and growth

The estimated number of Palestinians in the world at the end of 2015 was about 12.4 million, of whom about 4.75 million (38.3%) live in the Palestinian Territories. Of these 4.75 million, 61.04% (2,898,927 people) live in the West Bank and 38.96% in the Gaza Strip (1,850,559 people) (PCBS[a], 2015), as shown in Table 3.1.

Table 3.1. Estimated Population of the Palestinian Territory by Region and Sex, end 2015.

Region	Females	Males	Both Sex	Percent
Palestinian Territory	2,336,086	2,413,400	4,749,486	100.00
West Bank	1,425,886	1,473,041	2,898,927	61.04
Gaza Strip	910,200	940,359	1,850,559	38.96

Source: (PCBS[b], 2015).

The unstable political and security situation in the Gaza Strip has had direct results in terms of fluctuations in population growth and population density in the Gaza Strip from 1948 up to now. In 1967, immediately prior to the Six-Day War with Israel, the population density reached 1,043 inhabitants/km², before falling back in 1970 to 1,008 inhabitants/km². It then started to rise again reaching 1458 inhabitants/km² by the year 1985 (and 3,102 per km² in the year 2000, as shown in Table 3.2.). According to the Ministry of the Interior the population of Gaza Strip reached two million on Monday, October 10, 2016, putting the population density at 5480 inhabitants per km². This makes Gaza one of the world's most densely populated regions. The population logically requires the provision of a large range of services, the most important being health and education. These must be increased in line with the annual increase in population.

In 1948, the Gaza Strip had a population of less than 100,000 people. By 2007, approximately 1.4 million Palestinians lived there.

The estimated population in 2014 is in excess of 1.8 million, distributed across five Governorates. Almost 1.22 million are UN-registered refugees and the majority of people live in refugee camps.

Table3.2. Population Growth from 1948- 2023

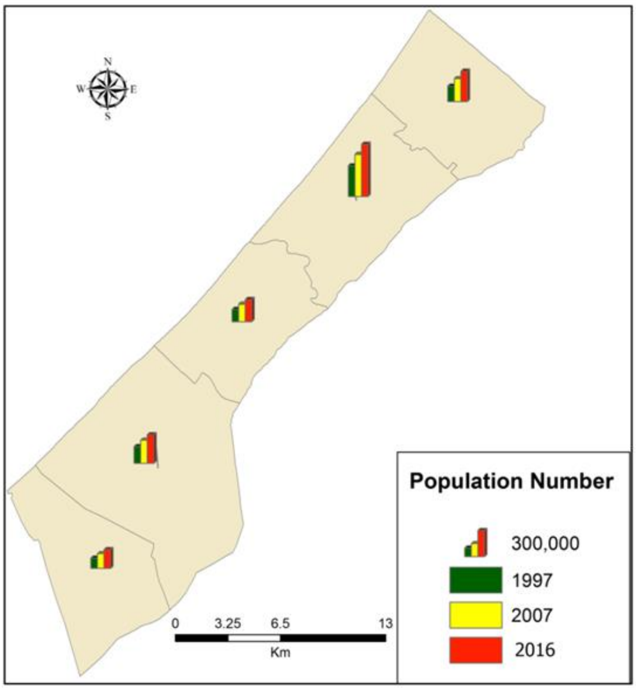
Year	Population Number	Density Pop. N./Area km²
[a] 1948	82,500	226.0
[b] 1950	240,000	657.5
[b] 1960	302,000	827.4
[c] 1966	454,960	1,246.5
[c] 1967	356,261	976.1
[d] 1970	368,000	1,008.2
[d] 1980	455,000	1,246.6
[d] 1985	532,000	1,457.5
[d] 1990	645,000	1,767.1
[e] 1997	995,522	2,727.5
[e] 2000	1,132,063	3,101.5
[e] 2007	1,395,720	3,823.9
[e] 2014	1,760,037	4,822.0
[e] 2015	1,819,982	4,986.3
[e] 2016	1,881,135	5,153.8
[f] 2023	2,390,094	6,548.2

Source: *[a] (Ennab1994), [b] (McCarthy, 1994), [e] Levy Economics Institute, [d] (U.S. Census Bureau), [e] (PCBS, 2016), and [f] estimated by the author.*

Gaza Strip has five Governorates, the biggest of which is Gaza City, which had about 635,514 inhabitants at the end of 2015. The other two main governorates are Khan Younis (346,664 inhabitants), and Rafah (229,514 inhabitants). The Northern governorate has 369,949 inhabitants, and the Middle governorate has 268,918 inhabitants, as illustrated in Figure 3.4.

The current total fertility rate (2014) is 4.5 births per woman, down from 5.2 in 2010 and 6.8 in 2000. The birth rate on the West Bank is significantly lower at 3.7 births per woman in 2014.

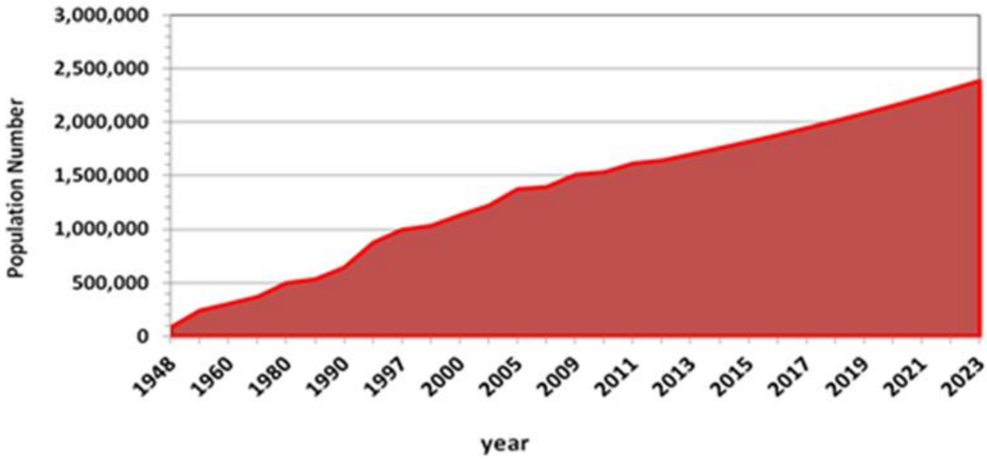
Figure 3.4. Population number in the Gaza Strip in 1997, 2007, and 2016.



Source: *by student depending on (PCBS 1997, 2007, 2016)*

Recent projections estimate that if the present birth rate continues, the population is likely to double by the year 2023, as can be seen in Table 3.2 and Figure 3.5.

Figure 3.5. Population Growth in the Gaza Strip from 1948 to 2023.

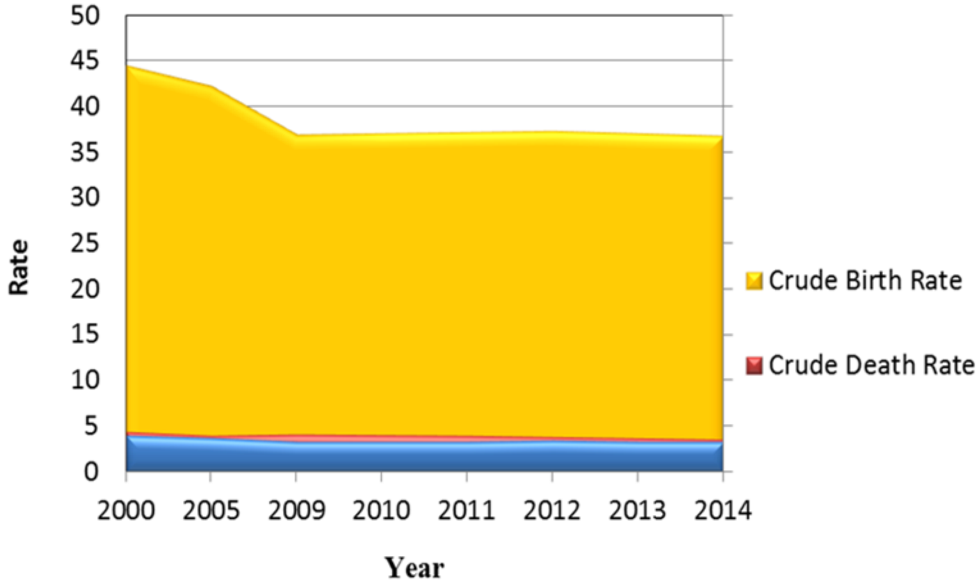


Source: *by student depending on [a] (Ennab1994), [b] (McCarthy, 1994), [e] Levy Economics Institute, [d] (U.S. Census Bureau), [e] (PCBS, 2016), and [f] estimated by the author.*

According to the Palestinian Statistics Center the natural population was increasing at a rate of 3.4% in 2014, while in 2000 it was 4.0% as shown in Figure 3.6, which also shows the increase in population from 1948 to 2013. By the year 2023 the population in the Gaza Strip will have increased to approximately 2.4 million, as shown in the previous Table

3.2. This puts the Gaza Strip in the top ten countries in the world with the fastest growing population rate; and number one in highest population density.

Figure 3.6. Crude Birth Rate, Crude Death Rate, and Natural Increase from 2000 to 2014.



Source: (PCBS, 2015)

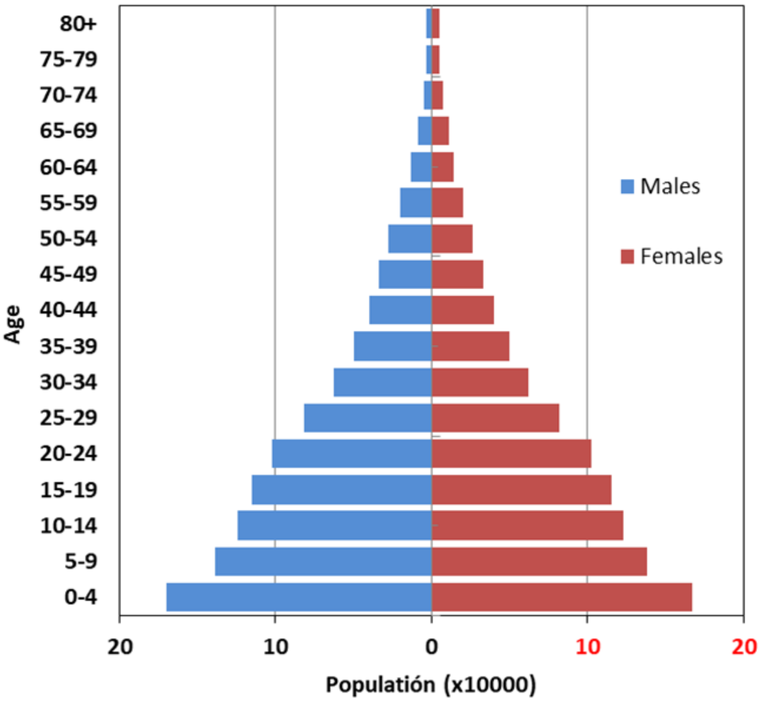
3.2.3. Population structure

The age structure of the Palestinian population in the Gaza Strip shows that children (0-14 years) made up about 39.6 % of the total population (37.4% in the West Bank and 42.8% in Gaza Strip), at the end of 2015 as seen in Figure 3.7 (PCBS, 2016). The percentage of the population in the Palestinian territories aged 65 years and older at the end of 2015 was estimated to be 2.9% of the total population (3.2% in the West Bank and 2.4% in Gaza Strip).

3.2.4. Population Density

The high population density of around 5154 inhabitant\km² in 2016 in the Gaza Strip is due to its small area of 365 km². The population density is even higher in the refugee camps, which have some of the highest densities in the world, so increasing the already high population density on the Gaza Strip. Table 3.3 and Figure 3.8 show the density distribution in 2016 and the estimated density by the year 2023 in the five Governorates. The highest density is in the Gaza Governorate with 8,719 inhabitants/km², followed by the Northern Governorate 6,083 inhabitants/km2, Middle 4,882 inhabitants/km², Rafah 3,892 inhabitants/km², and Khan Younis 3,114 inhabitants/km².

Figure 3.7. Population pyramid for the Gaza Strip (end of 2015).



Source: (PCBS, 2016)

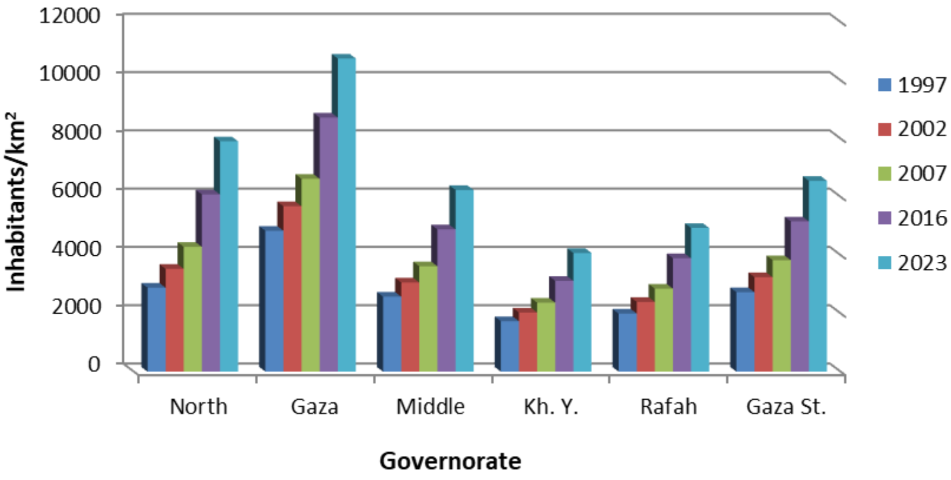
Table 3.3. Density distribution of the projected population in the Gaza Strip in 2016 and 2023.

Gov.	Area (km²)	(Area %)	Population 2016 (%)	Density 2016 (people /km²)	Population 2023 (%)	Density 2016 (people /km²)
Northern	62	16.99	20.0	6,083	20.5	7,903
Gaza	74	20.27	34.3	8,719	33.3	10,743
Middle	56	15.34	14.5	4,882	14.6	6,232
Kh. Younis	113	30.96	18.7	3,114	19.3	4,072
Rafah	60	16.44	12.4	3,892	12.4	4,932
Gaza Strip	365	100.00	100.0	5,154	100.0	6,548

Source: (PCBS, 2016)

1) The Gaza Governorate covers only Gaza City, and contained more than a third (34.3%) of the population of Gaza Strip in 2016 with only 20.3% of its total area. It has a population of 645,204 inhabitants, the highest of all the governorates. Despite its position in the north of the Gaza Strip it is the main population centre and capital city, as well as the main hub for economic activities and social services, especially higher education institutions and health services with specialized hospitals and medical centres. It also includes all commercial and ministerial institutions.

Figure 3.8. The population density in the different Governorates on the Gaza Strip in 1997, 2002, 2007, 2016, and 2023.



Source: (PCBS, 1997, 2007, 2016)

2) Northern Governorate is in second place with 20% of the total population of the Gaza Strip with 377,126 inhabitants in 2016 and a population density of 6083 people\km². It has three cities (Beit Lahiya, Beit Hanoun, Jabalia) and the population is highly concentrated in the Jabalia area, and in particular the Jabalia refugee camp, which had a population of 58,517 inhabitants in 2016 with a population density of 40,356 inhabitants/km².
3) Middle Governorate is in third place in terms of population with 273,381 inhabitants in 2016. This is due to the large number of refugee camps in this Governorate. In particular, it houses three big refugee camps, namely Nusairat-Albureij- Amaghazy- Deir al-Balah. Like the other camps in the Gaza Strip, these are typically very high density with a limited area and a rising birth rate and fertility rate amongst women.
   - Deir al-Balah city, considered the main city in the Middle Governorate includes Deir al-Balah refugee camp, and has a population density of 10,443 inhabitants\km²,
   - The population density in Al-Bureij town and refugee camp is also high at 8,040 inhabitant\km².
   - The population density in Alnusairat town and refugee camp is 9,094 inhabitants\km².
4) Rafah Governorate is the fourth most crowded governorate with a population of 233,490 inhabitants in 2016 (12.4% of the total population of the Gaza Strip) and a density of 3,892 inhabitants/km². This is due to the fact that it houses the Rafah refugee camp.

5) Khan Younis Governorate is the fifth and final governorate in terms of population density. Although it accounts for nearly 18.7% of the total population it has the largest area with 113 km² (31% of the total area of the Gaza Strip). This results in a lower population density of 3,114 inhabitant\km²in 2016 compared to Gaza governorate for example, which has a much higher population in a much smaller area. The city of Khan Younis is the second most important city in the southern Gaza Strip and attracts people away from other urban areas surrounding the city towards the east, such as Absan which is the least densely populated town with 1,271 inhabitants\km². This is because it is located in the eastern governorate and has few resources and services compared to other cities.

The above shows that whenever we move north or south from Gaza City, the population density falls. We can also see that the population density in the northern area (Gaza and North) is higher than in the southern governorates. On the basis of these figures we have divided population density in the Gaza Strip into three types:

1) Population density of less than 3,000 inhabitants/km², as in Khan Younis Governorate, due to its large area compared to the other governorates.
2) Population density of between 3,000-5,000 inhabitants/km², as in Deir al-Balah and Rafah Governorates.
3) Population density of more than 5,000 inhabitants/km², as in Gaza and the Northern Governorates.

According to projections, the population density in the Gaza Strip will increase from 5,154 inhabitants/km²in 2016 to 6,548 inhabitants/km²by the year 2023.

It is clear from the population pyramid in Figure 3.7, that the population of the Gaza Strip is very young. The wide base for the percentage of young people in the Gaza Strip is the result of the high crude birth rate that has reached 35.8 births per thousand people in 2016.

The main reasons for high population in the Gaza Strip are the high birth rate and the median age at first marriage, which in 2014 was 24.1 years for men and 20.2 years for women (PCBS, 2016).

3.3. Socioeconomic Status

The current land use patterns in the Gaza Strip have been strongly influenced by the political conflicts resulting from the Israeli occupation of Palestinian land. Although the current land use patterns create environmental stress throughout the Gaza Strip, this stress is most visible in urban areas, and in the coastal and marine environment.

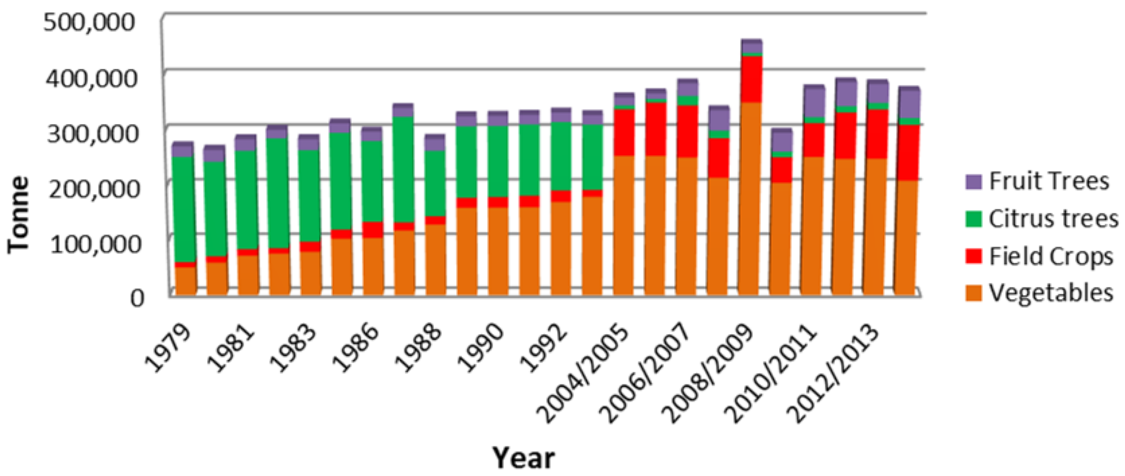
Economic development in the Gaza Strip is highly reliant on the Israeli economy, with some industries and agriculture. Agricultural products form the base of the economy.

Agricultural land therefore plays a significant role within local society, as it supplies food products to the majority of the local population. It also makes a valuable contribution to the economy as an earner of foreign exchange. Its share of the GDP was about 5.6 % in 2005 and 6.2% in 2014. About 10.7% of the employed labour force in the Gaza Strip worked in the agricultural sector in 2014, with many more considered to be active in informal agriculture. Moreover, in times of political and economical difficulties such as the ongoing intifada (uprising), agriculture has been known to absorb large numbers of unemployed people who had lost their jobs in Israel or in other sectors of the shrinking local economy (MOAg, 2014).

In the Gaza Strip and the West Bank, agricultural production consisted roughly of 35% vegetable crops, 25% citrus, 25% non-citrus fruit trees, and 15 % field crops (cereals etc) and forage. (Laeremanl and Sourani , 2005).

In the last 30 years, economic and political considerations have drastically reshaped agricultural production in the Gaza Strip. There has been a significant shift in both irrigated farming, from fruit trees to vegetables and flowers, and rain-fed farming from field crops to olives. In an attempt to meet the needs of foreign markets, farmers adopted new agricultural technologies and practices (Abuelanamel, 1979; PARC 2004). Figure 3.9 offers an illustrated breakdown of agricultural production by the tonne in the Gaza Strip from 1979 – 2014.

Figure 3.9. Agriculture production from 1979 to 2014.



Source: (Abuelanamel, 1979; MOAg, 2014; Al Astal K., n.d)

From Figure 3.9, we reached the following conclusions:

1) The production of vegetables and potatoes increased in response to increased demand, due to the expansion in the cultivated area at the expense of citrus fruit, and the use of modern agricultural methods in greenhouses.

2) The production of field crops, melons, cucumbers and other rain-fed crops is affected by rainfall levels, which fluctuate from one year to the next.
3) Citrus fruits require large amounts of water. This, combined with poor financial returns due to water and soil salinity and obstacles to export as a result of the occupation, has led to the uprooting of trees.
4) Influence of the Palestinian uprising (Intifada), during which citizens were encouraged to return to and invest in agricultural land, especially after the leaders of the uprising called for a boycott on Israeli products, and prevented them from entering the Palestinian market. As a result watermelon production grew during the Intifada years (1987-1994).

3.4. Land Changes

Before 1948

The Gaza Strip was an important part of historic Palestine before the war in 1948. There are three main methods of agriculture in Palestine:

1) National-traditional agriculture: traditional cultivation using conventional agricultural methods that depend above all on the rain. The crops typically planted were divided into winter crops, such as wheat and barley, and summer crops such as watermelon and corn. Farmers also planted grain, olives, grapes, apples and figs in the valleys and foothills of the mountains.
2) Citrus: citrus cultivation was widespread in the coastal plains, which had fertile soil and groundwater. Citrus cultivation expanded during the Britain mandate in Palestine when 70% of citrus fruit production was exported to Britain, making it one of the best sources of income for Palestine.
3) Intensive agriculture: agriculture depends on water supply, fertilization and capital investment. The land is sown more than once a year with diversified agricultural crops such as vegetables and fruit (Abuelnamel, 1976; Tamper, 2009; Dossett, 2016).

From 1948 to 1967

As a result of the 1948 War, there was a significant decrease in the agricultural land owned by Palestinians, causing population pressure on agricultural land and increasing the demand for agricultural production. By 1966 agricultural density had risen to about 1,000 persons/km2 and the total area covered by agricultural land had increased by 35%. Over the same period, the population increased by 75%.

In 1961, the total area of irrigated land in the Gaza Strip was about 137,000 dunums (1 dunum = 0.1 hectares)

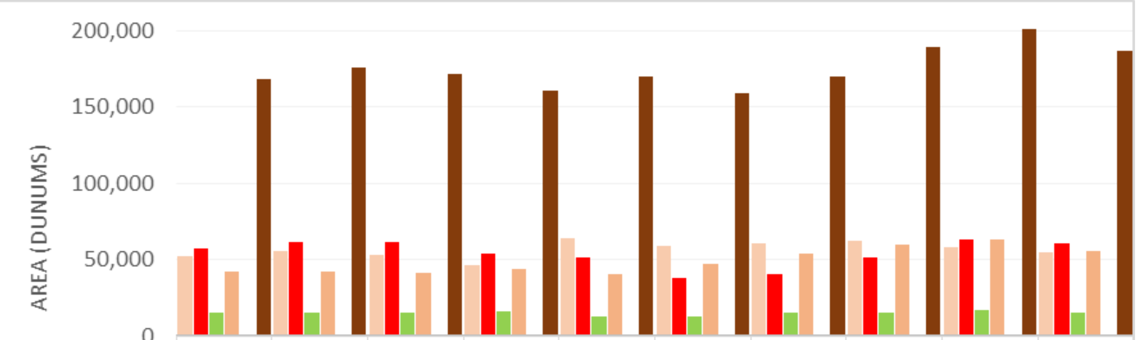
Citrus fruits have been the main agricultural product in the Gaza Strip since 1948, and by 1960 they covered an area of 16 thousand dunums (Khlosa, 1967). By 1961 this area had grown to 21 thousand dunums, and expanded rapidly to reach 68 thousand dunums in 1966. The Gaza Strip had become dependent on a single crop, and money transfers to the Gaza Strip helped to expand the cultivation of citrus (Abuelanamel, 1979), such that citrus exports accounted for 70.5% of total exports in 1954 and 89.4% in 1966 (Roy, 1995).

The expansion of citrus cultivation is the main reason for the improved economic conditions in the mid-seventies, when the citrus trees planted in the sixties began to bear fruit. However the total land area cultivated with citrus fell to less than 70 thousand dunums after theSix-Day War in 1967 (Almadni, 1985).

From 1967 to 2015

By 1966 there was about 170,000 dunums of agricultural land in the Gaza Strip. By 1968 this had expanded to a peak of 198,000 dunums. After that the farmed area fluctuated considerably, between 144,000 and 174,000 dunums. The estimated area of agricultural land for the season 1997/1998 was about 195,139 dunums or 54.5% of the Gaza Strip. Figure 3.10 shows the variations in agricultural land over the period 2004-2014.

Figure 3.10.Variation in agricultural crops and areas from 2004/2015 to 2013/2014.



	2004/ 2005	2005/ 2006	2006/ 2007	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014
Vegetales	52,562	55,730	53,612	46,231	63,938	59,162	60,984	62,107	57,926	55,041
Fiel Crops	57,483	61,740	61,442	54,150	51,885	38,424	40,471	51,516	63,369	60,563
Citrus trees	15,483	15,656	15,088	16,199	12,865	13,181	15,015	15,435	16,694	15,322
Fruit trees	41,956	42,248	41,045	43,629	40,921	47,656	53,629	59,641	62,970	56,066
Flower & medical p.	457	730	420	404	403	479	333	367	195	91
Total	167,941	176,104	171,607	160,613	170,012	158,902	170,432	189,066	201,154	187,083

Source: (MOAg, 2015)

In 1996, the Palestinian Ministry of Planning presented the first map of land use and land cover with the data shown in Table 3.4.

Table 3.4. Land Use and Land Cover in 1996

Class	Area (km^2)
Built-up	55.0
Almonds	6.27
Citrus	26.20
Citrus mixed with other crops/trees	12.89
Dates	7.94
Grapes	5.51
Greenhouses	10.72
Horticulture	23.64
Olives	1.98
Rain-fed Crops	123.92

Source: MOPIC, 1996

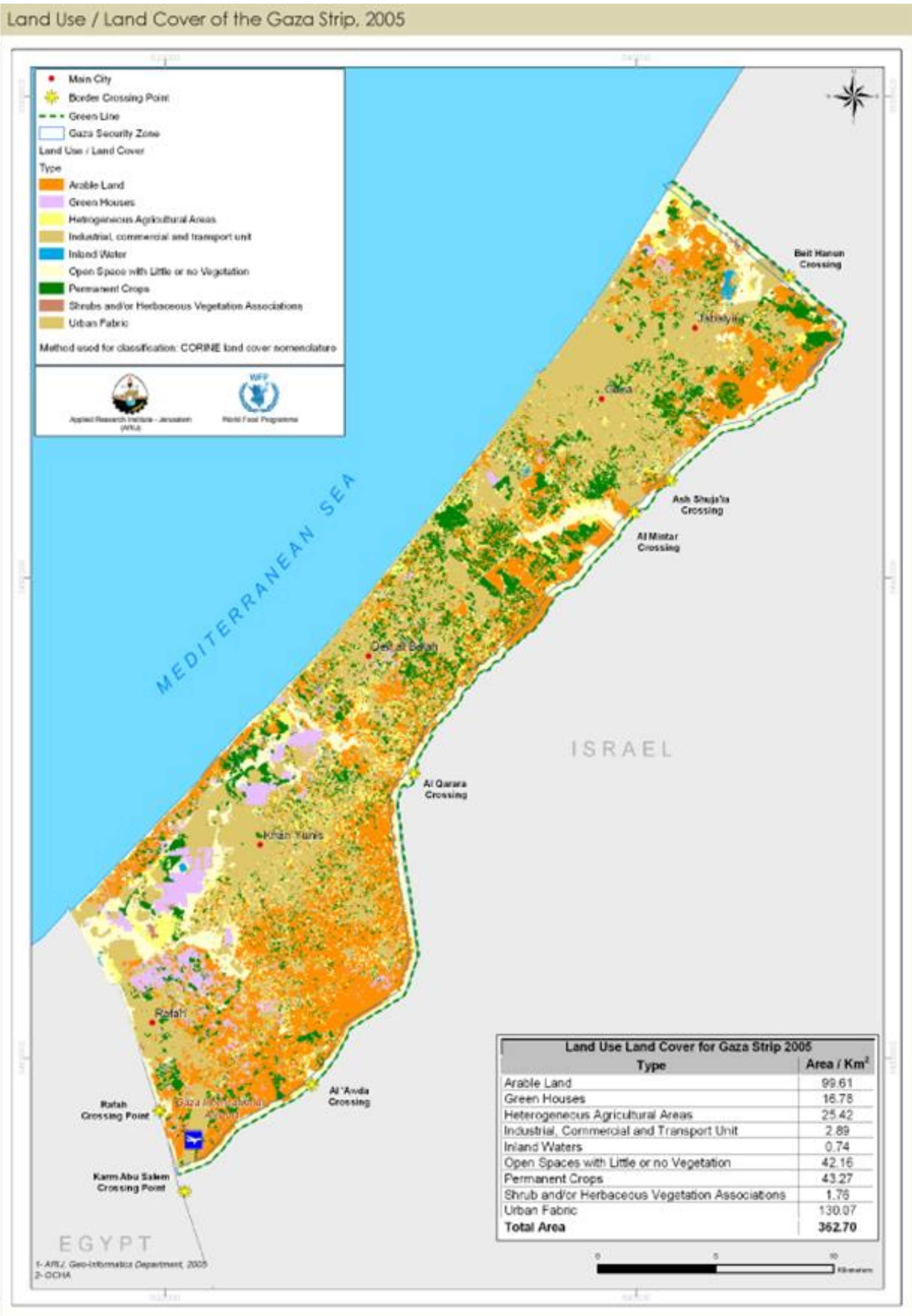
More land use and land cover data was provided by the Applied Research Institute Jerusalem (Arij) in 2005 as can be seen in Figure 3.11 and Table 3.5 below.

Table 3.5. Land Use and Land Cover in 2005.

Class	Area (Km^2)
Arable Land	99.61
Green houses	16.78
Heterogeneous Agricultural areas	25.42
Industrial, commercial and Transport Unit	2.89
Inland Waters	0.74
Open spaces with little or no Vegetation	42.16
Permanent Crops	43.27
Shrub and / or Herbaceous vegetation associations	1.76
Urban Fabric	130.07
Total Area	362.70

Source: Arij, 2005

Figure 3.11. Land Use/Land Cover in the Gaza Strip, 2005.



Source: Arij, 2005

The most recent study of land use and land cover changes in the Gaza Strip was carried out under the auspices of the Climate Induced Changes on the Hydrology of

Mediterranean Basins (CLIMB) Project from 2010 to 2012. The study also presented the Land Use land cover data for 2004 and 2010 as can be seen in the following Table 3.6.

Table 3.6. Land Use and Land Cover in 2004 and 2010.

Class/Year	Area 2010 (Km^2)	Area 2004 (Km^2)
Built-up areas	90.8	83.7
Natural vegetation	13.7	25.8
Horticulture	14.4	23.6
Greenhouses	9.3	13.7
Sand	32.5	42.6
Citrus orchards	37.2	31.8
Rain-fed agriculture	4.1	1.9
Mixed agriculture	117.3	145.4
Olive orchards	47.4	-
Water	0.7	0.9

Source: CLIMB, 2012

The aforementioned studies of land use and land cover do not provide any uniform classification method for monitoring land changes clearly. This is because:

- The Gaza Strip has been subject to various different administrations over the last century, from the British Mandate (1917-1948), the Egyptian administration (1948-1967), the Israeli occupation (1967-1994) and finally the Palestinian Authority (1994 -). This unstable political situation affected the different land plans and laws, which were weakly enforced.
- Lack of ongoing financial support for the accurate classification and monitoring of land use.

3.4.1. Reasons of declining of Agricultural land

1) Confiscation by the Israeli occupation authorities of government-owned and private agricultural land for new settlements. In many cases the Israelis uprooted fruit trees to build settlements and the roads connecting them.
2) Many workers migrated from the Gaza Strip to work in Israel, where they could earn higher incomes.
3) The high costs of agricultural production in terms of fertilizers, pesticides, plastic, water etc.
4) Control of the sale of agricultural products linked to the needs of the Israeli market.

A total of 113,800 dunums of land was confiscated by the Israeli occupation in 1989, around 31.3% of the area of the Gaza Strip.

In recent years the area farmed with vegetables and field crops, has increased at the expense of fruit trees, especially citrus fruit. In the 2004/2005 season, the area of field crops was estimated at 57.5 thousand dunums, 52.6 thousand dunums of vegetables, and about 42 thousand dunums of other fruit trees, while citrus trees only accounted for about 15.5 thousand dunums. The decline of fruit trees was due to the high salinity of the water and soil in the citrus fruit area, which led to a fall in the productivity per dunum, and an increasing demand for and rising incomes from vegetables. This led farmers to uproot trees and plant vegetables that could be exported to the Israeli market.

General observations on agricultural land in the Gaza Strip:

1) Farmers used modern agricultural methods such as irrigation techniques, improved seed varieties, fertilizers, pesticides and greenhouses.
2) Urban sprawl and vegetables replaced the citrus trees whose production had declined due to the high salinity of the soil and water.
3) Citrus cultivation is concentrated in the northern part of the Gaza Strip, and farmers are beginning to move towards olive cultivation, which can better withstand the high salinity of the soil.

3.4.2. Obstacles to successful agriculture in the Gaza Strip

In recent years agricultural production has been hit by many different problems. The following are some of the most important:

1) Israeli occupation of the agricultural sector, taking control of Palestinian land and displacing its population.The various measures they took included:
   - Confiscation of agricultural land from civilians - a total of 164 thousand dunums of land was seized (46%) until the Israeli withdrawal from Gaza in 2005.
   - Uprooting fruit trees and leveling agricultural land in name of the security of settlers.
   - Control of the sale of products within Israeli occupied areas.
   - Control and effect on water quality, quantity and suitability for agricultural products, as well as the control of the price of agricultural inputs such as pesticides and fertilizers, and the mechanization of farms.
2) Drought problem: this is due to the fluctuation in rainfall levels and particularly affects the cultivation of field crops, as well as the fresh water supply.
3) The high salinity of the soil and the water: as a result of excessive pumping of ground water, the salinity of the soil and the water has increased, affecting the

quality of the crops, such as citrus fruits and the increased cultivation of crops that can withstand salinity, such as olives and guava.

4) Fluctuations in the number of agricultural workers, as a result of the occupation, many were forced to leave their own land and work in Israel, which affected the amount of agricultural production.

3.5. Transportation

The only method of transport in the Gaza Strip is by road. Roads are classified into four types, regional roads, main roads, local roads and tracks.

The Rasheed Coastal Road runs along the coastline of Gaza from north to south. The main highway is the Salah al-Din Road, which runs through the middle of the Gaza Strip as shown in Figure 3.12, connecting the different towns and cities. It is about 46 kilometres long, and connects Biet Hanoun in the north to Rafah in the south passing through Jabalia, Deir al-Balah and Khan Yunis. To the north it crosses into Israel at the Erez Crossing (Biet Hanoun) and it crosses into Egypt at the Rafah Crossing.

Omar Mukhtar Street is the main street in Gaza city running north to south from the Old City down to the Rasheed coastal road on the Mediterranean Sea, and crossing the Salah ad-Din road.

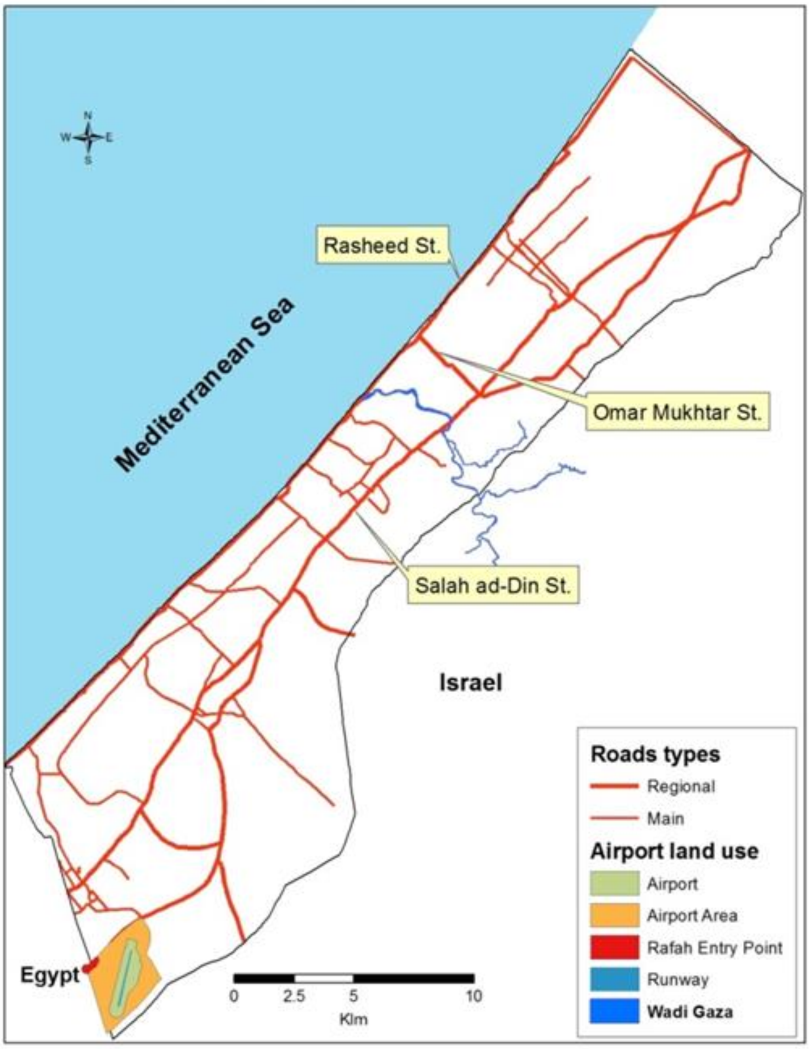
After the 1967 war, when the Israelis occupied the Gaza Strip, the main railway fell into disrepair and was then removed by the Israeli occupation in order to build high watchtowers from which to control local people looking for iron and wood during the first intifada (1987-1994).

The Yasser Arafat International Airport opened in 1998 near Rafah in the southern Gaza Strip after the Oslo Accords of 1994. Its runways and facilities were completely destroyed by the Israeli Army in 2001 and 2002, rendering the airport unusable. (Almonitor website, n.d.).

3.6. Contribution of the Gaza Strip to Climate change

The earth's land-cover and vegetation interact with the atmosphere altering several environmental conditions such as temperature, humidity deficit, radiation, CO_2 concentration, and soil moisture. Carbon is mostly found in the atmosphere as carbon dioxide produced by animal and plant respiration and human activities. Natural reactions are part of a large, complex cycle of carbon generation and absorption referred to as the carbon cycle. Carbon is absorbed through three major carbon stores, or “sinks” in nature. These are the oceans, the atmosphere, and the terrestrial system, including forests, plants, soils and geological forms such as fossil fuel stores (Panigrah, 2010).

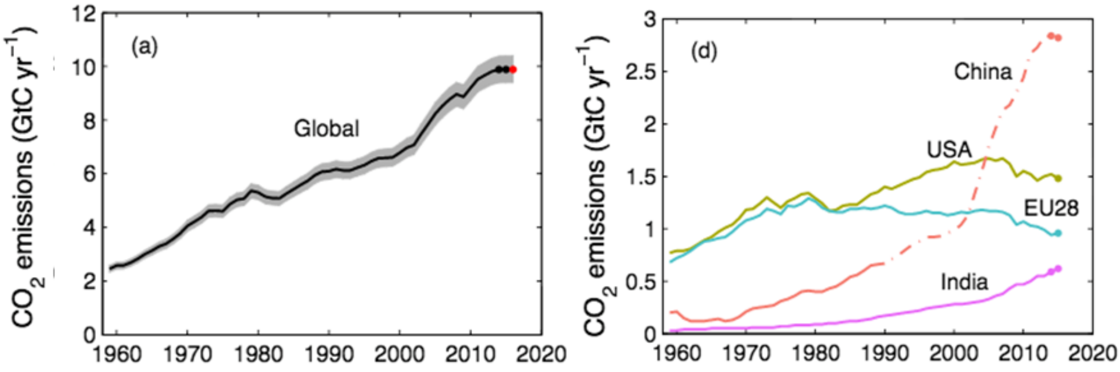
Figure 3.12. Map of the Transportation system in the Gaza Strip.



Source: MOPIC, 2013

Carbon dioxide (CO_2) is the most important greenhouse gas (GHG) because of its long atmospheric life span; other greenhouse gases include chlorofluorocarbons (CFCs), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). Large amounts of carbon dioxide are produced by burning fossil fuels (coal, gas and oil), primarily for transportation and power generation, significantly increasing CO_2 concentrations in the atmosphere. CO_2 can also be emitted as a direct result of human-induced impacts on soil degradation and land use and cover changes such as deforestation or conversion of ecosystems into agricultural crops and urban areas. It is estimated that approximately 2 billion tonnes of carbon are released globally into the atmosphere annually due to tropical deforestation and changing land management practices (Houghton et al., 1990). The concentration of carbon dioxide (CO_2) in the atmosphere has increased from approximately 277 parts per million (ppm) in 1750 (Joos and Spahni, 2008), at the beginning of the industrial era, to 399.4±0.1 ppm in 2015 (Dlugokencky and Tans, 2016). In 2016, the Global Emissions by Gas was 65%CO_2 by fossil fuel burning and industrial processes, 11%$CO_2$by forestry and other land use, 16 % Methane (CH_4), 6% Nitrous oxide (N_2O) and 2% Fluorinated gases (F-gases) (EPA, 2017). The increase in global CO_2emissions produced by industrial countries is illustrated in Figure 3.13.

Figure 3.13. Global CO_2 emissions from fossil fuel and industry since 1960 (left); territorial emissions from biggest emitters (right).



Source: (Le Quéré, C. et al., 2016).

The size of the human population and the technological ability of humans to exploit and manipulate environmental resources are putting enormous pressures on the basic requirements of water, food, energy and space on which all life forms ultimately depend (Thomas et al. 2004).

Vegetation and soil play an important role as carbon stores, while at the same time exchanging large quantities with the atmosphere. Deforestation is the second major global source of atmospheric CO_2 after emission of carbon by fossil fuel combustion. Agricultural practices tend to increase the amount of CH_4 andN_2O in the atmosphere, but also of CO_2, mainly because humans manipulate the carbon and nitrogen cycle to produce food (Dolman et al., 2003). Plant photosynthesis converts water, radiation and into carbohydrates (sugars), a process known as carbon fixation or absorption. The rate of change appears to be proportional to the initial organic carbon content of the soil. Soil organic matter (SOM) decline is also of particular concern in the Mediterranean region (Jones et al., 2005). Soil respiration (CO_2realization) rates depends on SOM content, soil microbial activity, and soil conditions (soil temperature, moisture, aeration), generally high soil temperatures and moist conditions accelerate soil respiration and thus increase CO_2 emissions (Brito et al., 2005). Soil without vegetation growing on it is commonly regarded as a source of CO_2. In fact, the net flux of $CO_2$is directed from the soil towards the atmosphere (Raich and Potter, 1995; Raich and Schlesinger, 1992).

Land-use and land-cover changes can contribute only modestly to the reduction of atmospheric CO_2 concentrations; some of the available options (e.g., carbon sequestration through afforestation) are cost-effective, in particular in countries with low prices for land and food (Groeneveld et al., 2003).

The Gaza Strip is affected by and affects climate change due to urban expansion and land use changes with rising CO_2 emission due to the decrease in vegetation cover and fossil fuel consumption.

3.6.1. Estimation of CO_2 emission in the Gaza Strip as a result of the decline in agricultura

CO_2 emissions in the Gaza Strip are mainly due to a combination of a high, rapidly increasing population, land-use changes, the decrease in agricultural lands and fuel-burning human activities. These emissions have been estimated on the basis of the main research data.

CO_2 absorption has been estimated on the basis of the data results obtained from research entitled "Investigation into CO_2 Absorption of the most representative Agricultural crops of the region of Murcia". Table 3.7 shows the data for CO_2 absorption calculated on the basis of the plantation density (plants per square meter) and the annual CO_2 absorption values.

Table 3.7. N_2O Fixation by different plants.

Type	CO_2 g /m²/ Year	Type	CO_2 g /m²/ Year
Tomato	3,180.0	**Barley**	1,300.0
Pepper	2,263.8	**Wheat**	1,375.0
Watermelon	595.6	**Apricot**	1,723.8
Melon	802.0	**Plum**	2,324.3
Lettuce hearts	831.0	**Peach**	2,836.9
Romaine lettuce	843.7	**Nectarine**	2,658.7
Broccoli- Arthenon	736.4	**Grape**	1,911.8
Broccoli-Naxos	835.5	**Lemon**	2,994.1
Cauliflower	1,198.8	**Orange**	2,072.5
Artichoke	1,297.8	**Mandarin**	1,306.2
Oats	1,360.6	**Average**	1,640.4

Source: Mota et. al., (n.d)

The database obtained from Landsat images 1972, 1982, 1990, 2002, 2013 (see Chapter 5) has been classified into two classes: urban and agricultural areas (non-urban areas) in Table 3.8.

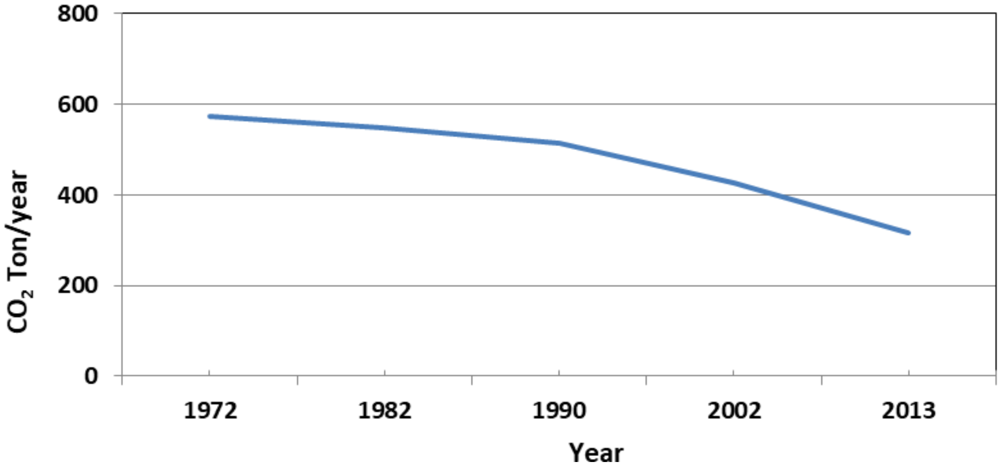
The history of CO_2 fixation year by year can be calculated by multiplying the agricultural areas (non-urban areas) in the Gaza Strip per year (Table 3.8) by the average Carbon dioxide fixation (absorption) for all the vegetation cover - around 1640.4 g/m²/year (see Table 3.7). CO_2 emission is considered minus (or negative) CO_2 fixation.

Table 3.8. Non-Urban Areas from 1972-2013.

Year	Non-Urban Km²
1972	349.06
1982	334.71
1990	313.12
2002	259.77
2013	193.71

Our calculations of CO_2 fixation in the Gaza Strip from 1972-2013 show a steady decline as illustrated in Figure 3.14. This means that CO_2 emission has increased as a result of a decrease in agricultural areas.

Figure 3.14.CO_2Fixation due to agriculture in the Gaza Strip from 1972-2013.



Source: estimated by student

The data analysis shows an increase in annual CO_2 emissions (in tons per year): 2,354 (1972-1982), 4,427 (1982-1990), 7,293 (1990-2002), and 9,851 (2002-2013). Table 3.9 illustrates the increase in the CO_2 emission rate in the Gaza Strip.

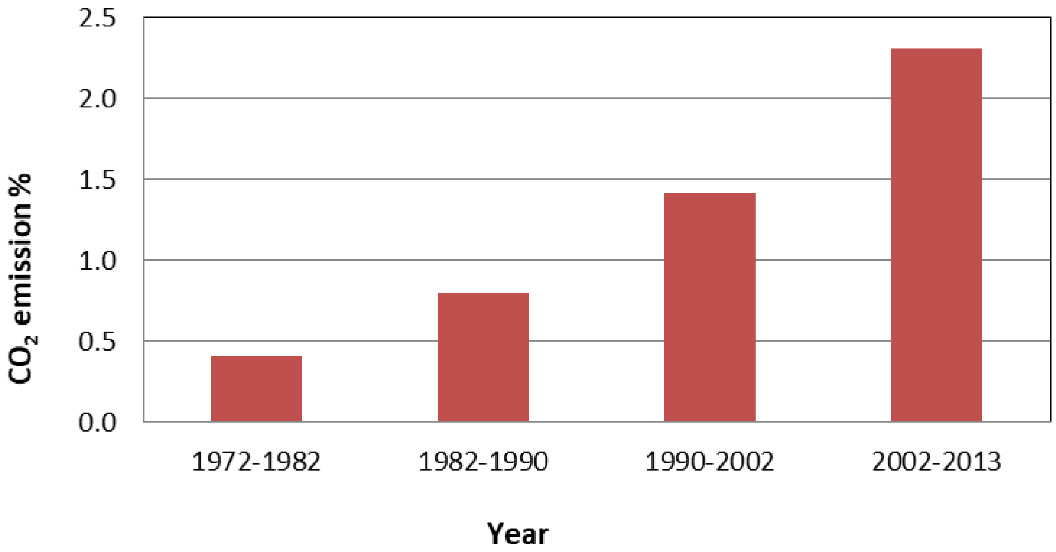
Table 3.9. The annual contributions of CO_2emissions (Ton) by periods.

Period	The annual CO_2 (Ton/Year)
1972-1982	2,354
1982-1990	4,427
1990-2002	7,293
2002-2013	9,851

Source: estimated by student

Using 1972 as base year, Gaza Strip emissions grew annually (0.41 % per year) between 1972 and 1982 as increases related to population growth and the decline in agriculture, while, over the period 1982-1990 CO_2emissions grew by around 0.81 % per year. The CO_2emission rate continued to increase over the periods 1990-2000, and 2002-2013, of 1.42% and 2.31%. This will continue due to the decrease in agricultural areas as shown in Figure 3.15.

Figure 3.15. Annual CO_2emissions by periods



Source: estimated by student

3.6.2 CO_2Emission by Fossil Fuel

Previously we presented an overview of CO_2emissions that shows the annual increase in carbon dioxide emission as due to the decline in agricultural areas.

There are other reasons for emissions that enhance the Gaza Strip's contribution to climate change such as fossil fuels, wastewater and soil degradation.

Table 3.10 illustrates the annual increase in CO_2emission due to fossil fuel consumption in the Gaza Strip (figures from the Palestinian Central Bureau of Statistics from 1996-2006). The fossil fuel consumed in the Gaza Strip is converted to carbon dioxide using the International carbon band and exchange website

http://www.icbe.com/carbondatabase/volumeconverter.asp.

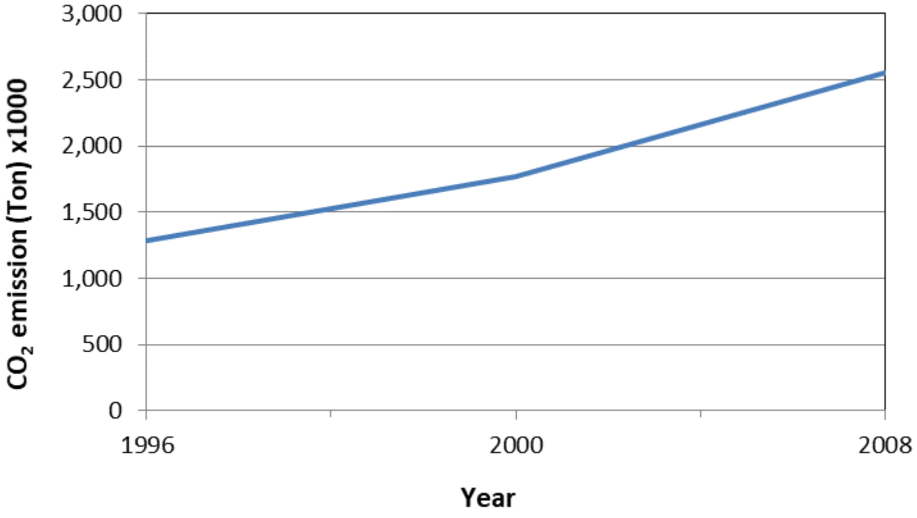
Table 3.10.CO_2emission (Ton) due to fossil fuel consumption between 1996-2006

Year	Wood and Coal (Ton)	LPG (Ton)	Diesel (Ton)	Kerosene (Ton)	Gasoline (Ton)
1996	1,229,988	2,751	28,764	7,653	15,706
2000	1,709,964	3,644	41,498	660	10,261
2008	2,119,979	66,790	354,463	1,298	9,677

Source: (PCBS, 1996,2000,2008)

In Figure 3.16, the selected years illustrate an increase in fuel-based CO_2emission from 1,284,860 Tons in 1996 to 2,552,206 Tons in 2008. This is probably due to an increasing number of cars, from around 46,898 vehicles in 1998 to 59,147 vehicles in 2006, 60,901 vehicles in 2010 and 70,000 vehicles in 2017.

Figure 3.16.CO_2emissions due to fossil fuel consumption by year.



Source: estimated by student depending on (PCBS,1996,2000,2008)

Greenhouse gas (GHG) emissions are also produced by Waste Water Treatment Plants (WWTPs) that produce carbon dioxide (CO_2), methane $CH_4$and nitrous oxide (N_2O) during the biological wastewater treatment processes. $CO_2$is also emitted during the production of the energy required for the operation of the plant. The CO_2released due to energy demand can be directly reduced by enhancing the energy efficiency of the WWTPs (Campos et al., 2016). The Gaza Strip produces around 120,000 cubic meter of wastewater every day, around 90,000 cubic meter is discharged into the sea as a result of overload of the WWTPs.

Gaza Strip is a very small area but can affect climate change with an increase in its urban areas and fossil fuel consumption and CO_2emissions into the atmosphere.

The following conclusions were drawn from the results of this section:

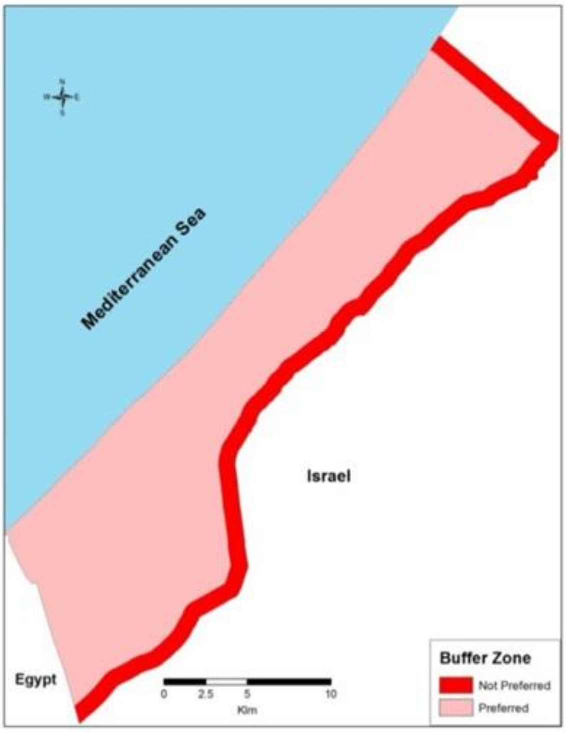
- An estimated 2,686,608 Tons of CO_2 was emitted into the atmosphere in 2013 as a result of the fall in agricultural lands and the increase in fossil fuel consumption.
- The rate of CO_2 emission due to the decrease in agricultural areas is around 0.4% of total emissions from the Gaza Strip
- The Gaza Strip emits around 2,757 Kton (0.01%) of the world total of 36,061,710 metric Kton (Wikipedia, n.d.) of CO_2 because the Gaza Strip is not an industrial region.

3.7. Political situation

The buffer zone is a military no-go area that extends along the entire northern and eastern perimeter of Gaza, bordering with Israel as in Figure 3.17. The area has increased from 50 to 300 meters wide since it was first imposed following the Oslo Accords. The no-go area is enforced with live fire by the Israeli military.

The Oslo Accords allowed the Israeli army to maintain a security perimeter between Israel and Gaza. This buffer zone soon turned into an area which was effectively off-limits to Palestinians and which the Israeli authorities expanded unilaterally after the second Intifada in 2000. Palestinians are prohibited from entering the buffer zone, which measures between 300 meters and 2 kilometres wide at its widest point in Northern Gaza. (Deeb et.al, 2011).

Figure 3.17. Israeli enforced buffer zones inside the Gaza Strip beyond the Truce Line of 1949.



Source: Deeb et.al., (2011)

4. Methodology

This thesis addresses two main practical research questions. First, land change analysis, scenarios and modelling and second, land change impacts on the environment within a study of water quality in the Gaza Strip as a result of land change, increasing population and a fall in agriculture areas.

The first question addressed is that of land change analysis and modelling (Part 4.1). The results and discussions of our research on this question are set out in Chapters 5 and 6:

- Chapter 5: Scenario of land use and land cover change in the Gaza Strip using Remote Sensing and GIS model,
- Chapter 6: Urban land use change analysis and modelling: a case study of the Gaza Strip.

The second main issue, namely the impacts of land change use on the environment is analyzed from two different perspectives:

- Part 4.2 shows the methodology used in Chapter 7 in which we assess the vulnerability of the aquifer to contamination in Khan Younis Governorate, Gaza Strip—Palestine, using the DRASTIC model within GIS.
- Part 4.3 shows the methodology used in Chapter 8 in which we study the efficacy of GIS as a tool for analyzing groundwater salinity, once again looking at the Gaza Strip as a case study.

4.1. Land Change Analysis and Modelling

The methodology we followed in this research was designed to achieve all the objectives we set ourselves. We began by studying the land use and land cover changes in the study area using Remote Sensing as the Monitoring Technique. We then made estimates, evaluations, simulations and analysis to help create scenarios and models. With these we reached conclusions, recommendations and suggestions for the stakeholders taking decisions in land-use planning. This process was divided into the following stages:

1. Review of the Literature. Data Acquisition and Interpretation.
    a) Collection of all available information needed for assessing land cover and land use in the Gaza Strip.
    b) Interpretation of Landsat Satellite images,
    c) Identification and design of a land use and land cover classification scheme based on the available data source.

d) Defining the different land use and land cover classes for different periods of time.
e) Reconnaissance survey to get a general idea of the environmental area and the accessible environmental features.

2. Data Acquisition, and Processing
   a) Data processing and verification.
   b) Production of GIS database for land use and land cover change analysis.
   c) Assessment of the land use and land cover change model.
   d) Analysis and prediction of future land use and cover change in Gaza Strip and correlations with the population growth rate and other factors.
3. Scenarios and Modelling
   a) Scenarios, Modelling, Prediction and Assessment of urban expansion and environmental indicators with different models.
   b) Conclusions and recommendations for decision-makers.

The flow chart in Figure 4.1 shows the methods used in the research in the Gaza Strip reported in this thesis, including the definition and creation of a database using remote sensing and GIS, land change analysis, proposal and testing of explanatory variables, modelling and the development of scenarios.

4.1.1. Dataset

The spatial database was produced using the historical Landsat images from 1972, 1982, 1990, 2002, 2013 and 2014, as shown in Table 4.1. The images were rectified from the aerial photos for 2007 using Erdas Imagine 2013. Generalized digitalization was used to build the urban GIS database using ArcGIS 10.2; interpretation was mainly visual, and both supervised and unsupervised classifications were used for more control and interpretation. The cell size of the entire dataset was converted to 15x15 meters. The database was validated before starting the analysis by tracking data with high resolution aerial photographs taken before and after a particular year. As no aerial photographs were available for the last year, we validated some points that were in doubt using the UNITAR database.

Figure 4.1. Methodology flow chart for land change analysis, potential and simulation.

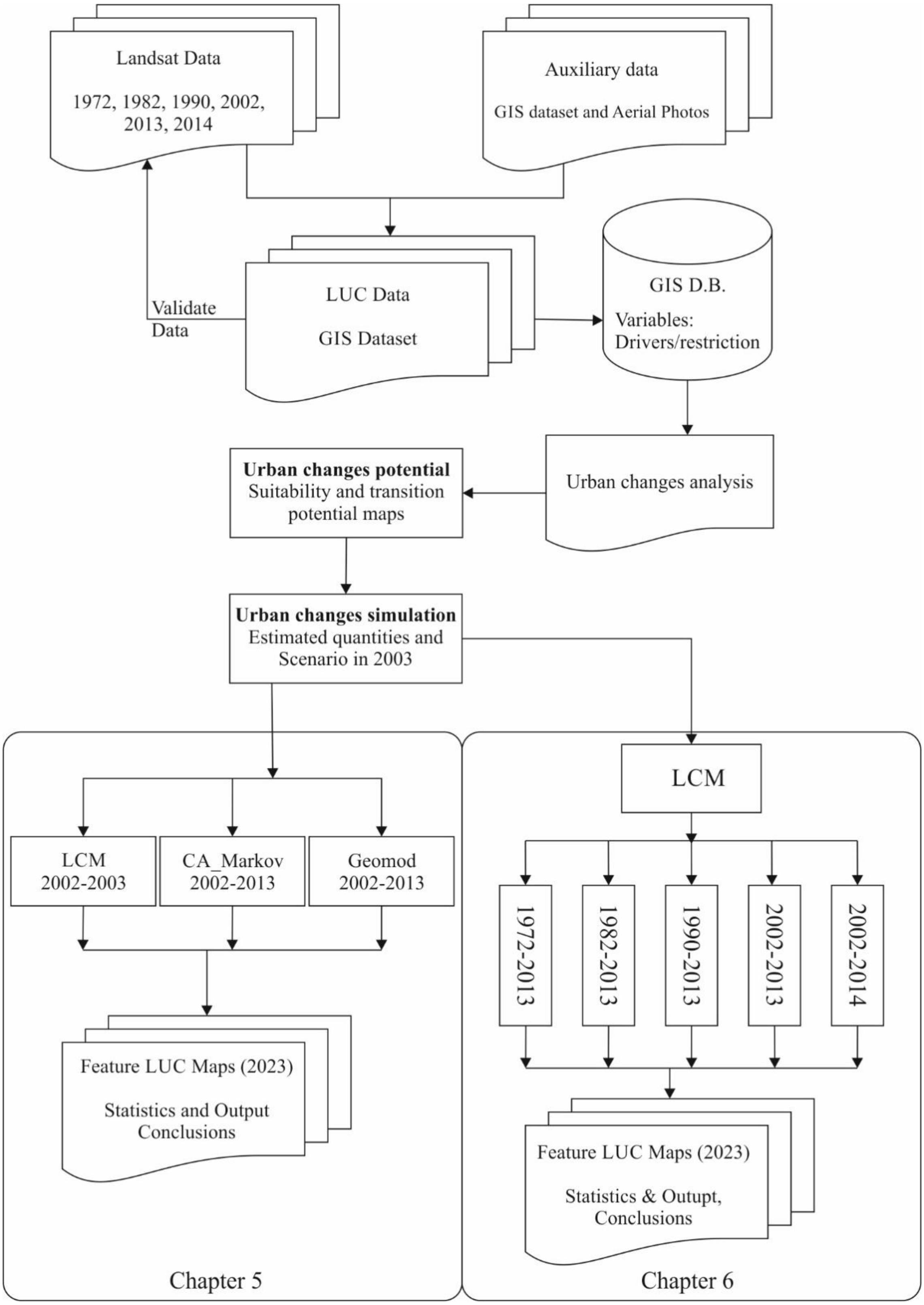


Table 4.1. Landsat data used in this study.

Sensor	Row	Data type
Landsat MSS	188/38	22/10/1972
Landsat 3 TM	188/38	13/08/1982
Landsat 5 TM	174/38	11/06/1990
Landsat 7 ETM+	175/38	05/07/2002
Landsat 8	175/38	25/06/2013
Landsat 7 ETM+	175/38	24/09/2014
GIS dataset of UNOSAT/UNITAR	Geodatabase	Field Survey, October/2014

For the purposes of this research, we considered the whole Gaza Strip area as suitable for agriculture and classified the land into two classes: urban and agricultural areas (non-urban areas). Some other land uses and land covers in the study area were also considered as agricultural in this study.

4.1.2. Land change analysis

The chronological series of LUC maps was analyzed to detect changes. A quantitative assessment of category-wise land use changes in terms of net changes, swap, gains, losses and total changes (Eastman 2012) was extracted from several pairs of data, and the results are shown in maps and statistics. The change analysis was performed by comparing two images from 1972, 1982, 1990, 2002, 2013 and 2014 to understand the transitions in land-use classes over the years. The CROSSTAB module of IDRISI was also used between two images to generate a cross-tabulation table in order to observe the consistency of the images and the distribution of image cells between the land use categories. A multiple regression line was created to predict the future urban area, and statistical values for the changes occurred in the area were represented on a scatter diagram.

Six static drivers were selected and tested to simulate and predict the future urban area in 2023. The first driver is the distance from the main and regional roads in 2013, given that the population prefers to buy and live in houses overlooking the roads, which are also considered good investments. The second and third drivers are elevation and slope, because people prefer high locations which are considered to be safe from floods during heavy rains and have a cooler climate in the summer months. The fourth driver is the distance from the urban area in 2013, since people prefer to live close to well-established urban areas with better infrastructure and services, which are safer during Israeli military attacks. The fifth driver is the 1 km wide buffer zone along the border between the Gaza Strip and Israel. This is a restricted area which people are forbidden to enter. The sixth driver is the buildings destroyed during the 2014 War. It is only used in the 2002-2014 scenario.

The quantitative measure of the influence of the variables can be obtained using Cramer's V. A high Cramer's V value indicates that the variable has good explanatory potential, but does not guarantee a strong performance since it cannot take into account the mathematical requirements of the modelling approach or the complexity of the relationship. However, a very low Cramer's V value is a good indication that a variable can be discarded (Eastman, 2012).

4.1.3. Scenarios and Modelling

Three GIS models in Idrisi Selva software were selected to try to project the urban area in 2023: Geomod, Cellular Automata Markov (CA_Markov) and Land Change Modeler (LCM). We also used statistical estimation using the regression function to highlight the quantitative difference between the regression and the Markov chain. The three GIS models were represented in Chapter 5 using only the calibrated period (2002-2013). In Chapter 6 we set out the LCM results for various calibration periods (1972- 2013), (1982-2013), 1990- 2013), and (2002- 2013), and (2002-2014) by year 2023.

4.1.3.1. Land change potential: Suitability and transition potential maps.

Two types of intermediate soft-classified maps, suitability maps and transition potential maps (Camacho Olmedo et al., 2013) were obtained for the land change potential study. Suitability maps are used in both CA_MARKOV and Geomod models, while transition potential maps are used in the LCM model. The same driver maps are used in the Geomod, CA_MARKOV and LCM models. A collection of factors are obtained from these drivers by the Natural Log Transformation. The Natural Log Transformation is effective in linearizing distance decay variables (e.g., proximity to roads) (Eastman, 2012).

The transition potential maps are in essence potential maps for each transition in LCM. A collection of transition potential maps is organized within an empirically evaluated transition sub-model that has the same underlying driver variables. A transition sub-model can consist of a single land cover transition or a group of transitions that are thought to have the same underlying driver variables. These driver variables are used to model the historical change process. The transition potential maps are obtained by Multilayer Perceptron (MLP) in LCM. The MLP option can run multiple transitions and undertakes the classification of remotely-sensed imagery through the artificial neural network multi-layer perceptron technique. It uses an algorithm to set the number of hidden layer nodes. MLP automatically evaluates and weights each factor and implicitly takes into account the correlations between the explanatory maps (Eastman 2012).

GEOMOD creates the suitability image by computing for each grid cell a weighted sum of all the reclassified driver images (Pontius, 2006). Hence, the suitability in each cell is calculated according to the following:

$$R(i) = [\sum_{a-1}^{A} W_a P_a] / \sum_{a-1}^{A} W_a \quad (1)$$

Where: R(i) = suitability value in cell(i), a a = particular driver map, A = the number of driver maps, W_a= the weight of driver map a, and $P_a(i)$= percent developed in category $a_x$of attribute map a, where cell(i) is a member of category a_x.

In CA_MARKOV, a suitability map may be produced from driver information or supplied (external), particularly by multi-criteria evaluation (MCE) (Paegelow and Camacho, 2008). Each driver is considered a real number (%). The suitability maps for each LUC category are created by MCE, using all drivers converted to factors.

4.1.3.2. Land change simulation: The estimated quantities

The Markov transition area matrix is based on land-use changes without drivers that are produced within the Markov chain from two different dates. This matrix results from the multiplication of each column in the transition probability matrix by the number of cells for the corresponding land use in the last image for the year 2013 or 2014.

Markov chain analysis is used to calculate the estimated quantities in 2023 with urban data for the years 2002 and 2013, which is used in LCM, CA_MARKOV, and to calibrate the Geomod model.

CA_MARKOV and LCM incorporate the quantity of estimated change and persistence using a Markovian matrix. The MARKOV module computes the transition areas matrix and the transition probability matrix by cross-tabulation between LUC categories from two maps (t0 to t1), which reflect data from the calibration stage, to project the estimated changes and persistence at the simulation stage (t1 to T). The estimation to T is based on the number of time periods between t0 and t1 and the number of time periods between t1 and T, respecting in all cases the same time units. A more detailed description of the MARKOV matrix can be found in the IDRISI Selva Help System and also in Mas et al. (2011, 2014). The Markov chain analysis is one of the most widely used stochastic approaches in ecological and environmental modelling (Paegelow and Camacho, 2008). For the study area, the estimated quantities in 2023 are based on the transitions during 2002-2013, using the MARKOV module of IDRISI. The same Markov transition probability matrix is used in both CA_MARKOV and LCM models.

Linear regression was used to compare the results of the Markov chain data. This approach uses the historical relationship between a dependent variable and one or more independent variables (the year and the population) to predict the future values of the dependent variable, in this case urban areas. The multiple linear statistical regression was used for simulation of the built-up area using the Enter method to enter all variables for the year 2023 at the same time, on the basis of the urban area in 1972, 1982, 1990, 2002, 2013 and 2014. The growth rate and other statistics were calculated using Microsoft Excel.

4.1.3.3. Land change simulation: The scenario

Various scenarios were simulated in three models to predict the likely urban areas in 2023.

GEOMOD simulates the changes between exactly two categories, state 1 and state 2 (Eastman, 2012), in our case study, urban and non-urban LUC. GEOMOD selects the location of the grid cells based on their suitability maps. The simulation can occur going either forwards or backwards in time. The output result of GEOMOD is a byte binary image that shows the end time.

The simulation of the GEOMOD model is based on (Clark Labs, 2012):

1. Specification of the start time, end time and time step for the simulation.
2. An image showing the allocation of land-use states 1 and 2 at the start time.
3. A decision whether to constrain the simulated change to the border between state 1 and state 2.
4. A map of suitability for the transition to land-use state 2.
5. The projected quantity of land-use states 1 and 2 at the end time.

Both LCM and CA_MARKOV models use an a priori identical Multi-Objective Land Allocation (MOLA) to solve the concurrences between different uses or transitions. This process is based on the choice of the most suitable pixels, i.e., those with the greatest change potential in the ranked change potential maps. Through the Markov matrix, the MOLA creates a list of host classes (categories that will lose surface, in rows) and claimant classes (categories that will gain surface, in columns) for each host. The allocation is made for all claimant classes of each host class, and solves any conflicts based on a minimum-distance-to-ideal-point rule using the weighted ranks. The final result is the overlay of each host class reallocation (Eastman et al., 1995; Mas et al., 2014).

Therefore, some differences exist in the MOLA algorithm in LCM and in CA_MARKOV (Eastman, 2012; Camacho Olmedo et al., 2015). The MOLA works only once in the LCM procedure, while, in CA_MARKOV, the MOLA runs once for each chosen iteration, i.e. the number of time units in the simulation period (t1 to T). The final result is the overlay of each new simulation map after each MOLA reallocation. A second difference is that in CA_MARKOV, Cellular Automata (CA) are used to obtain a spatial situation and distribution map. This means that CA transition rules use their current neighborhood of pixels to estimate land-use type in the future. The state of each cell is affected by the states of its neighboring cells in the filter. Besides, the use of CA transition rules and land-use transition is governed by maximum probability transition and will follow the constraint of cell transition that happens only once for a particular land use, and will never be changed again during simulation. In order to compare CA_MARKOV and LCM more effectively, in our case study we used a non-filter (Camacho Olmedo et al., 2015), ignoring the Cellular Automata. As a result the contiguity effect disappeared.

4.1.3.4. Calibration and Validation

In Chapter 5 the three models used the same calibration period (2002-2013) to make forecasts for the year 2023. In Chapter 6 we used the LCM model in the various calibration periods (1972- 2013), (1982- 2013), 1990- 2013), (2002- 2013), and (2002-2014) to make forecasts for the year 2023.

The models were validated by congruence. To measure the congruence of models and the individual model contributions, the three simulation maps of stability and changes from 2013 (specifically the simulated urban stability and simulated urban growth for 2013) were intersected by the logical operator AND. The intersection score measures the congruence of the models, and all supplementary contributions made by combinations of two models (Geomod and LCM, Geomod and CA_Markov, CA_Markov and LCM) are calculated with the remaining individual contributions (Paegelow et al., 2014). This can help in the analysis of spatial differences.

4.2. Assessment of aquifer vulnerability to contamination

4.2.1. Dataset

The required data were collected for the study area, the Khan Younis Governorate in the south of the Gaza Strip. The data were obtained from different sources: the Palestinian Water Authority (PWA), the contour map for the study area, the Ministry of Agriculture, and the Ministry of Planning and International Cooperation. The data include depth to water table, aquifer media (geology), soil media (texture), Topography map, Impact of vadose zone, and Hydraulic conductivity.

4.2.2. Methodology

The DRASTIC model of groundwater vulnerability is an overlay and index method. This is one of the most commonly used categorical rating methods as well as one of the earliest.

It was developed by the US Environmental Protection Agency (US EPA) as a standardized system for evaluating groundwater pollution potential due to hydrogeologic setting (Aller et al. 1987; US EPA1993; Vrba and Zaporozec 1994). The DRASTIC model is used to prepare a vulnerability map for the study area. The name DRASTIC is taken from the initial letters of seven environmental parameters, used to evaluate the intrinsic vulnerability of aquifer systems. These seven parameters are: (Aller et al. 1987; Babiker et al. 2005; and Baalousha2010).

- Depth (D) to water table: the greater the depth of the water, the smaller the chance of the contaminant reaching it, as compared with a shallow water table.
- Net (R) recharge: this represents the total quantity of water that reaches the water table. This is the process through which the contaminants are transported to the aquifer. The greater the recharge, the more vulnerable the aquifer (Aller et al. 1987).
- Aquifer (A) media (geology): this reflects the attenuation characteristic of the aquifer material and the mobility of the contaminants through it. For example, the larger the grain size, the more fractures or openings there will be in the aquifer, the higher the permeability, the greater the vulnerability of the aquifer.
- Soil (S) media (texture): different kinds of soil have differing water absorption capacity, which influences the travel time of the contaminants.
- Topography (T; slope): this refers to the slope of the land surface. A steep slope increases runoff and erosion, so reducing the possibility of contaminants affecting the groundwater.
- Impact (I) of vadose zone: this is the unsaturated area above the water table. The texture of the vadose zone affects the time it takes for the contaminants to travel through it.
- Hydraulic conductivity (C): refers to the ability of an aquifer to transmit water. When hydraulic conductivity is higher, there is greater potential for contamination because contaminants can move easily through the aquifer. This model produces a numerical value called the DRASTIC INDEX, which is derived from the rating and the weights assigned to the parameters used in the model. Using the seven DRASTIC parameters (Table 1), a numerical ranking system of weights, ranges, and ratings has been devised to evaluate the potential of groundwater contamination (Aller et al. 1987).

Weights: A relative parameter value ranging from 1 to 5, where 1 represents the least significant factor and 5 the most significant. The DRASTIC model assumes that all the contaminants move vertically downwards with the water and are introduced at the soil surface. A combination of variable weights was evaluated and based on the results obtained, a specific weight was assigned to each DRASTIC parameter. The weight determines the relative significance of each parameter in terms of its pollution potential (Table 4.2).

Table 4.1. Weights of DRASTIC parameters.

Parameters	DRASTIC weight
Depth to water table	5
Net recharge	4
Aquifer media	3
Soil media	2
Topography	1
Impact of vadose zone	5
Hydraulic conductivity	3

Source: (Aller et al. 1987)

- Ranges: each of the DRASTIC parameters was divided into either ranges or significant media types that have an impact on contamination potential.
- Ratings: each of the DRASTIC parameters was assigned a rating from 1 to 10 based on a range of values, and based on its relative effect on aquifer vulnerability e(Almasri 2008). Ratings are taken from USPEA 1993 as they depend on the physical character of the parameters, which are more or less constant.

The DRASTIC INDEX value (pollution potential) for a given area is calculated by multiplying each factor rating by its weight and adding together the resulting values. The total impact factor score for the DRASTIC INDEX can be calculated as: (Aller et al. 1987; Hammouri and El-Naqa 2008).

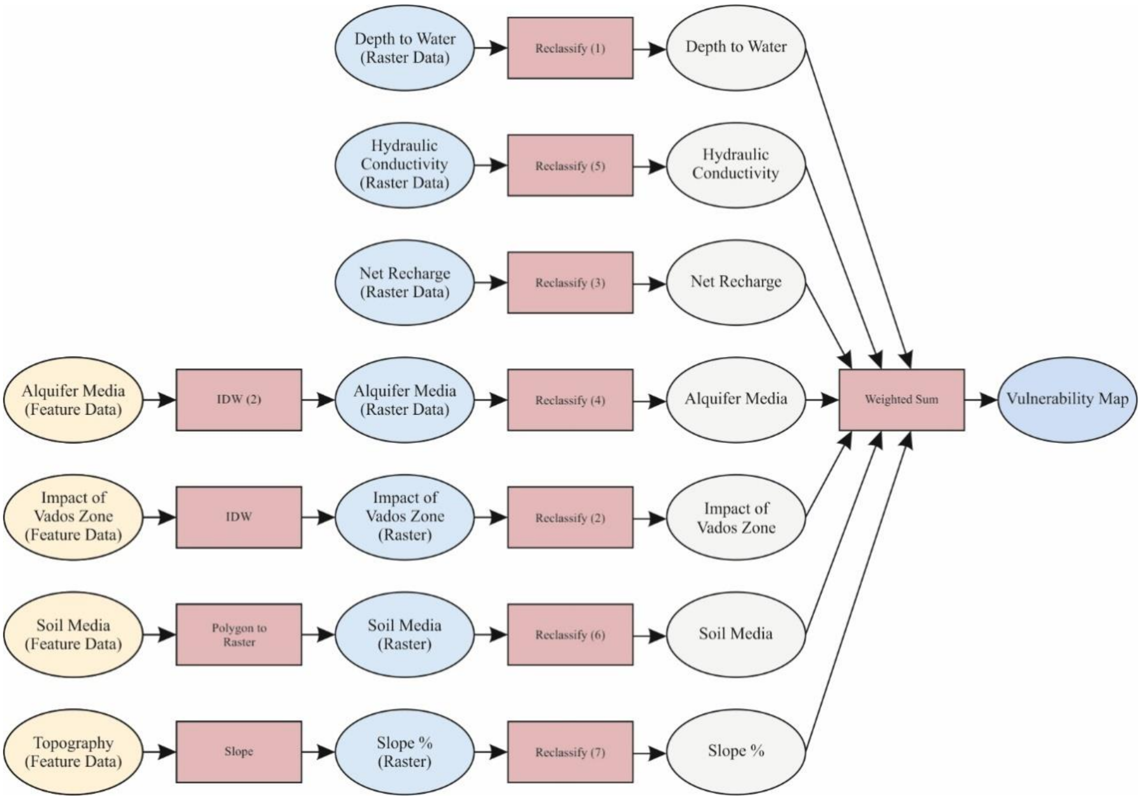
$$DRASTIC\ Index = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \qquad (2)$$

where: D, R, A, S, T, I, and C are the seven hydrogeological parameters; r is the rating for the area being evaluated (1– 10); w is the weight for the factor (1–5). The resulting DRASTIC index value is a relative measure of groundwater vulnerability. The higher the DRASTIC index the greater the vulnerability of the aquifer to contamination. A site with a low DRASTIC index is not free from groundwater contamination, but it is less susceptible to contamination compared to sites with high DRASTIC indices. The DRASTIC index can be converted into qualitative risk categories of low, moderate, high, and very high.

4.2.3. Groundwater Vulnerability Modelling

Groundwater vulnerability maps are designed to show the areas with the greatest potential for groundwater contamination on the basis of hydrogeological and anthropogenic (human) factors. The thematic raster maps are mainly developed using the ArcGIS 9.3 software to combine data layers, such as soils and depth of water table. Usually, groundwater vulnerability is determined by assigning point ratings to the individual data layers and then adding the point ratings together when these layers are combined into a vulnerability map. The seven maps needed for the DRASTIC model were prepared and built using the available hydrogeological data. The methodology flow chart is shown in Figure 4.2.

Figure 4.2. Flow chart for groundwater vulnerability analysis using the DRASTIC model in GIS.

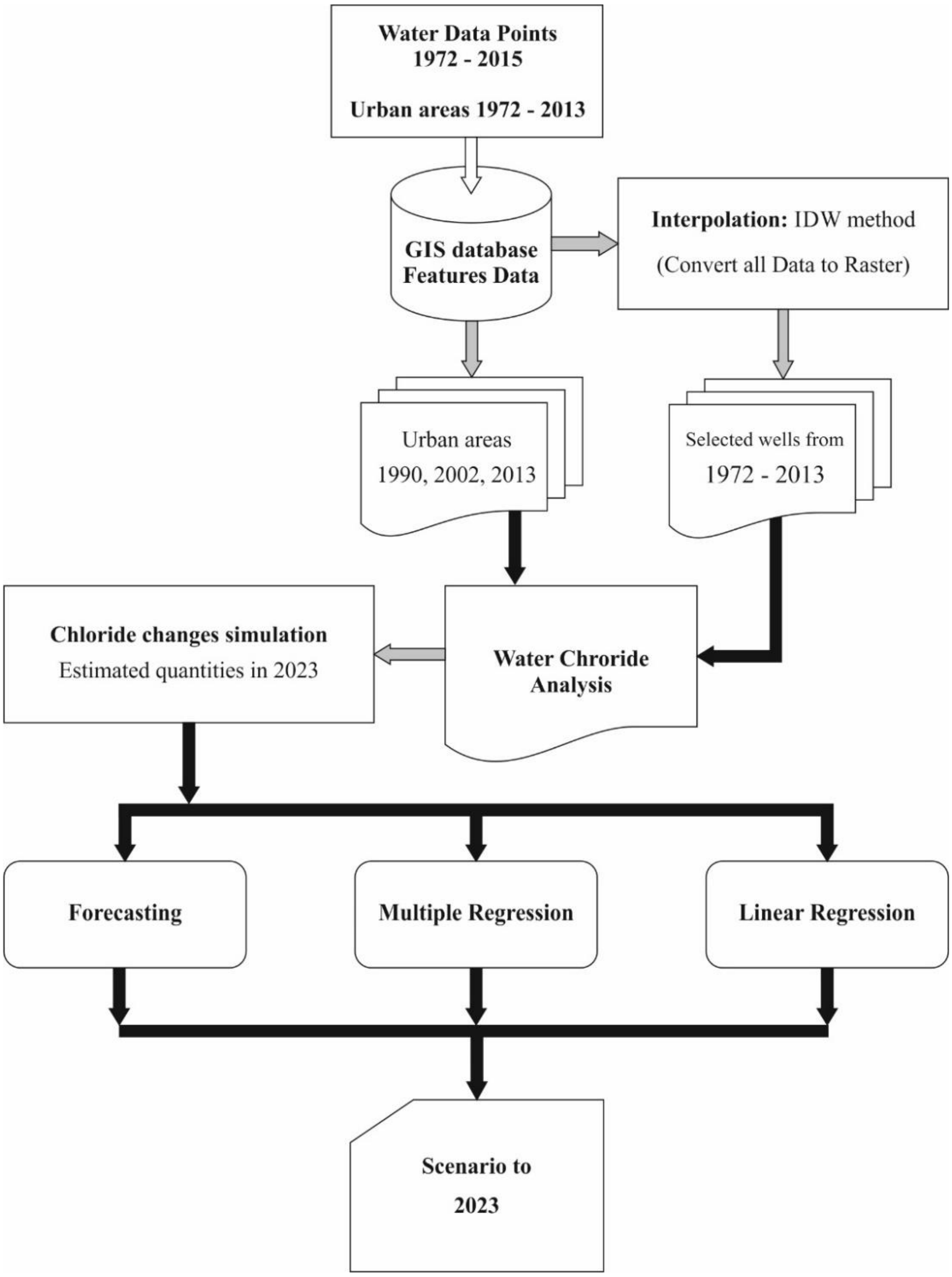


Source: by student

4.3. Groundwater Chloride Analysis and modelling

The methodology was based on our aim to analyze the chloride concentration in the groundwater of the Gaza Strip with a view to assessing the future scenario in 2023, given that chloride levels are likely to rise due to urban expansion and the high population rate which will lead to increased water extraction from the groundwater wells. Scenarios are created on the basis of historical data for the wells. One past trend scenario was evaluated using the input parameters within three models: the Forecasting, Linear, and Multiple linear regression models shown in Figure 4.3.

Figure 4.3. Methodology flow chart of water chloride analysis.



Source: by student

4.3.1. Dataset

The available data for agricultural and municipal wells were collected from the Palestinian Water Authority and Ministry of Agriculture as series time data for the years 1972 to 2015, and all data were converted from Microsoft Excel to Shapefiles using ArcGIS 10.3, which has coordinates for all the wells. The chloride ions were only selected for analysis and simulation. The number of wells varies according to the year but has increased since the early years. There were 486 wells in 2013. We filtered this down to 180 wells depending on all the selected years from 1990 to 2013 as series time data for modelling and scenario by the year 2023 using the three models. The year 2015 was selected for validation of the models. The urban GIS database was used to analyze the effect of urban expansion on water salinity for 1993, 2003 and 2013.

4.3.2. Interpolation

There are many methods that use interpolation algorithms of data to create surface maps. The Inverse Distance Weighted (IDW) (Tolosana-Delgado et al., 2011) method is used for the interpolation of irregularly-spaced data. It is one of the most popular methods used by geoscientists and geographers (Lu et al., 2008; Mather et al., 2011).

Interpolation of all the points is based on the IDW method for estimation of the unknown cells in the space, using the ArcGIS10.3 software. The formulation of the IDW method is used as follows. The value u at a given point X interpolated from a set of known samples ui=u(Xi)ui=u(Xi) for i=0,1, …, Ni=0,1,…,N can be calculated by

$$u(X) = \sum_{i=0}^{N} \frac{w_i(X)u_i}{\sum_{j=0}^{N} w_j(X)}, R_{(i)} = \left[\sum_{a-1}^{A} W_a P_a^{(i)}\right] \Big/ \left[\sum_{a-1}^{A} W_a\right] \tag{3}$$

Where $w_i(X) = 1/d(X, X_i)^p$, $wi(X) = 1/d(X, Xi)p$is a simple IDW weighting function, as defined by (Shepard, 1968), $d(X, Xi)$ is the distance function from unknown points X to known point $X_i$with positive power parameter p, and N is the number of known points included in the calculation.

From Eq. (1)it can be concluded that the points that are further from the unknown point X will get smaller weights in the interpolation process. Greater values of p assign greater influence to values closest to the interpolated point.

4.3.3. Water chloride analysis and simulation

The analysis of water chloride concentration depends on the classification of data using the main ArcGis10.3 software based on the following concepts:

1. Classification of the chloride concentration into six classes, taking into consideration the salinity above 250 mg\L of the WHO parameter and the maximum value of chloride concentration.
2. Analysis of chloride concentration transition from one class to another during the time series to show the changes clearly.

Analysis of chloride concentration profiles within six cross sections depending on the "Stack Profile" tool in the ArcGIS 10.3 software for the selected layers from 1972, 1982, 1993, 2003, 2013 and 2023, which are estimated by three models. This creates a table and optional graph denoting the profile of line features over one or more multipatch, raster, TIN or terrain (ArcGIS 10.3 help, 2016). The chloride changes map is a continuous surface raster data such as a terrain. A terrain profile is a cross sectional view along a line drawn through a landform. Cross sections, which are valuable tools for visualizing structures (Radford University, 2014), show the terrain of a vertical plane below the earth's surface.

4.3.4. Scenarios and modelling of water chloride changes

This research uses three models to predict chloride concentration for the year 2023: Forecasting, linear regressions, and multiple regression. The three models process the chloride concentration as a dependent variable. Forecasting and linear regression are determined over the time series (years) only as independent variables, but multiple regression is determined by time series, population, water level, precipitation and groundwater pumping (production). The RMSE is used to assess the goodness-of-fit of the three models, by comparing their results with the real data for the year 2015.

4.3.4.1. Forecasting

Forecasting is the process of making predictions about the future based on past and present data and analysis of trends. Forecasting estimates values at certain specific future times. Forecasting methods can be classified as qualitative or quantitative. It is assumed time series method or a causal method.

Time series forecasting treats the historical data as a time series, and attempts to discover a pattern in the historical data and then extrapolate the pattern into the future. The forecast is based solely on past values of the variable and/or on past forecast errors. Causal forecasting methods are based on the assumption that the variable we are forecasting has a cause-effect relationship with one or more other variables (Camm et al., 2015).

The forecast time series modelling the study was produced in Microsoft Excel depending on the Forecasting Function which takes the form: The FORECAST (x, known y's, known x's) function returns the predicted value of the dependent variable (represented in the data by known y's) for the specific value 'x' of the independent variable (represented in the data by known x's) by using a best fit (least squares) linear regression to predict y values from x values (Microsoft, n.d.). The dependent variable is the chloride concentration, and the independent variable is the time series as years from 1990 to 2013.

The equation (4) for FORECAST is $a + bX$ (4)

Where:

$$a = \bar{Y} - b\bar{X} \tag{5}$$

And

$$b = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sum(X-\bar{X})^2} \tag{6}$$

Where $\bar{X}$ and $\bar{Y}$ are the average (known X's) and average (known Y's).

4.3.4.2. Linear regression

Linear regression is used when we want to predict the value of a variable based on the value of another variable. If plots of data versus time suggest a simple linear increase or decrease over time, a linear regression of the water quality variable Y against time T may be fitted to the data (Gilbert, 1987). Linear regression analysis is the most widely used of all the statistical techniques for the modelling and analysis of numerical data. It exploits the relationship between two or more variables so that we can gain information about one of them by knowing the values of the other. Regression can also be used for prediction, estimation, testing hypotheses, and modelling causal relationships.

A linear regression line has an equation (7) with the form:

$$Y = B_0 + b_1 X + c \tag{7}$$

Where X is the explanatory variable and Y is the dependent variable, b_0 and b_1 are constants known as model regression coefficients or parameters (i.e. b_0 is the intercept or constant coefficient, and b_1 is the slope of the least squares regression line), and c is a random disturbance or error in the approximation of Y. It is assumed that within the range of the observations being studied, the linear equation provides an acceptable approximation to the true relation between Y and X, which is the predicted value of Y when $X = 0$.

The y-intercept (b_0) and the slope (b_1) of the line are recognized by equations 8 and 9:

$$\mathrm{b}_0 = \frac{\mathrm{n}(\sum \mathrm{xy}) - (\sum \mathrm{x})(\sum \mathrm{y})}{\mathrm{n}(\sum \mathrm{x}^2) - (\sum \mathrm{x})^2} \tag{8}$$

$$\mathrm{b}_1 = \frac{(\sum \mathrm{y})(\sum \mathrm{x}^2) - (\sum \mathrm{x})(\sum \mathrm{xy})}{\mathrm{n}(\sum \mathrm{x}^2) - (\sum \mathrm{x})^2} \tag{9}$$

The IBM SPSS statistics software was used to run the model in which the chloride concentration is the dependent variable and the year from 1990-2013 is the independent variable.

4.3.4.3. Multiple Linear regression

Multiple linear regression is the most common form of linear regression analysis. As a predictive analysis, multiple linear regression is used to explain the relationship between one continuous dependent variable (criterion or endogenous or regress variable) and two or more independent variables (predictor or regressor variables).Multiple linear regression analysis is the task of fitting a single line through a scatter plot. More specifically, the multiple linear regression fits a line through a multi-dimensional cloud of data points. The simplest form has one dependent and two independent variables, the general form of the multiple linear regression (Montgomery et al., 2006).

A dependent variable is modeled as a function of several independent variables with corresponding coefficients, along with the constant term. Multiple regression requires two or more predictor variables, hence its name. The multiple regression model is explained by the following formula (10):

$$Y = b_1X_1 + b_2X_2 + \cdots + b_nX_n + c \qquad (10)$$

The response variable, indicated by Y, is measured along with a set of predictor variables, symbolized by $X_1; X_2; \ldots; X_n$, where n is the number of predictor variables, for b_i(i=1,2, ... n) are the regression coefficients+, which represent the value at which the criterion variable changes when the predictor variable changes. $c$is the error term.

When selecting the model for the multiple linear regression analysis another important consideration is the model fit. Adding independent variables to a multiple linear regression model will always increase its statistical validity and improve the model fit, because it will always explain a bit more variance.

In the study, the IBM SPSS statistics software is used to run the multiple regression model where the dependent variable is the chloride concentration, and the independent variables are the population, water level, the rainfall in the whole of the Gaza Strip, and the production of each well in a time series, i.e. using stepwise linear regression, a method that depends on multiple variables while simultaneously removing those that are not important. Stepwise regression essentially carries out multiple regression several times, each time removing the weakest correlated variable. At the end you are left with the variables that best explain the distribution.

4.3.4.4. Root Mean Square Error (RMSE)

The root mean square error (RMSE), also called the root mean square deviation (RMSD), is a frequently used measure of the difference between the values predicted by a model and the values actually observed from the environment that is being modeled. These individual differences are also called residuals, and the RMSE aggregates them into a single measure of predictive power. The RMSE of a model prediction with respect to the estimated variable $X_{model}$is defined as the square root of the mean squared error (11):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i}-X_{model,i})^2}{n}} \quad (11)$$

whereX_{obs} is observed values and X_{model} is modeled values at time/place i. The RMSE values can be used to distinguish model performance in a calibration period with that of a validation period, as well as to compare the individual model performance to that of other predictive models (Fujita et al., 2014). RMSE is also used to assess the goodness-of-fit of models.

PART II. Results and Discussion: Land Change analysis and modelling

5. Scenario of land use and land cover change in the Gaza Strip using remote sensing and GIS models

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COMMENT

Scenario of land use and land cover change in the Gaza Strip using remote sensing and GIS models

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Abstract Land use and land cover change is a major global environmental change issue, and projecting changes are essential for the assessment of the environment. The Gaza Strip will have grown over 2.4 million inhabitants by 2023, and the land demands will exceed the sustainable capacity of land use by far. Land use planning is one of the most difficult issues in the Gaza Strip given that this area is too small. Continuous urban and industrial growth will place additional stress on land cover, unless appropriate integrated planning and management actions are instituted immediately. Planners need further statistics and estimation tools to achieve their vision for the future based on sound information. Therefore, this study combines the use of satellite remote sensing with geographic information systems (GISs). The spatial database is developed by using five Landsat images gathered in 1972, 1982, 1990, 2002 and 2013. Three GIS models are selected for simulation by the year 2023: Geomod, CA_Markov and Land Change Modeler using Idrisi Selva. The projected urban area will have undergone an increase of 212.3 km^2 by the year 2023 in the used models, and the percentage of urban area will account for 58.83 % of the Gaza strip by 2023.

Keywords Land use and land cover change · Scenario · Urban · Geomod · CA_Markov · Land Change Modeler

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Introduction

The population of the Gaza Strip will have grown over two million by 2020, with the growth population rate at 3.44 % in 2013(PCBS 2013). The demand of land will exceed the sustainable capacity of land use by far. The continuous urban growth and the implementation of different projects will place additional stress on land cover, unless appropriate integrated planning and management actions are instituted immediately.

There have been severe changes in the vegetation cover in most of the Gaza Strip. The effects of limited natural resources coupled with a high population growth have posed many environmental challenges. The limited water resources, heavy application of fertilisers and pesticides, inappropriate agricultural practices and overgrazing have produced much of the desertification features that are now prominent over the past years and could be irreversible in many parts of the Gaza Strip.

These conditions have a significant impact on land fertility decline. In order to overcome this deep deterioration, the Palestinian Environment Strategy considered 11 elements, namely, wastewater management, water resources management, solid waste management, agricultural and irrigation management, industrial pollution control, land use planning, public information and awareness, monitoring and database management, environmental standards, some thematic issues and international political issues (MEnA 1999).

Many human and natural factors in the Gaza Strip have led to various types of pressures on the land, resulting in the degradation of land quality and quantity.

The Gaza Strip has been a theatre of conflict for decades. Each of these conflicts has left its mark, and over time, a significant environmental footprint has developed in the Gaza Strip (UNEP 2009).

Land use and land cover change (LUCC) is a key driver of global environmental change and has important implications

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for many national and international policy issues (Nunes and Augé 1999; Lambin et al. 2001) indicating that the impacts of land use and land cover change are critical to many governmental programmes such as documenting the rates, driving forces and consequences of change. Land use/land cover change is often related to land planning, food watch and urban growth (Paegelow and Camacho 2008). In developing countries, urban sprawl is worsened by the lack of land use planning (Jat et al. 2008; Bayramoglu and Gundogmus 2008; Han et al. 2009; Biggs et al. 2010; Lee and Choe 2011).

Remote sensing as a monitoring technique is very useful to achieve the required data for land use changes, urban planning, urban sprawl and other environmental issues. This leads to the need for monitoring by updating the knowledge to support the decision making, at suitably intervals. Monitoring of land use and land cover requires the support of two parameters: spatial resolution and temporal frequencies (Curran 1985; Janssen 1993; Hualou et al. 2007).

Satellite imagery provides an excellent source of data for performing landscape structural studies. Simple pattern measurements, such as the number, size and shape of patches, can indicate more about the functionality of a land cover type than the total area of cover alone (Forman 1995). When fragmentation statistics are compared across time, they are useful in describing the type of land cover change and indicating the resulting impact on the surrounding habitat. The areas of land cover change between images can also be compared to landscape characteristics to determine if change is more likely to occur in the presence of certain environmental and human-induced factors. This level of classification detail presents opportunities to analyse land cover change patterns at a structural scale (Gerylo et al. 2000).

Fung (1990) indicated that the techniques and methods of using satellite imageries as data sources have been developed and successfully applied for land use classification and change detection in various environments including rural, urban and urban fringes. Satellite-based remote sensing technology cannot yet be used to monitor land use at the level of accuracy required by developers, engineers and planners' interests.

Modelling can be defined in the context of geographic information systems (GISs) as occurring whenever operations of the GISs attempt to emulate processing the real world, at one point in time or over an extended period (Goodchild 2005; Paegelow et al. 2013). GIS models go further to evaluate the future and are used to assess different scenarios, depending on the historical data which are retrieved from multiple resources.

Scenarios have emerged as useful tools to explore uncertain futures in ecological and anthropogenic systems (Sleeter et al. 2012). Scenarios typically lack quantified probabilities (Nakicenovic and Swart 2000; Swart et al. 2004), instead functioning as alternative narratives or storylines that capture important elements about the future (Nakicenovic and Swart 2000; Peterson et al. 2003; Swart et al. 2004). Alcamo et al. (2008, p. 15) define scenarios as "descriptions of how the future may unfold based on 'if-then' propositions." Scenarios are used to assist in the understanding of possible future developments in complex systems that typically have high levels of scientific uncertainty (Nakicenovic and Swart 2000; Raskin et al. 1998).

Very few studies deal with land cover change in the Gaza strip without determining the percentage of land degradation. The MedWetCoast project (2003) studied land use planning in Wadi Gaza (Gaza Valley) using GIS and remote sensing, and the UNEP studied the destroyed areas during the conflict in 2002 in the north and south of the Gaza Strip by using remote sensing(UNEP 2003).

This study aimed to analyse urban growth data, the expansion of the urban mass in the Gaza Strip and the impact of this growth on land use and land cover changes, as important future driver of water quality, food safety and climate change. One past trend scenario and models are used within GIS techniques and remote sensing data, in order to identify the plots of the future of Gazans in 2023 that can be useful for decision makers.

In this paper, we will present the study area, and the methodology including land change analysis, simulation and modelling. Finally, we will present the results, discussion and conclusions.

Study area

The Gaza Strip is a narrow area on the Mediterranean coast. It borders Israel to the east and north and Egypt to the south. It is approximately 41 km long, and between 6 to 12 km wide, with a total area of 365 km^2 as shown in Fig. 1.

The Gaza Strip has a temperate climate, with mild winters and dry, hot summers subject to drought. Average rainfall is of about 300 mm (MOAg 2013). The terrain is flat or rolling, with dunes near the coast. The highest point is 105 m above sea level. There are no permanent water bodies in the Gaza Strip.

In 1948, the Gaza Strip had a population of less than 100, 000 people (Ennab 1994). By 2007, approximately 1.4 million Palestinians lived in the Gaza Strip, of whom almost 1 million were UN-registered refugees.

The current population in 2013 is estimated to be in excess of 1.7 million, distributed across five governorates (PCBS 2013). Gaza City, which is the biggest governorate, has some 588,033 inhabitants. The two other main governorates are Khan Younisand Rafah, where the population is of some 320,835 and 210,166 inhabitants, respectively, located in the south of the Gaza Strip, in addition to the population in the Northern Governorate which is of about 335,253, and the Middle Governorate whose population is of some 247,150 inhabitants. The smallest governorate in terms of area is the Middle Governorate which is 55.19 km^2, and then Rafah

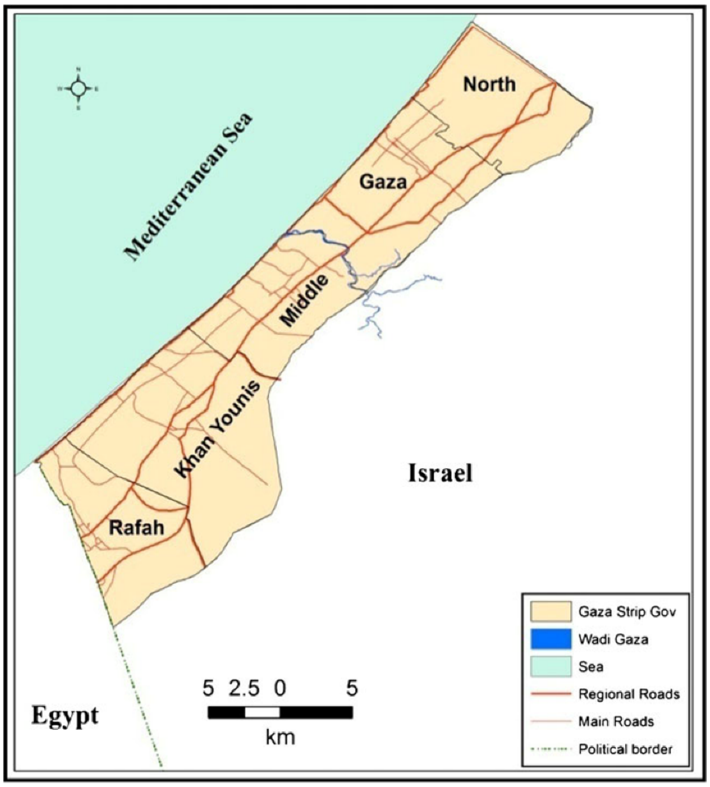

Fig. 1 Location of the Gaza Strip

(60.19 km^2), Northern Governorate (60.66 km^2) and Gaza (72.44 km^2), being Khan Younis the largest, with 111.61 km^2 as shown in Fig. 1.

On the Gaza coastal plain, the original Saharo-Sindian flora has been almost completely replaced by farmland and buildings. Gaza comprises six main vegetation zones: the coastal littoral zone, the stabilised dunes and blown-out dune valleys, the Kurkar, alluvial and grumosolic soils in the northern part, the loessial plains in the eastern part, and three wadi (river) areas (UNEP 2006).

Methodology

The methodology of this study is based on the evaluation of land changes, land analysis, land change potential and land change simulation on the Gaza Strip using remote sensing and GIS as shown in the methodology in Fig. 2.

Model of land use and data

The spatial database has been elaborated using the historical Landsat images from 1972, 1982, 1990, 2002 and 2013 (Table 1). The images were rectified from the aerial photo of 2007 using Erdas Imagine 2013, then were interpreted depending on the visual interpretation mainly, and used a supervised and unsupervised classification for more control and interpretation. Therefore, these methods used generalised digitalisation to obtain more accurate urban database using ArcGIS 10.2 and the cell size of all dataset converted to 15 × 15 m. The database was checked before starting the analysis.

In this study, the whole Gaza Strip area is considered suitable for agriculture. Hence, the Gaza Strip is classified into two classes of land use and cover (LUC), which are urban and agricultural areas (non-urban areas). However, there are other land uses and land covers in the study area which were considered as agriculture in this study.

Five drivers are selected to simulate and predict the future urban area in 2023. The first driver is the distance from the main and regional roads of 2013. People prefer to stay in houses overlooking the roads as economical places. The second driver is elevation and the third one is slope. People prefer high places with fewer slopes as safe places from floods during rainfalls and temperate climate during summer. The fourth driver is a distance

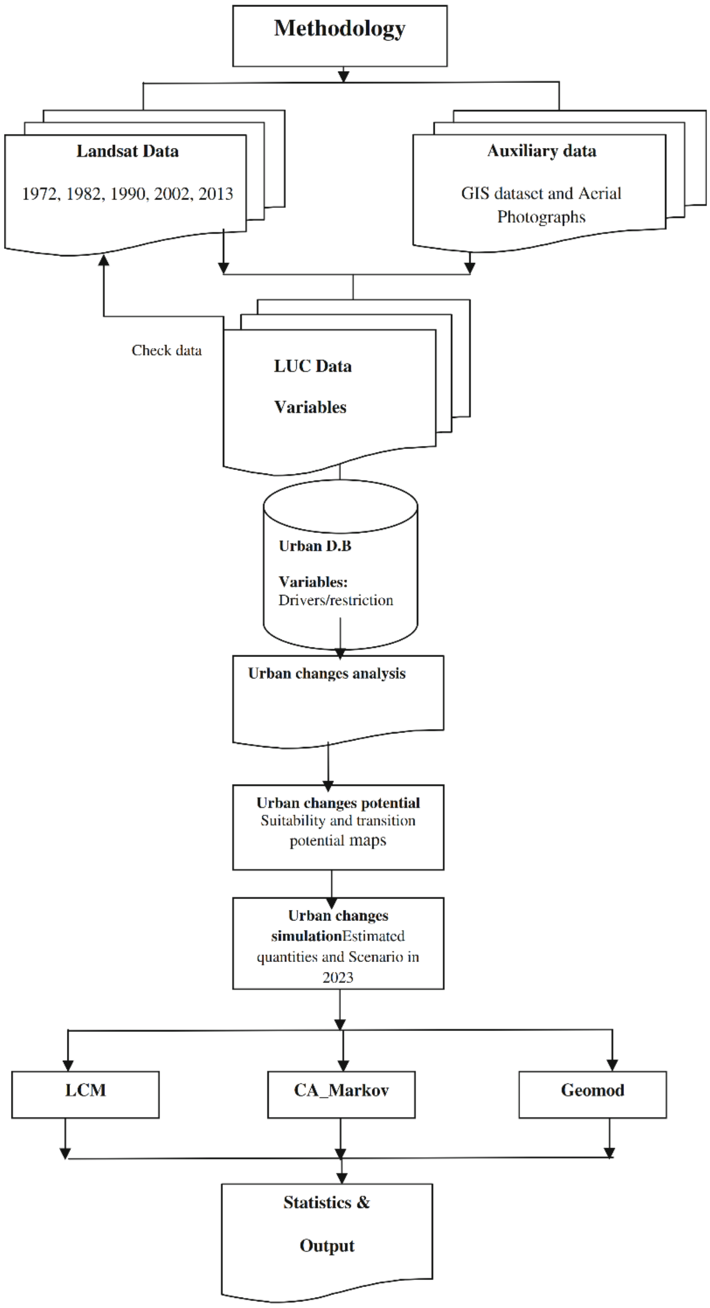

Fig. 2 Methodology flow chart of for land change analysis, potential and simulation

around urban area in 2013 because areas close to previous urban areas have better infrastructure and services and are safer during the invasion of the Israeli military. The fifth one is the buffer zone inside the Gaza Strip from the north and the east border line between the Gaza Strip and Israel that is considered a restricted area as people do not inhabit the border area given its dangerousness.

The buffer zone is of around 1 km in length which is selected as the average of distance between the eastern and northern border and the main street (Salah Eldin) on

Table 1 Landsat data used in this study

Sensor	Row	Data type
Landsat MSS	188/38	22/10/1972
Landsat 3 TM	188/38	13/08/1982
Landsat 5 TM	174/38	11/06/1990
Landsat 7 ETM+	175/38	5/07/2002
Landsat 8	175/38	25/06/2013

the one hand, and the distance between the border and the urban areas that are near the borders in the Gaza Strip on the other hand.

The quantitative measure of the variables' influence can be obtained by Cramer's V. A High Cramer's V value indicates that the potential explanatory of the variable is good but does not guarantee a strong performance since it cannot account for the mathematical requirements of the modelling approach used and the complexity of the relationship. However, it is a good indication that a variable can be discarded if Cramer's V is very low (Eastman 2012). The Cramer's V values are as follows: elevation 0.143, slope 0.060, roads 0.169, distance to built-up 0.707 and border buffer 0.230.

Cramer's V of the collection of factors is obtained in Land Change Modeler (LCM) before running multi-layer perceptron (MLP). The LCM includes include tools for the assessment and prediction of land cover change, and its implications are organised around major task areas: change analysis, change prediction and planning interventions (Eastman 2012).

MLP automatically evaluates and weights each factor and implicitly takes into account the correlations between the explanatory maps. All drivers are static. We also used Cramer's V to obtain the weights using the Saaty method under the analytical hierarchy process (AHP), and we introduced them in Geomod and in weighted linear combination (WLC) of MCE to obtain the suitability maps. This procedure is characterised by full trade-off between factors and an average level of risk, that means exactly midway between the minimisation (AND operation) and maximisation (OR operation) of areas to be considered suitable in the final result (Clark Labs 2012).

Methodology for land change analysis, potential and simulation

Three GIS models in Idrisi Selva software are selected for projection of the urban area in 2023, Geomod, Cellular Automata Markov (CA_Markov) and Land Change Modeler (LCM), in addition to statistical estimation using the regression function to highlight the quantitative difference between the regression and Markov chain.

Figure 2 shows the methodology flow chart for land change analysis potential and simulation applied to the study area.

Land change analysis

The chronological series of LUC maps is analysed to detect changes. The LCM module provides quantitative assessment of category-wise land use changes in terms of net changes, swap, gains, losses and total changes (Eastman 2012), which are extracted from several pairs of dates, and the results are shown in maps and statistics. The change analysis was performed specifically between the images from 2002 and 2013, to understand the transitions of land use classes during the years. The CROSSTAB module of IDRISI was also used between two images to generate a cross-tabulation table in order to observe the consistency of images and distribution of image cells between the land use categories.

Besides, the statistics of the changes occurred in the area during different periods generated using a scatter diagram in Microsoft Excel.

Land change potential: suitability and transition potential maps

Two types of intermediate soft-classified maps, suitability maps and transition potential maps (Camacho Olmedo et al. 2013), are obtained for the land change potential study. Suitability maps are used in both CA_MARKOV and Geomod models; transition potential maps are used in the LCM model. The same driver maps are used in the Geomod, CA_MARKOV and LCM models. A collection of factors are obtained from these drivers by the natural log transformation. The natural log transformation is effective in linearising distance decay variables (e.g. proximity to roads) (Eastman 2012).

GEOMOD creates the suitability image by computing for each grid cell a weighted sum of all the reclassified driver images (Pontius, 2006). Hence, the suitability in each cell is calculated according to the following:

$$R(i) = \left[\sum_{a-1}^{A} W_a P_a\right] \Big/ \sum_{a-1}^{A} W_a$$

where $R(i)$ = suitability value in *cell*(i), a = particular driver map, A = the number of driver maps, W_a = the weight of driver map a, and $P_a(i)$ = percent developed in category a_X of attribute map a, where *cell*(i) is a member of category a_X.

In CA_MARKOV, a suitability map may be produced from driver information or supplied (external), particularly by multi-criteria evaluation (MCE) (Paegelow and Camacho 2008). Each driver is considered a real number (%). The

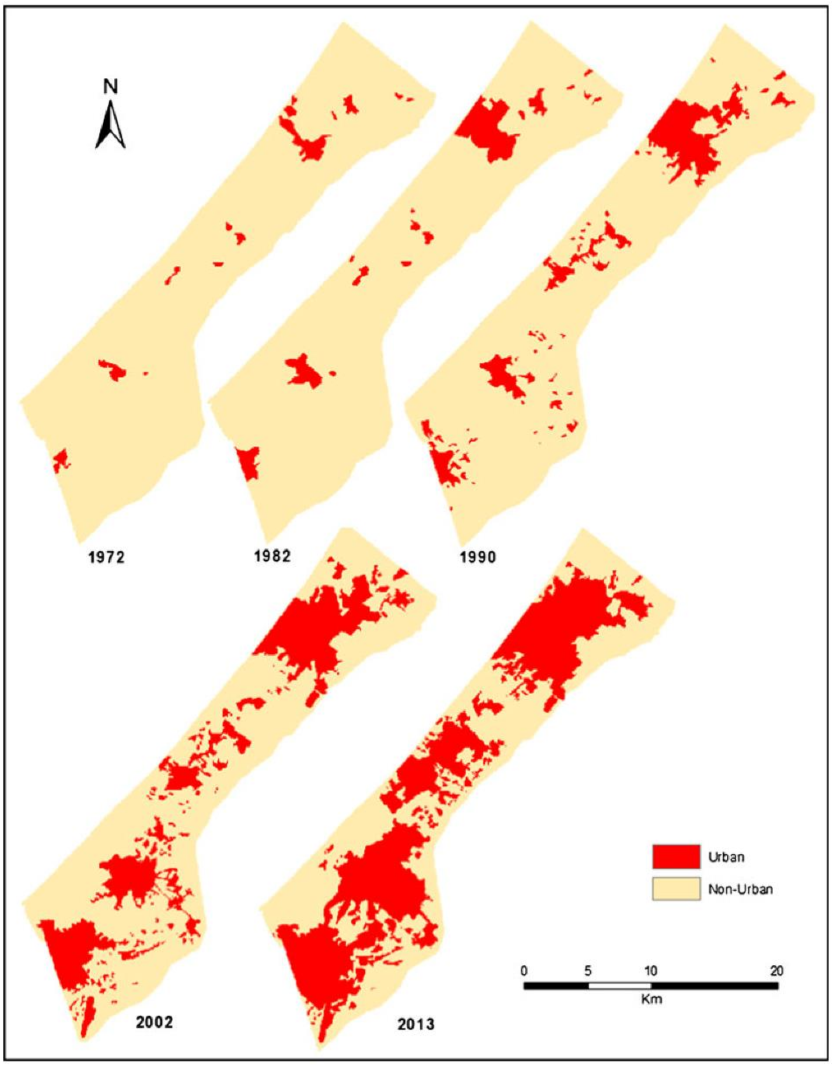

Fig. 3 Urban areas from 1972 to 2013

suitability maps for each LUC category are created by MCE, using all drivers converted to factors.

The transition potential maps are in essence potential maps for each transition in LCM. A collection of transition potential maps is organised within an empirically evaluated transition sub-model that has the same underlying driver variables. A transition sub-model can consist of a single land cover transition or a group of transitions that are thought to have the same underlying driver variables. These driver variables are used to model the historical change process. The transition potential maps are obtained by multi-layer perceptron (MLP) in LCM. The MLP option can run multiple transitions and undertakes the classification of remotely sensed imagery through the artificial neural network multi-layer perceptron technique, and it uses an algorithm to set the number of hidden layer nodes (Eastman 2012).

Table 2 Urban and non-urban areas from 1972 to 2013

Year	Urban (km^2)	Urban (%)	Non-urban (km^2)	Non-urban (%)
1972	10.94	3	349.06	96.96
1982	25.29	7	334.71	92.98
1990	46.88	12.8	313.12	86.98
2002	100.23	27.4	259.77	72.16
2013	166.29	46.2	193.71	53.81

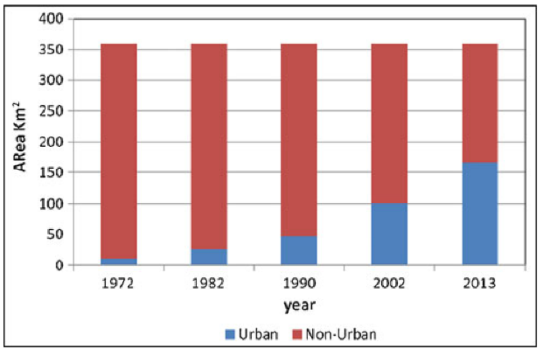

Fig. 4 Urban and non-urban areas from 1972 to 2013

Land change simulation: the estimated quantities

Markov chain analysis is used to calculate the estimated quantities in 2023 within urban data for the years 2002 and 2013, which is used in LCM model, CA_MARKOV, and to calibrate the Geomod model.

CA_MARKOV and LCM incorporate the quantity of estimated change and persistence using a Markovian matrix. The MARKOV module computes the transition areas matrix and the transition probability matrix by cross-tabulation between LUC categories from two maps (t0 to t1), which reflect data from the calibration stage, to project the estimated changes and persistence at the simulation stage (t1 to T). The estimation to T is based on the number of time periods between t0 and t1 and the number of time periods between t1 and T, respecting in any cases the same time units. A more detailed description of the MARKOV matrix can be found in the IDRISI Selva Help System and also in Mas et al. (2014). The Markov chain analysis is one of the most widely used stochastic approaches in ecological and environmental modelling (Paegelow and Camacho 2008). For the study area, the estimated quantities in 2023 are based on the transitions during 2002–2013, using the MARKOV module of IDRISI. The same Markov transition probability matrix is used in both CA_MARKOV and LCM models.

Linear regression is applied as a method to compare the results of the Markov chain data. A regression uses the historical relationship between an independent (the dates) and a dependent variable to predict the future values of the dependent variable such as urban areas. The linear statistical regression was used for simulation of the built-up area for the year 2023 depending on the urban area in 1972, 1982, 1990, 2002 and 2013. The growth rate and other statistics were calculated using Microsoft Excel.

Land change simulation: the scenario

The three models are used to simulate likely urban areas in 2023 in a single scenario.

GEOMOD simulates the changes between exactly two categories, state 1 and state 2 (Eastman 2012), in our case study, urban and non-urban LUC. GEOMOD selects the location of the grid cells based on their suitability maps. The simulation can occur either forwards or backwards in time. The output result of Geomod is a byte binary image that shows the ending time.

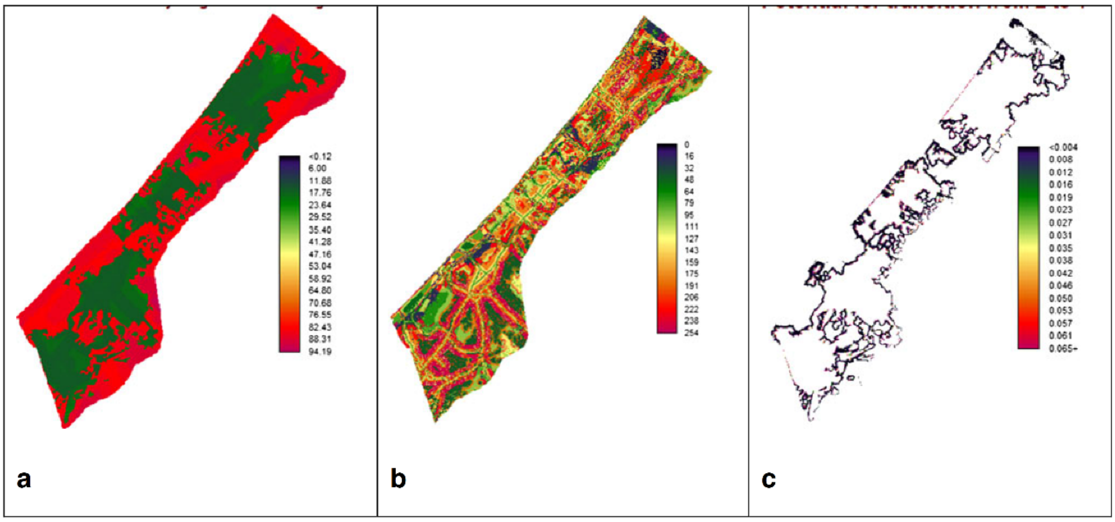

Fig. 5 **a** Geomod suitability map for urban area, **b** MCE suitability map for urban area for CA_MARKOV, **c** MLP transition potential map from non-urban to urban area for LCM

Table 3 Transition area matrix for estimation of urban areas in the year 2023 by using 2002 and 2013 in cells and area (km^2)

Matrix	Urban area (km^2)	Non-urban area (km^2)	Total area (km^2)	Percentage
Urban	166.29	0	166.30	**46.1**
Non-urban	46.05	148.59	194.64	**53.9**
Total	212.34	152.20	360.94	**100**
Percentage	58.83	42.17		100

The simulation of the Geomod model is based on the following (Clark Labs 2012):

1. Specification of the beginning time, ending time and time step for the simulation
2. An image showing the allocation of land use states 1 and 2 at the beginning time
3. A decision whether to constrain the simulated change to the border between state 1 and state 2
4. A map of suitability for the transition to land-use state 2,
5. The projected quantity of land-use states 1 and 2 at the ending time.

Both LCM and CA_MARKOV models use an a priori identical multi-objective land allocation (MOLA) to solve the concurrences between different uses or transitions. This process is based on the choice of the most suitable pixels, i.e. those with the greatest change potential in the ranked change potential maps. Through the Markov matrix, the MOLA creates a list of host classes (categories that will lose surface, in rows) and claimant classes (categories that will gain surface, in columns) for each host. The allocation is done for all claimant classes of each host class, and then it solves the conflicts based on a minimum-distance-to-ideal-point rule using the weighted ranks, and the final result is the overlay of each host class reallocation (Eastman et al. 1995; Mas et al. 2014).

Therefore, some differences exist in the MOLA algorithm in LCM and in CA_MARKOV (Eastman 2012; Camacho Olmedo et al. 2015). The MOLA works only once in the LCM procedure, while, in CA_MARKOV, the MOLA runs once for each chosen iteration, that is the number of time units of the simulation period (t1 to T), and the final result is the overlay of each new simulation map after each MOLA reallocation. A second difference is that in CA_MARKOV, cellular automata (CA) are used to obtain a spatial situation and distribution map; it means that CA transition rules use their current neighbourhood of pixels to estimate land use type in the future. The state of each cell is affected by the states of its neighbouring cells in the filter considered. Besides, using CA transition rules and land use transition is governed by maximum probability transition and will follow the constraint of cell transition that happens only once to a particular land use, which will never be changed further during simulation. For better comparing CA_MARKOV and LCM, in our case study, we used a non-filter (Camacho Olmedo et al. 2015), ignoring the cellular automata; therefore, the effect of contiguity disappeared.

A validation by congruence of models is applied. To measure the congruence of models and the individual model contributions, the three simulation maps of stability and changes from 2013, specifically the simulated urban stability and simulated urban growth from 2013, are intersected by the logical operator AND. The intersection score measures the congruence of models, and all supplementary contributions of the two model combinations (Geomod and LCM, Geomod and CA_Markov, CA_Markov and LCM) are calculated with the remaining individual contributions (Paegelow et al. 2014). That can help to analyse the spatial differences.

Results

Land change analysis of chronological series of LUC maps

The results showed a drastic change in the land cover and growth of the urban area from 1972 to 2013 as shown in

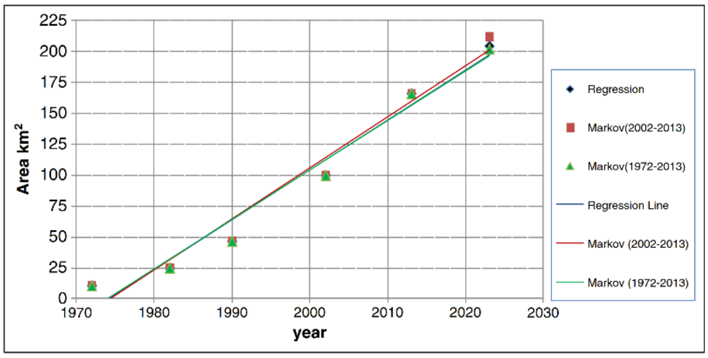

Fig. 6 The scatter plot for Urban area in square kilometres from 1972 to 2023 versus year from Markov chain 2002–2013, Markov chain 1972–2013 and regression analysis

Table 4 The simulated urban area (km^2) in 2023 as a result of using different models

Gov.	Built. 2002 (km^2)	% in 2002	Built. 2013 (km^2)	% in 2013	Geomod (km^2)	% in 2023 Geom	CA-Markov (km^2)	% in 2023 CA-Markov	LCM (km^2)	% in 2023 LCM
North	**17.29**	**4.80**	**24.07**	6.69	**31.89**	8.86	**30.61**	8.50	**30.59**	8.50
Gaza	**27.56**	**7.66**	**33.53**	9.31	**44.26**	12.29	**42.23**	11.73	**41.75**	11.60
Middle	**12.05**	**3.35**	**28.1**	7.81	**35.46**	9.85	**37.15**	10.32	**40.13**	11.15
K.Younis	**21.01**	**5.84**	**47.2**	13.11	**57.85**	16.07	**61.99**	17.22	**59.51**	16.53
Rafah	**22.30**	**6.19**	**33.37**	9.27	**42.88**	11.91	**40.38**	11.22	**40.34**	11.21
Total	**100.21**	**27.84**	**166.2**	46.2	**212.3**	58.98	**212.3**	58.98	**212.3**	58.98

Fig. 3, while the agricultural areas were converted to urban areas. This reveals the need for land use managers and city planners to understand future growth and plan further developments.

Urban areas are continuously increasing in time, whereas non-urban areas are decreasing represented by agricultural areas as shown in Table 2 and Fig. 4.

Suitability maps/transition potential maps

The auto-created suitability map run by the Geomod model shown in Fig. 5 was created depending on the factors of drivers. In Fig. 5b, the MCE suitability map for urban area is shown, which will be used in CA_MARKOV with the suitability map for non-urban area. A pixel completely within the urban area has the highest suitability value, and other pixels would have fewer suitability values depending on the included values. These suitability maps in Geomod and in MCE are obtained from the latest date in the calibration period for 2013.

The MLP neural network in LCM was used to obtain the transition potential map from non-urban to urban area as shown in Fig. 5c, based on the real transition from the calibration period 2002–2013. The output map is the result of high weight of distance to built-up area (0.707 Cramer's value). We must remember that MLP automatically evaluates and weights each factor and takes into account the correlations between them. In Fig. 5c, the biggest density of cells with high values of transition potential is around the built-up area (low distance).

The estimated quantities

The Markov transition area matrix is based on land use changes without drivers, that is, each category will change to the other category. This matrix results from the multiplication of each column in the transition probability matrix by the number of cells of the corresponding land use in the last image for the year 2013. Rows represent land use in the calibration period in 2013and columns represent land use in the simulation date 2023. The matrix showed a transition area between two categories in cells or area (km^2) as shown in Table 3, which is used for the estimation of the urban area in 2023, based on the last period 2002–2013, that is, a past trend scenario, in Geomod, CA_MARKOV and LCM.

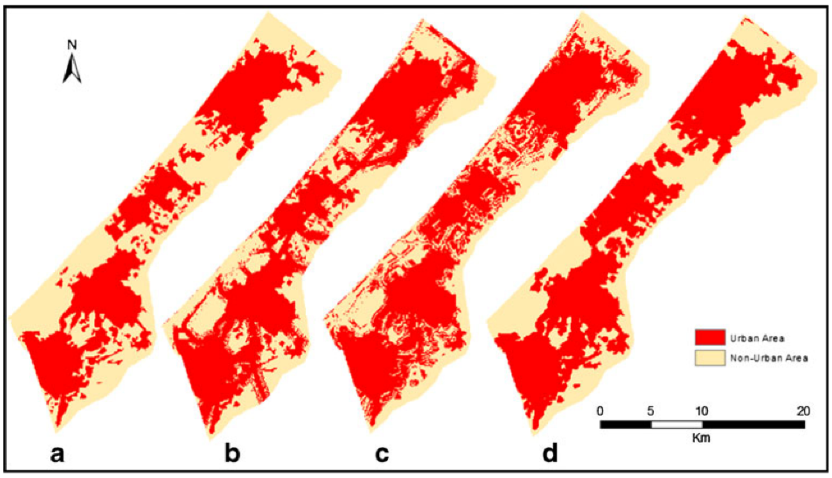

Fig. 7 **a** Real map 2013 and simulated urban maps for the year 2023 as results of **b** Geomod, **c** CA_Markov, and **d** Land Change Modeler

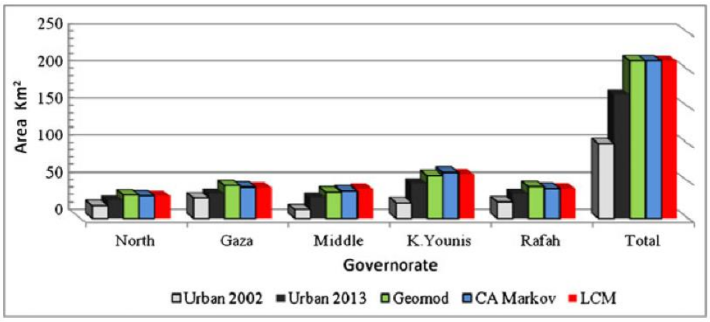

Fig. 8 Urban area for the years 2002, 2013 and 2023 for Geomod, CA_Markov and LCM models

A regression analysis shows the historical relationship between the urban area versus a year to predict the future of urban area for the year 2023, that is 204.8.

Therefore, the adjusted R^2 is 0.97 and the equation of regression can be expressed as follows:

$$y = 4.5768\,X - 9054.022$$

In Fig. 6, the scatter diagram shows the comparison between three past trend scenarios. The first one is the Markov chain from 2002–2013 to 2023, the second one is the Markov chain from 1972–2013 to 2023, and the third one is the regression line to 2023 depending on the basic data. That shows that 204.8 km^2 of the projection of regression line is near 202.4 km^2 of Markov chain line 1972–2013 to 2023, but the Markov chain line 2002–2013 to 2023 is clearer: 212.3 km^2.

Simulations maps: scenario to 2023

The results of the simulation showed the same quantities in the three models according to the Markov chains, i.e. 212.3 km^2, but variations were observed in the results of the three models

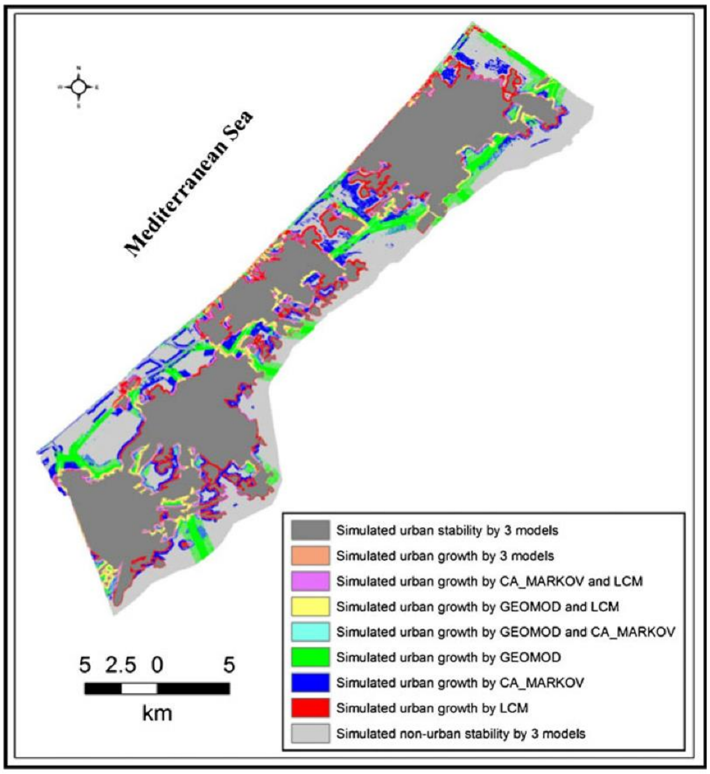

Fig. 9 Congruence of the three simulated maps by Geomod, CA_MARKOV and LCM, specifically the simulated urban stability and simulated urban growth from 2013

Table 5 Area (km^2) and percent of congruence of the three simulated maps by Geomod, CA_MARKOV and LCM, specifically the simulated urban stability and simulated urban growth from 2013

Class	Simulation	Area (km^2)	Percent
1	Urban stability by 3 models	166.2	46.2
2	Urban growth by 3 models	5.7	1.58
3	Urban growth by CA_MARKOV and LCM	10.8	2.99
4	Urban growth by GEOMOD and LCM	11.1	3.07
5	Urban growth by GEOMOD and CA_MARKOV	4.8	1.33
6	Urban growth by GEOMOD	24.5	6.79
7	Urban growth by CA_MARKOV	24.7	6.84
8	Urban growth by LCM	18.5	5.12
9	Non-urban stability by 3 models	94.6	26.20

in the urban areas according to the five governorates of the Gaza Strip as shown in Table 4 and Fig. 7.

There are variations in the rate of urban expansion in each governorate. Figure 8 shows those differences.

Figure 9 and Table 5 show the result of congruence of the three simulated maps by Geomod, CA_MARKOV and LCM, specifically the simulated urban stability, simulated urban growth from 2013, the area and percent of obtained classes from this map.

Discussion

This paper presents the results of analysing and simulating land use change by using the three GIS models.

The results of the past trend scenario of spatial distribution in 2023 presented some differences in Fig. 8; there are similarities in the allocation of urban area, both in Geomod and in CA_Markov, and there are differences in LCM, where it is shown that the urban expansion covers 59 % of the area. The results of the three models are located spatially near urban 2013. This clearly makes sense given that buildings are usually constructed and money is usually invested around main roads beside the urban areas. Otherwise, Geomod expands clearly near the roads that have been noticed in the north area near the border in the restricted area (buffer zone driver).

Differences have been noticed in the spatial distribution of all models in each Governorate. In KhanYounis and Middle Governorates from Table 4 and Fig. 10, the percentage of urban area from 2002 to 2013 has grown by more than 100 %.The Israeli withdrawal from the Gaza Strip in 2005, and leaving the settlements are the main reasons which restrain urban growth in these two governorates; the settlements in these governorates had an area of around 40–50 % of the total area in Rafah and Khanyounis, which does not allow natural growth. After the Israeli withdrawal, the population began to immigrate to those areas after the people had left them because of barrier settlements, and also the price of land is cheaper than in the northern areas. In addition to this, the government housing projects were internationally supported.

In Fig. 10, the Gaza Governorate has fewer urban areas with high population as compared to Rafah and others. This is due to the vertical urban buildings that house a high proportion of the population.

The data analysis shows an increase in the urban area—10.9 (1972), 25.3 (1982), 46.9 (1990), 100.2 (2002), 166.3 (2013) and 212.3 km^2 (2023)—which constitutes the average area percentage from all simulations of the whole Gaza Strip,

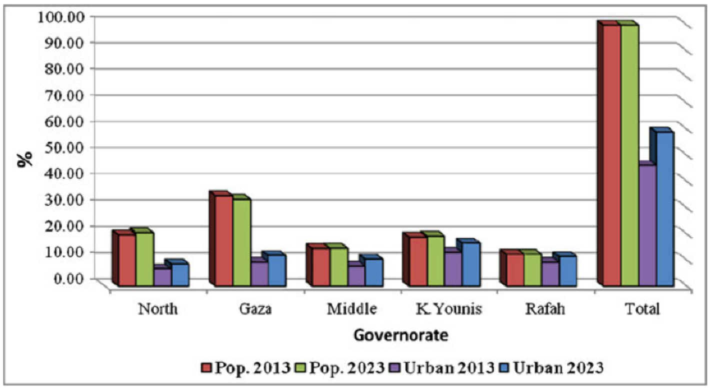

Fig. 10 The population and urban areas from 2013 to 2023

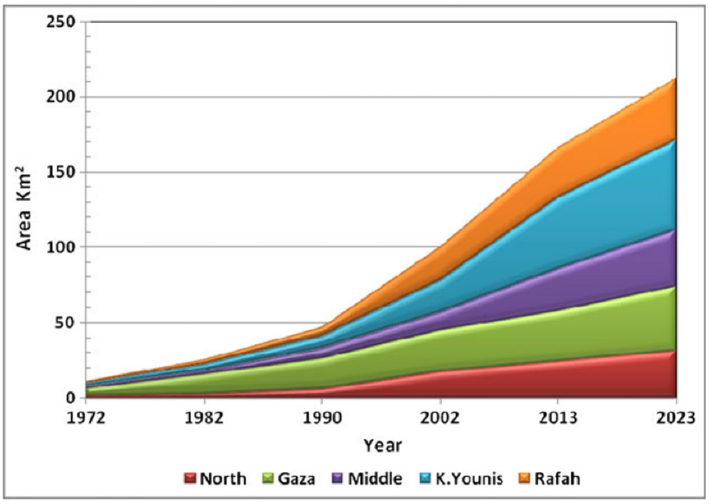

Fig. 11 Growth of the urban area in governorates from 1972 to 2023

i.e. around 58.8 %. Figure 11 illustrates the increase in the urban area and the same is listed in Table 6.

Table 6 shows that urban expansion is positively correlated with population growth. So the density of population in the Gaza Strip will increase from 4661.5 in 2013 to 6704.3 inhabitants per square kilometre in 2023. However, the actual density of population is 10,231.1 in 2013 and 11,526.4 inhabitants per square kilometre in 2023, because most Gazans live in urban areas, which is considered one of the highest population densities in the world.

The study results showed that there is a decrease in the agricultural land (non-urban area), which will continue with growth of population in absence of management and planning. The study shows a rapid urban growth rate in each time period 1972–1982, 1982–1990, 1990–2002, 2002–2013 and 2013–2023, which are consequently 1.4, 2.7, 4.4, 6, and 3.8 km^2. This will continue in decreasing of agricultural areas as seen in Table 7.

During the period from 1972 to 2000, the Palestinian economy in the Gaza Strip grew parallel to the Israeli economy. From 1972 until the eruption of the first Intifada (uprising) in 1987, there was a dramatic rise in the Palestinian standard of living. The main reason for that rise was the opening of the rapidly expanding Israeli job market to Palestinian workers (Swirski 2008). The situation continued until the signing of the 1993 Oslo Accords. From 1994 to 2000, there were huge urban projects and many investments leading to urban expansion.

After the conflicts from 2000 to 2013, the Palestinian workers in Israel became unemployed, in addition to the siege that started in 2007 around the Gaza strip, which prevented the urban expansion from keeping the same growth rate as in previous periods. From 1972 to 1994, urbanisation distibuted more vertically than horizontally, and the situation reversed after the period 1994 to 2013.

The simulation of land uses in the year 2023 clearly shows that the urban area increased rapidly due to the high population growth rate and to the lack of management and future planning. The master plan of the Gaza Strip was developed by the Ministry of Planning that did not take into account land degradation and rapid growth, and to take other directions including vertical urban construction as a policy to raise public awareness.

In addition, the power is necessary to support laws and legislations through tighter regulation and implementation of laws on sold lands by the owners as well as governmental lands, development of the master plan based on the temporal

Table 6 Increase of the urban area from 1972 to 2023

Year	Population no.	% area	Area (km^2)
1972	393,800	3.0	10.9
1982	511,115.2	7.0	25.3
1990	642,814	12.8	46.9
2002	1,182,908	27.4	100.2
2013	1,701,437	46.2	166.3
2023	2,447,054	58.8	212.3

Table 7 The annual growth of urban areas per period

Period	The annual growth (km^2)
1972–1982	1.4
1982–1990	2.7
1990–2002	4.4
2002–2013	6
2013–2023	4.6

scenario and finding a solution for the Palestinian political situation in the Gaza Strip.

Figure 9 and Table 5 show the probability trend of urban expansion in most areas that are high, and the simulated non-urban stability is 26.2 %. The results are obtained from different models that are important to the decision-maker and give a full visual for the future of urban growth in the Gaza Strip. The differences in these results provide different future simulations for the Gaza Strip, which will affect water quality and quantity as well as land and food security.

The research deals with the situation as for the year 2013, before the war on the Gaza Strip that started on 8 July 2014 and ended on 28 August 2014.

Shelter Cluster, co-chaired by the UN Refugee Agency and the Red Cross, estimates that under current conditions, it will take approximately 20 years to import the aggregates required to complete the housing reconstruction. This time frame is based on the current operational capacity of Kerem Shalom crossing for aggregates (100 truckloads daily), and the estimated 97,334 housing units required in the Gaza Strip (Shelter Palestine 2014).

The report of UNDP about war 2007/2008 1 year after, 2009, mentioned that three quarters of the damage inflicted on buildings and infrastructure remains unrepaired and unreconstructed, and at least 6268 homes were destroyed or severely damaged. The civilian population suffered further from damage to electricity, water and sewage systems (UNDP 2009). In 2012, most buildings and infrastructure were rebuilt and returned to the natural growth. The Cairo Donor Conference took place on 12 October 2014. More than USD 5.4 billion were pledged by international donors in support of the plan to rebuild the Gaza Strip.

After the 2014 war on the Gaza Strip, the following scenarios can be envisaged:

- The siege will continue up to 2023, and then there will be no reconstructions and there will be a shortage of the urban areas as compared to 2013.
- The siege could come to an end with a political solution, and two scenarios could be possible:

– Rebuilding of what was destroyed in 2014 only and no noticeable increase will take place as compared to 2013.
– Rebuilding of what was destroyed in 2014, added to the needs of natural population growth, which will go in the aspects of three models by the year 2023.

Conclusions

This paper presents, evaluates and simulates urban expansion using the historical and free Landsat data from 1972 to 2013.These simulations are based on the continuity of observed past trends and are not predictions, but a plausible scenario of future state underlying the maintenance of macro-political and social conditions.

The following conclusions were drawn from the results of this research about urban expansion simulation for the year 2023 using three land change models:

- The percentage of urban area will be around 58.8 % of the Gaza Strip.
- There are differences in the spatial distribution of each model from place to place.
- In terms of services and management of the Gaza Strip, planners should take into account that there are going to be three blocks instead of many urban areas.
- Urban expansion will lead to dramatic changes and more stress on the agricultural areas, soil erosion and water quality and quantity.
- The increase of agricultural land and pressure on natural resources in the Gaza Strip will contribute to the local and global climate change.

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6. Urban land use change analysis and modeling: a case study of the Gaza Strip

13 Urban land use change analysis and modeling: a case study of the Gaza Strip

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Abstract Analysis of land use and land cover change is of prime importance for understanding the ecological dynamics resulting from natural and human activities, and for the assessment and prediction of environmental change. The population of the Gaza Strip will have grown to more than 2.4 million by 2023 all of whom are forced to live within an area of some 365 km². This growth in population will lead to an increase in land demand, and will far exceed the sustainable land use capacity. The Gaza Strip is a relatively small area in which land use planning has not kept up with land development. Continued urban expansion and population growth in the future will place additional stress on land cover, unless appropriate integrated planning and management decisions are taken immediately. Decision-makers need further statistics and estimation tools to achieve their vision for the future of the Gaza Strip based on sound, accurate information. This study combines the use of satellite remote sensing with geographic information systems (GISs). The spatial database was developed by using six Landsat images taken in 1972, 1982, 1990, 2002, 2013 and 2014, together with different geodatabases for those years. Five past trend scenarios were selected for simulation to be completed by the year 2023 using the Land Change Modeler in the Idrisi Terrset software. These different scenarios, one of which takes into account the damage incurred during the 2014 War, try to cover the possible variations in areas and spatial distribution resulting from changes in land use. As an average over the five scenarios, by 2023 the projected urban area will have increased to 206.24 km² or 57.13% of the Gaza Strip.

Keywords: Land use and land cover change, scenario, urban, Land Change Modeler

1 Introduction

Understanding, predicting and analyzing land use and cover change is enormously important for future planning. One of the major factors affecting land use in the Gaza Strip is rapid population growth, one of the most significant issues in Palestinian society today. According to the Palestinian Central Bureau of Statistics (PCBS), with the recent growth rates of 3.44% in mid-2013, and 3.41% in mid 2014 (PCBS 2014) the population of the Gaza Strip will have grown to over 2.4 million by 2023. This area already has one of the highest population densities in the world with an estimated 3,956 persons/ km^2 in 2006. This figure is even higher in the Gaza governorate (around 6,834 persons / km^2) where most of the population is concentrated. Another serious problem in Gaza is urban sprawl. The number of housing units in the Gaza Strip increased from 116,445 in 1997 to 147,437 in 2007 (PCBS 2012). Many human and natural factors have increased pressure on land use in this region, resulting in deteriorating quality and quantity of land (Abuelaish and Camacho 2016). Urbanization leads to increasing pressure on natural ecosystems (Taubenbock et al. 2012, Haas and Ban 2014) and brings with it soil, water and air pollution (Duh et al. 2006, Ren et al. 2003).

The Gaza Strip has been a theatre of conflict for decades. Each of these conflicts has left its mark, and a significant environmental footprint has developed in the Gaza Strip over time (UNEP 2009). The population growth rate and the urban expansion it drives affect the whole region. In general people prefer to live close to the urban facilities and infrastructures, usually found in the center of the residential areas, and to avoid the dangerous areas. The Gaza Strip has been directly involved in many wars, most recently in 2008, 2012 and 2014. The 2014 war was the most destructive in terms of buildings and infrastructure. The Israeli offensive against the Gaza Strip was launched on 8th July and continued until 26th August 2014. It left devastation all across this region, ranging from damage to complete destruction of thousands of homes. Post-war reconstruction is likely to exacerbate the normal urban growth rate, so adding a greater burden on this already congested country.

Several monitoring techniques, such as Remote Sensing, are very useful for gathering the data required for land use change assessment, urban planning, urban sprawl and other environmental issues. Land use changes must be monitored at suitable intervals in order to update the knowledge required to support decision making. Monitoring of land use and land cover requires the support of two parameters: spatial resolution and temporal frequencies (Curran 1985, Janssen 1993, Hualou et al. 2007). Modeling can be defined within the context of geographic information systems (GISs) as occurs whenever GIS operations attempt to emulate processing in the real world, at one point in time or over an extended period (Goodchild 2005, Paegelow et al. 2013). GIS models go beyond simply evaluating the future and are used to assess different scenarios, on the basis of the historical data retrieved from multiple resources. Scenarios have emerged as useful tools to explore uncertain futures in ecological and anthropogenic systems (Sleeter et al. 2012). Scenarios typically lack quantified probabilities (Nakicenovic and Swart 2000, Swart et al. 2004), functioning instead as alternative narratives or storylines that capture important elements about the future (Nakicenovic and Swart 2000, Peterson et al. 2003, Swart et al. 2004). Alcamo et al. (2008) define scenarios as "descriptions of how the future may unfold based on 'if-then' propositions." Scenarios provide a structured framework for the exploration of alternative future pathways, and are used to assist in the understanding of possible future developments in complex systems that typically have high levels of scientific uncertainty (Nakicenovic and Swart 2000, Raskin et al. 1998). Plausible scenarios generally require knowledge of how drivers of change have acted to influence historical and current conditions (Sleeter et al. 2012).

This study aimed to analyze urban growth and monitor the spatial and temporal changes from 1972-2014 within five past trend scenarios using a model based on GIS techniques and remote sensing data. One of these scenarios takes into account the damage caused by the 2014 war. Scenarios are proposed to 2023, which can be helpful for planning decisions to be taken in the Gaza Strip within this timeframe. These decisions will be have an enormous impact on the future of environmental issues and urban development.

This paper begins by presenting the study area of the Gaza Strip. We then explain the methodology, including data processing, land change analysis, simulation and modeling of the study area before and after the 2014 war in the Gaza Strip. Finally, we present the results, discussion and conclusions.

2 Study area and dataset

2.1 Study area

The Gaza Strip is a narrow area on the Mediterranean coastal plain. It is approximately 41 km long, and from 6 to 12 km wide, with a total area of 365 km². It shares a 12 km border with Egypt to the southwest and is surrounded by Israel to the east and north (the rest of the Strip - 51 km of borders), as shown in Figure 1. The Gaza Strip has a temperate climate, with mild winters (about 13ºC) and hot summers with frequent droughts (high 20s ºC). Average rainfall is about 300 mm a year (MOAg 2013). The terrain is flat or rolling, with dunes near the coast. In terms of topography the Gaza Strip slopes gradually downwards from east to west with the land surface elevation varying between 10 m above sea level in the west to 110 m above sea level in the east.

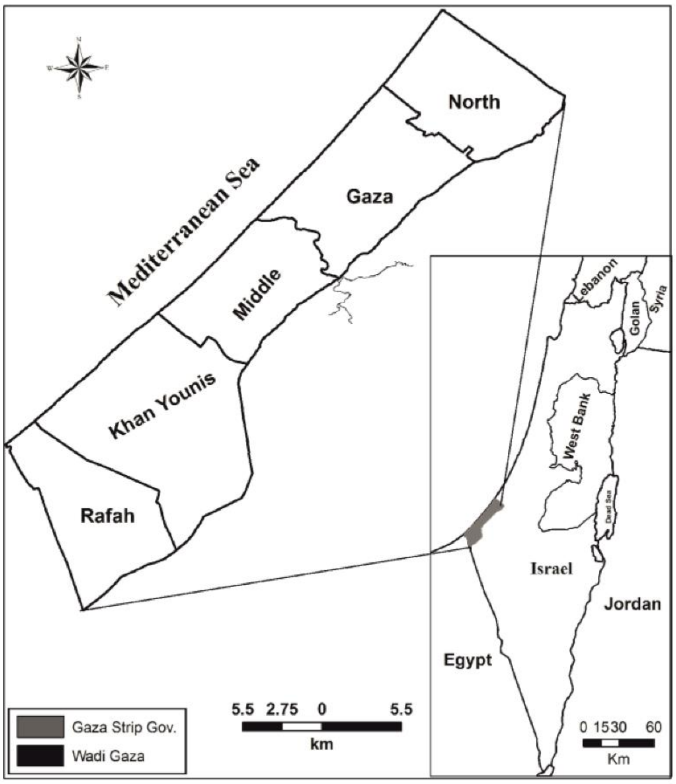


Fig. 1. Location on the Gaza Strip.

In 1948, the Gaza Strip had a population of less than 100,000 people (Ennab 1994), however by 2007, it had risen sharply to around 1.4 million (Census 2007). The total population in 2014 was estimated to be in excess of 1.79 million and, at the end of 2015, about 1.82 million inhabitants, distributed across five Governorates (PCBS 2015), of whom almost 1.3 million were UN-registered refugees. Gaza City, which is the biggest governorate, has some 625,824 inhabitants. The other two main governorates are Khan Younis and Rafah in the southern part of the Gaza Strip, which have 341,393 and 225,538 inhabitants, respectively. There is also the Northern Governorate, with a population of about 362,772, and the Middle Governorate, which has 264,455 inhabitants. The smallest governorate in terms of area is the Middle Governorate, with 55.19 km². This is followed by Rafah (60.19 km²), the Northern Governorate (60.66 km²), and Gaza (72.44 km²). The largest governorate is Khan Younis with an area of 111.61 km², as shown in Figure 1.

Agriculture is the economic mainstay of the employed population, and nearly three quarters of the land area is under cultivation. On the Gaza coastal plain the original Saharo-Sindian flora has been almost completely replaced by farmland and buildings. Gaza has six main vegetation zones: the littoral zone along the coast, the stabilized dunes and blown-out dune valleys, the Kurkar, alluvial and grumosolic soils in the northern part, the loessial plains in the east, and three wadi (valley) areas (UNEP 2006).

2.2 Dataset

The spatial database has been produced using the historical Landsat images from 1972, 1982, 1990, 2002, 2013 and 2014, as shown in Table 1. The images were rectified from the aerial photos for 2007 using Erdas Imagine 2013. Generalized digitalization was used to build the urban GIS database using ArcGIS 10.2; interpretation was mainly visual, and both supervised and unsupervised classifications were used for more control and interpretation. The cell size of the entire dataset was converted to 15x15 meters. The database was validated before starting the analysis by tracking data with high resolution aerial photographs taken before and after a particular year. As no aerial photographs were available for the last year, we validated some points that were in doubt using the UNITAR database.

Table 1. Landsat data used in this study.

Sensor	Row	Data type
Landsat MSS	188/38	22/10/1972
Landsat 3 TM	188/38	13/08/1982
Landsat 5 TM	174/38	11/06/1990
Landsat 7 ETM+	175/38	05/07/2002
Landsat 8	175/38	25/06/2013
Landsat 7 ETM+	175/38	24/09/2014
GIS dataset of UNOSAT/UNITAR	Geodatabase	Field Survey, October/2014

For the purposes of this research, we considered the whole Gaza Strip area as suitable for agriculture and classified the land into two classes: urban and agricultural areas (non-urban areas). Some other land uses and land covers in the study area were also considered as agricultural in this study.

On 20th November 2014, the UNRWA, UNDP and the Ministry of Public Works and Housing (MOPWH) announced the conclusion of their assessment of the damage caused to housing during the 2014 War, which they had conducted jointly over a two month period. 6,761 residential buildings were totally destroyed (including more than 11,000 housing units), 3,565 were severely damaged and 4,938 units were moderately damaged, as shown in Table 2. The UNITAR/UNOSAT created geodatabases based on field work and high resolution satellite images. All images used to analyze the conflict were taken by the Pleiades satellites operated by Airbus Defense and Space, which provide 50cm resolution images (UNITAR/UNOSAT 2014). The UNITAR/UNOSAT Geodatabase contains a total of 22,745 sites with crater impacts or some form of damage to housing after attacks during the war.

Table 2. Buildings damaged during the 2014 War.

	Destroyed	Severely Damaged	Moderately Damaged	Total Structures Affected	Crater Impact
North	1,253	761	1,000	3,014	1,702
Gaza	1,963	1,127	1,378	4,468	1,765
Middle	809	406	683	1,898	553
KhanYounis	1,749	898	1,379	4,026	1,549
Rafah	987	373	498	1,858	1,904
TOTAL	6,761	3,565	4,938	15,264	7,473

Source: UNITAR/UNOSAT 2014.

3 Methodology and practical application to the datasets

The flow chart in Figure 2 shows the methods used in the research reported in this paper, including the definition and creation of a database using remote sensing and GIS, land changes analysis, proposal and testing of explanatory variables, modeling and scenarios development of scenarios in the Gaza Strip.

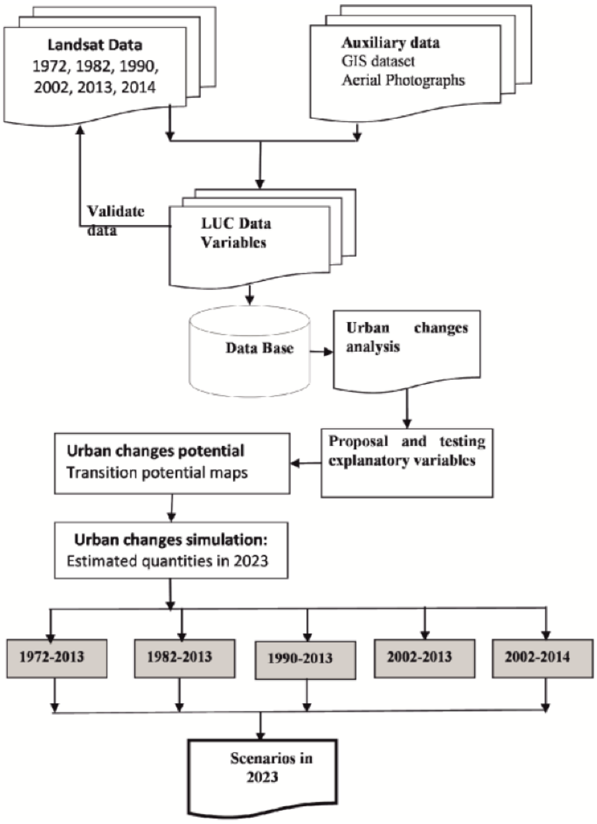


Fig. 2. Methodology flow chart of land-change analysis, potential and simulation.

3.1 Land Use Model and Data

3.1.1 Land change analysis

The chronological series of LUC maps was analyzed to detect changes. A quantitative assessment of category-wise land use changes in terms of net changes, swap, gains, losses and total changes (Eastman 2012) was extracted from several pairs of data, and the results are shown in maps and statistics. The change analysis was performed specifically between two images from 1972, 1982, 1990, 2002, 2013 and 2014 to understand the transitions in land-use classes over the years. A multiple regression line was created to predict the future urban area, and statistical values for the changes occurred in the area were represented on a scatter diagram.

3.1.2 Proposal and testing of explanatory variables

Five static drivers were selected to simulate and predict the future urban area in 2023. The first driver is the distance from the main and regional roads in 2013, given that the population prefers to buy and live in houses overlooking the roads, which are also considered good investments. The second driver is elevation, because people prefer high locations which are considered to be safe from floods during rainfalls and have a more temperate climate in summer. The third driver is the distance from the urban area in 2013, since people prefer to live close to well-established urban areas with better infrastructure and services, which are safer during Israeli military attacks. The fourth driver is the 1 km wide buffer zone along the border between the Gaza Strip and Israel. This is a restricted area which people are forbidden to enter. The fifth driver is the buildings destroyed during the 2014 War. It is only used in the 2002-2014 scenario.

The quantitative measure of the influence of the variables can be obtained using Cramer's V. A high Cramer's V value indicates that the variable has good explanatory potential, but does not guarantee a strong performance since it cannot take into account the mathematical requirements of the modeling approach or the complexity of the relationship. However, a very low Cramer's V value is a good indication that a variable can be discarded (Eastman 2012). The Cramer's V values for these drivers for all the calibrated periods were Elevation 0.142, Roads 0.169, Distance to built-up areas 0.707 and Border buffer zone 0.230.

We noticed that the Cramer's V values were similar for all the calibrated periods using the same latest land cover map (2013). Cramer's V values for the calibrated period (2002-2014) were also very similar, and its fifth key driver of "buildings destroyed during the war" obtained a value of 0.0294.

Even though the "buildings destroyed during the war" variable could be discarded because it has a very low Cramer's V value of 0.0294, we decided to include it because it is a key driver for reconstruction.

The results from the categories revealed that the distance to built-up areas and away from the border buffer zone were the main drivers for all predictions.

3.2 Methodology for modeling and scenario development

In order to project the urban area in 2023, we selected a GIS model in Idrisi Terrset software called the Land Change Model (LCM). This model is used to analyze land cover change, empirically modeling its relationship to explanatory variables and projecting future changes (Eastman 2012).

3.2.1 Land change potential: transition potential maps

To predict the change, each land use transition must be modeled empirically on maps called transition potential maps. These maps are used together with driver maps. A collection of factors are obtained from these drivers by the Natural Log Transformation. The Natural Log Transformation is effective in linearizing distance decay variables (e.g., proximity to roads) (Eastman 2012).

The transition potential maps are in essence potential maps for each transition in LCM. A collection of transition potential maps is organized within an empirically evaluated transition sub-model that has the same underlying driver variables. A transition sub-model can consist of a single land cover transition or a group of transitions that are thought to have the same underlying driver variables. These driver variables are used to model the historical change process. The transition potential maps are obtained by Multilayer Perceptron (MLP) in LCM. The MLP option can run multiple transitions and undertakes the classification of remotely-sensed imagery through the artificial neural network multi-layer perceptron technique. It uses an algorithm to set the number of hidden layer nodes. MLP automatically evaluates and weights each factor and implicitly takes into account the correlations between the explanatory maps (Eastman 2012).

3.2.2 Land change simulation: The estimated quantities

The Markov transition area matrix is based on land-use changes without drivers that are produced within the Markov chain from two different dates. This matrix results from the multiplication of each column in the transition probability matrix by the number of cells for the corresponding land use in the last image for the year 2013 or 2014.

Markov chain analysis is used to calculate the estimated quantities in 2023 within the urban data for all the scenarios (1972-2013), (1982-2013), (1990-2013), (2002-2013) and (2002-2014) up to 2023.

The MARKOV module computes the transition areas matrix and the transition probability matrix by cross tabulation between LUC categories from two maps (t0 to t1), which reflect data from the calibration stage, to project the estimated changes and persistence at the simulation stage (t1 to T). The estimation to T is based on the number of time periods between t0 and t1 and the number of time periods between t1 and T, respecting in any case the same time units. A more detailed description of the MARKOV matrix can be found in the Idrisi Terrset Help System and also in Mas et al. (2014). The Markov chain analysis is one of the most widely used stochastic approaches in ecological and environmental modeling (Paegelow and Camacho 2008).

Linear regression was used to compare the results of the Markov chain data, i.e. an approach which uses the historical relationship between a dependent variable and one or more independent variables (the year and the population) to predict the future values of the dependent variable, in this case urban areas. The multiple linear statistical regression was used for simulation of the built-up area using the Enter method to enter all variables for the year 2023 at the same time on the basis of the urban area in 1972, 1982, 1990, 2002, 2013 and 2014. The growth rate and other statistics were calculated using Microsoft Excel.

3.2.3 Land change simulation: The scenario

The five scenarios are simulated in a single model to predict the likely urban area in 2023. The LCM model uses an a priori identical Multi-Objective Land Allocation (MOLA) to solve the concurrences between different uses or transitions, in which the MOLA works only once. This process is based on the choice of the most suitable pixels, i.e., those with the greatest change potential in the change potential maps (ranked from high to low). Through the Markov matrix, the MOLA creates a list of host classes (categories that will lose area, in rows) and claimant classes (categories that will gain area, in columns) for each host. The land allocation process is conducted for all the claimant classes in each host class. In this way it solves the conflicts based on a minimum-distance-to-ideal-point rule using the weighted ranks, and the final result is the overlay of each host class reallocation (Eastman et al. 1995, Mas et al. 2014).

4 Results

4.1 Land change analysis of chronological series of LUC maps

The results showed a drastic change in land cover and the growth of the urban area between 1972 and 2014, as shown in Figure 3, when many agricultural areas were urbanized. This has happened in a largely unplanned, somewhat chaotic fashion, so revealing the need for land-use managers and city planners to understand future growth and plan further developments. Over this period urban areas have grown continuously, whereas non-urban (agricultural) areas have shrunk at similar rates, as shown in Table 3.

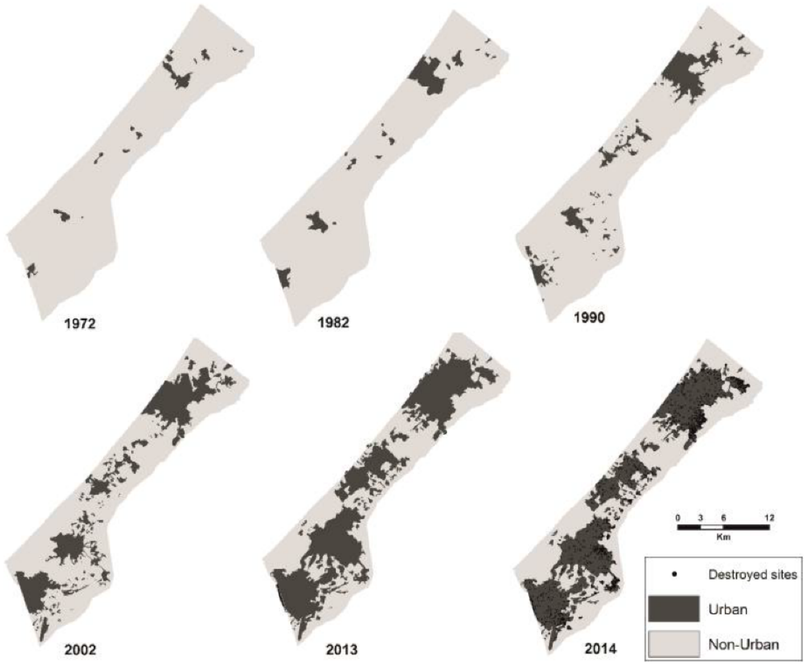


Fig. 3. Urban areas from 1972 to 2014.

Table 3. Urban and Non-Urban areas from 1972 to 2014.

Year	Urban Km²	Urban %	Non-Urban Km²	Non-Urban %
1972	10.94	3.00	349.06	96.96
1982	25.29	7.00	334.71	92.98
1990	46.88	12.80	313.12	86.98
2002	100.23	27.40	259.77	72.16
2013	166.29	46.20	193.71	53.81
2014	164.80	45.78	195.20	54.22

4.2 Transition potential maps

The MLP Neural network was used to obtain the transition potential map for the transition from Non-Urban to Urban area, as shown in Figure 4A to Figure 4E, based on the real transition over the various calibration periods (1972, 1982, 1990, and 2002) to 2013, and (2002) to 2014. The high transition potential values are located around the built-up area with the biggest population density (low distance). Figure 4 shows the transition potential maps for the five scenarios.

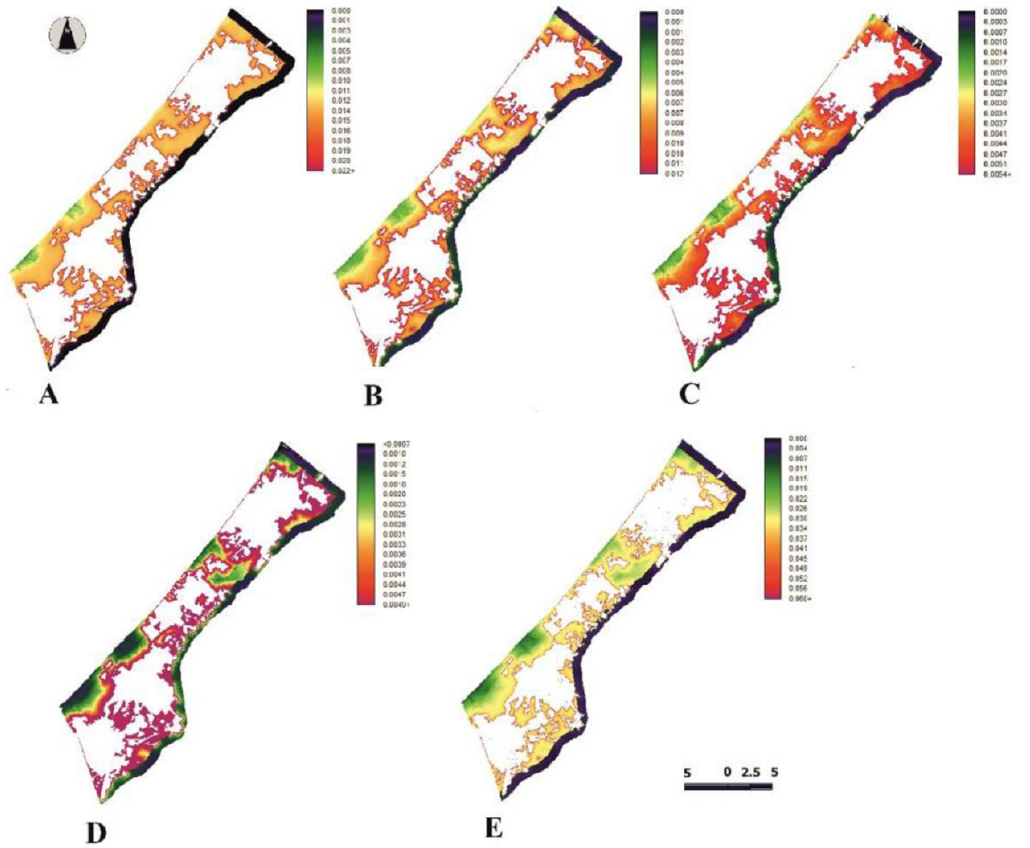
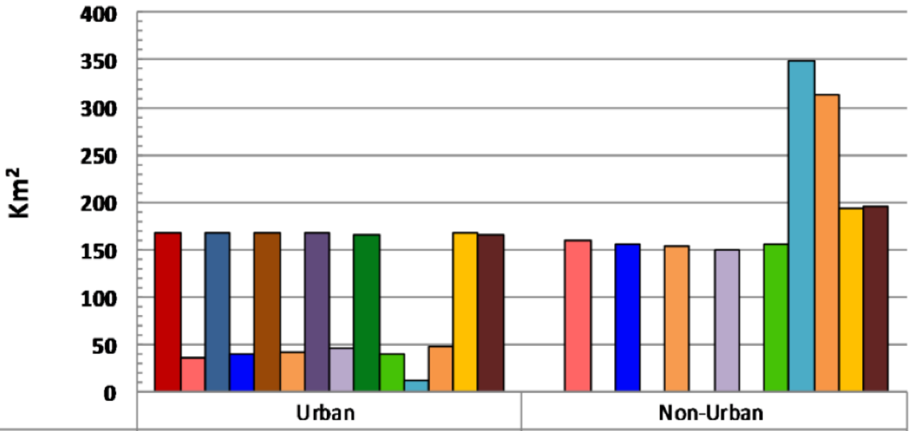


Fig. 4. MLP transition potential map from Non-Urban to Urban Area for LCM for a) (1972-2013), b) (1982-2013), c) (1990-2013), d) (2002-2013), e) (2002-2014).

4.3 The estimated quantities

The Markov transition area matrix (Figure 5) shows areas (Km²) in which a transition between two classes will have taken place by 2023. Rows represent land use in the calibration period in 2013 or 2014 and columns represent land use in the simulation year 2023, based on the five scenarios.



	Urban	Non-Urban
Urban 1972-2013	166.29	0
Non-Urban 1972-2013	36.09	158.56
Urban 1982-2013	166.29	0
Non-Urban 1982-2013	38.61	156.03
Urban 1990-2013	166.29	0
Non-Urban 1990-2013	40.67	153.97
Urban 2002-2013	166.29	0
Non-Urban 2002-2013	46.06	148.59
Urban 2002-2014	165.55	0
Non-Urban 2002-2014	39.18	155.86
1972	10.94	349.06
1990	46.88	313.12
2013	166.29	193.71
2014	164.80	195.20

Fig. 5. Transition area matrix for the estimation of urban areas in the five scenarios by the year 2023, and 1972, 1982, 1990, 2002, 2013 and 2014 in area (km²).

A multiple regression analysis shows the historical relationship between the urban area, the year and the population (independent variables) to project the future of the urban area for the year 2023, i.e. 240.79 km² , using the Enter method. The results of the stepwise method show that population growth has had a direct effect on urban expansion. The significant number is around zero and the urban area is 246.5 Km².

The adjusted R2 is therefore 0.98, meaning that predicted values statistically demonstrate a high ‘goodness of fit’. The stepwise regression equation can be expressed as follows:

$$Y = -1{,}016.667 + 0.501\mathbf{X_1} + 9.985*10^{-5}\mathbf{X_2}$$

The diagram in Figure 6 shows a comparison between six past trend scenarios. The first five scenarios are the Markov chains from (1972-2013), (1982-2013), (1990-2013), (2002-2013) and (2002-2014) to 2023; and the sixth one is the regression line to 2023 depending on the basic data using the Enter method, which gave areas of 202.35, 204.89, 206.95, 212.32, 204.70 and 240.79 Km², respectively.

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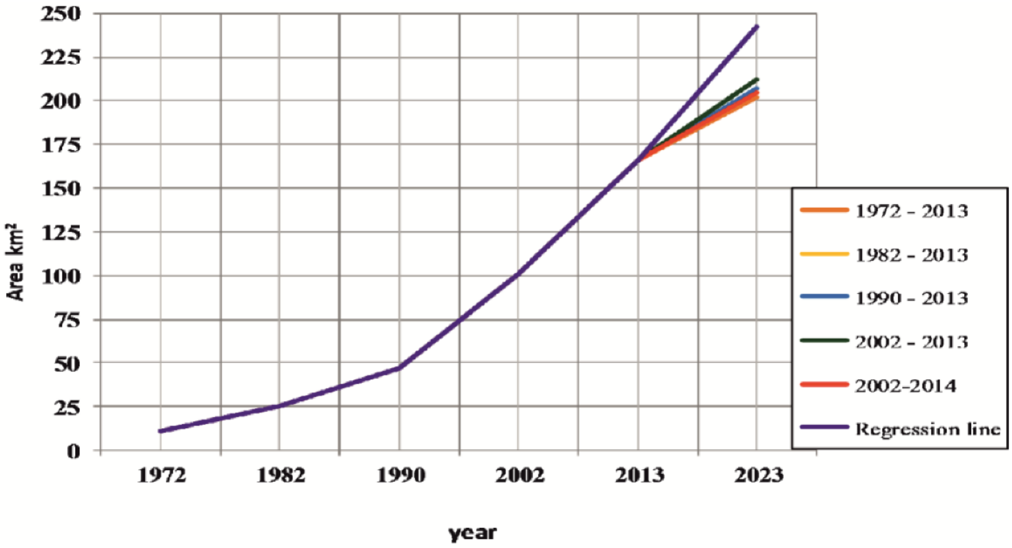

Fig. 6. The plot lines for Urban area in Km² from 1972 to 2023, Markov chain (1972-2013), Markov chain (1982-2013), Markov chain (1990-2013), Markov chain (2002-2013), Markov chain (2002-2014), and regression analysis.

4.4 Simulation maps: Scenario to 2023

The results of the simulation in the five scenarios varied according to the Markov chains, i.e. (1972-2013), (1982-2013), (1990-2013), (2002-2013) and (2002-2014) were 202.35, 204.89, 206.95, 212.32 and 204.70 km², respectively, as shown in Figure 7.

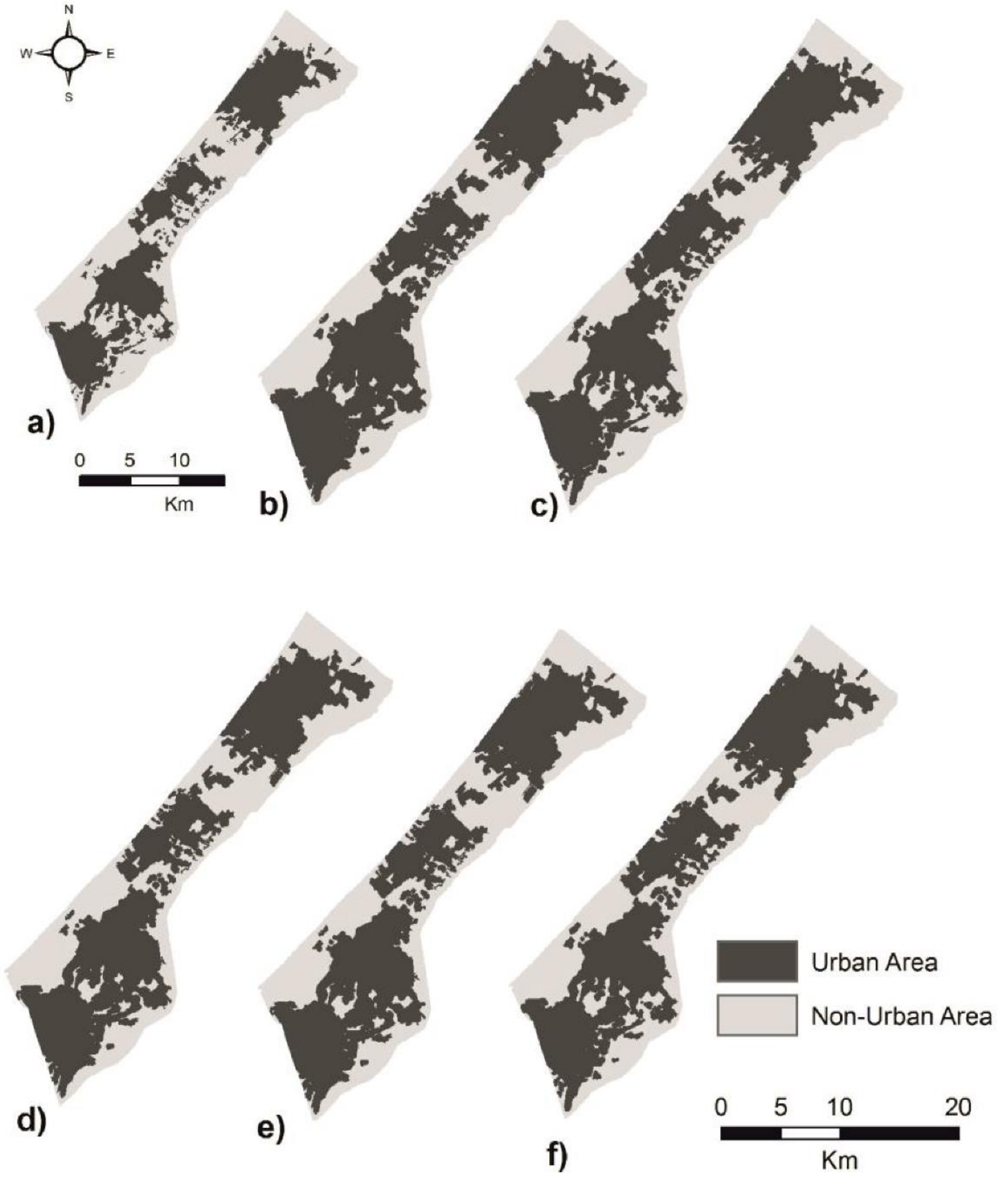

Fig. 7. a) Real map 2013 and simulated maps for the year 2023 as results of b) Scenario (1972-2013), c) Scenario (1982-2013), and d) Scenario (1990-2013), e) Scenario (2002-2013), f) Scenario (2002-2014).

The results of the simulation (individual results for each scenario and the average of all five) are presented in Figure 8 and Table 4, which show an increase in urban areas and a decrease in non-urban areas between 1972 and 2014. The predicted urban and non-urban areas for 2023 for the periods (1972 – 2013), (1982 – 2013), (1990 – 2013), (2002 – 2013), and (2002 -2014 after the war) are presented in Table 4.

Urban land use change analysis and modeling: a case study of the Gaza Strip 15

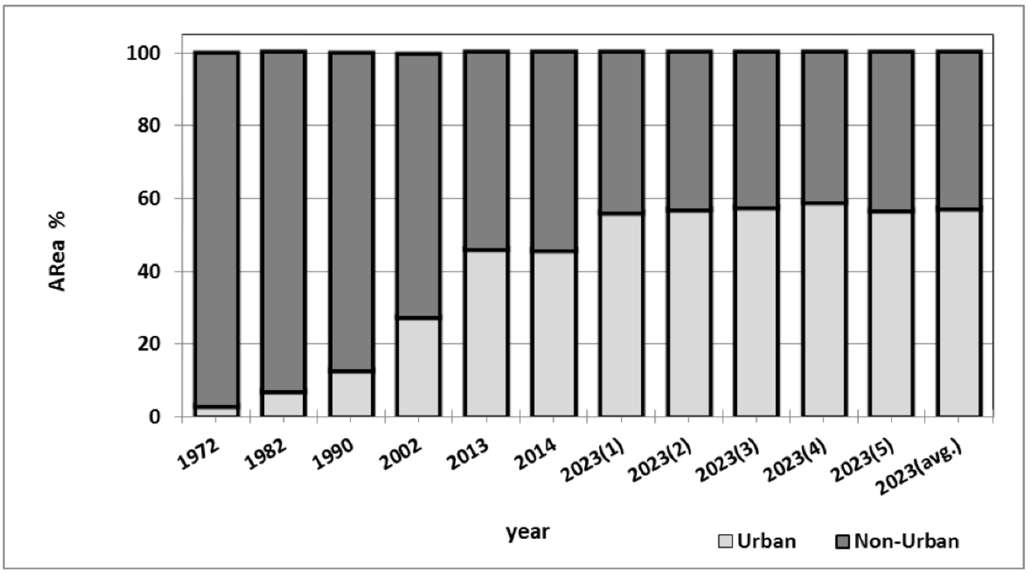

Fig. 8. Increase in urban areas and decrease in non-urban areas from 1972 to 2023.

Table 4. Area and percentage of urban and non-urban areas in all scenarios.

Scenario	Year	Urban Km²	Urban %	Non-Urban Km²	Non-Urban %
1972- 2013	2023(1)	202.37	56.21	157.63	43.79
1982-2013	2023(2)	204.89	56.91	155.11	43.09
1990-2013	2023(3)	206.95	57.49	153.05	42.51
2002-2013	2023(4)	212.34	58.98	147.66	41.02
2002-2014	2023(5)	204.70	56.86	155.30	43.14
Average	2023(avg.)	206.25	57.29	153.75	42.71

5 Discussion

The overall results of the five LCM scenarios analyze and simulate land-use changes in the Gaza Strip. The results of the past trend scenarios for spatial distribution per area in 2023 presented both differences and similarities in the allocation of urban area. We discovered an inverse relationship between the predicted area by 2023 and the length of the calibration period, in that the longer the calibration period the smaller the growth in urban area predicted. The urban areas for 2023 predicted by the calibration periods (1972-2013), (1982-2013), (1990-2013) and (2002-2013) were 202.35 km², 204.89 km², 206.95 km² and 212.32 km². The calibration period (2002-2014), which showed an increase in urban area to 204.7 km² by 2023, is slightly exceptional due to the fact that it includes the 2014 War.

The results for calibration periods 2002-2013 and 2002-2014 have a high "goodness of fit", because they both obtained values close to the regression analysis value (240.79) used to measure statistical best fit values, while the values for the other scenarios were substantially further away from the regression analysis value.

As a percentage of the total area of the Gaza Strip, the scenarios predict that between 56.21 and 58.98% will be urbanized by 2023. The data analysis shows an increase in the urban area from 10.9 (1972) to 25.3 (1982), 46.9 (1990), 100.2 (2002), 166.3 (2013) and 206.24 km² in 2023, the average area predicted by the various simulations for the whole Gaza Strip (i.e. around 57.13% of the total). While the decrease in Agricultural areas (Non-Urban Area) was caused by an increase in population growth rate and a lack of management and future planning.

Figure 9 illustrates the increase in the rate of growth in urban area as a percentage of the total area of the Gaza Strip for each time period (1972-1982), (1983-1990), (1991-2002), (2003-2013), 2014 and (2015-2023), with rates of 0.40, 0.7584, 1.35, 1.83, -0.39 and 1.44% from 1972 to 2023, which implies a positive relationship with the rate of population growth.

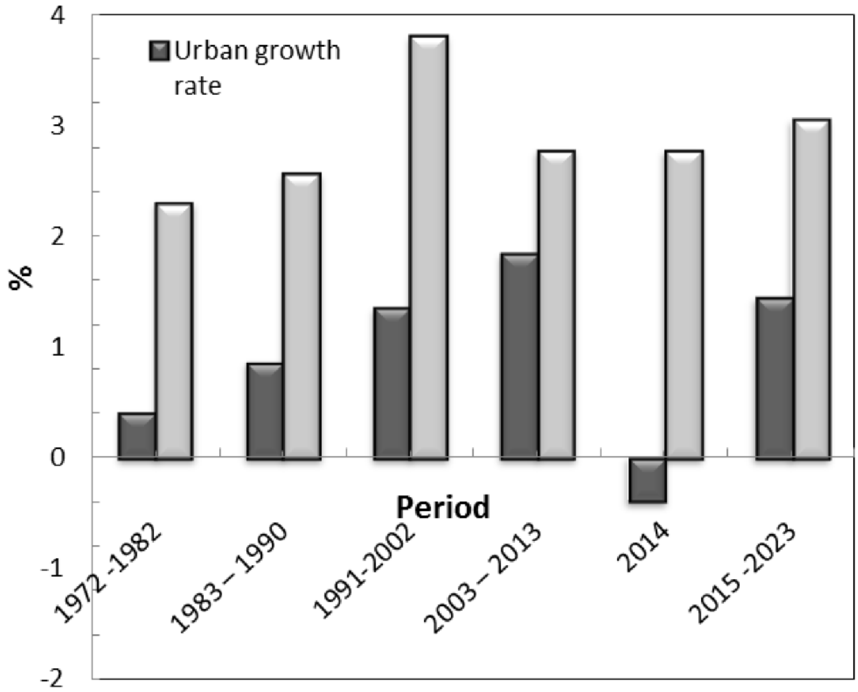

Fig. 9. Population and urban growth rates for the different periods, from 1972 to 2023.

The population density for the whole of the Gaza Strip will therefore have increased from 4,661.5 inhabitants per km² in 2013 to 6,704.3 inhabitants per km² in 2023. However, in the urban areas the increase will be from 10,231.1 inhabitants per km² in 2013 to 11,865.1 inhabitants per km² in 2023. Table 5 shows that urban expansion is positively correlated with population growth in the Gaza Strip, which already has one of the highest population densities in the world.

Table 5. Increase in Urban Area, Population Number and Population Density from 1972 to 2023

Year	Population No.	Area (km²)	% Area	Population Density No./area	Actual Pop. Density
1972	393,800	10.9	3	1,078.9	36,128.4
1982	511,115	25.3	7	1,400.3	20,202.2
1990	642,814	46.9	12.8	1,761.1	13,706.1
2002	1,182,908	100.2	27.4	3,240.8	11,805.5
2013	1,701,437	166.3	46.2	4661.5	10231.1
2014	1,760,037	164.80	45.78	4822.0	10679.84
2023	2,447,054	206.24	57.13	6704.3	11865.1

The Palestinian economy in the Gaza strip grew in line with the Israeli economy over the period from 1972 to 2000. There was a dramatic rise in the Palestinian standard of living from 1972 until the eruption of the first Intifada (uprising) in 1987. The main reason for improved living standards was the opening of the rapidly expanding Israeli job market to Palestinian workers (Swirski 2008). The situation continued until the signing of the 1993 Oslo Accords. From 1994 to 2000 there were huge urban projects and a great deal of investment leading to urban expansion (Abuelaish and Camacho 2016).

Many of the Palestinian workers in Israel, considered the mainstay of the Palestinian economy have been unemployed since the conflicts in 2000. In 2007 an economic blockade was started around the Gaza Strip, which for a short period prevented urban expansion from continuing at the same rate as before. From 1972 to 1994 urbanization was more vertical than horizontal, a situation that was reversed thereafter (Abuelaish and Camacho 2016).

Effects of the 2104 War

According to the Ministry of Public Works and Housing (MOPWH), an estimated 2,000 tons of cement for residential construction purposes enter the Gaza Strip daily. This would give a monthly figure of around 44,000 tons. Ground floors require about 0.54 tons of cement per m2, while all other floors require 0.21 ton/m²; the average area of buildings in the Gaza Strip is 150m². Of the 11,000 housing units destroyed during the war, 5,990 had ground floors, and there were 5,189 on other floors. Hence, 648,643.5 tons of cement would be required for reconstructing all the destroyed housing units. At the current supply rate of 44,000 tons a month, reconstruction would therefore take 15 months. This is an ideal scenario in which allowing cement to enter the country and receiving funds to rebuild the residential housing units are essential factors.

According to the temporary agreement for the Gaza Reconstruction Mechanism (GRM) in Shelter Cluster Palestine (February, 2016), 1,107,519 tons of cement have entered the Gaza Strip since October 2014. Around 44% has been used for residential purposes, i.e. 487,308.36 tons. This is enough cement to rebuild 6,016 ground-floor apartments or 15,470 apartments above ground-floor level.

Table 6 shows the completed housing units, those in progress, funded, and awaiting funds from donors as of February 2016, according to Shelter Cluster Palestine. Around 83% of the destroyed housing units are still awaiting funds from donors, which means that a significant amount of the cement must be being used to build new housing units in different places. These construction materials are not only being used to reconstruct destroyed buildings but also to cover normal urban growth and supply building companies everywhere. The black market is playing a major role in selling cement outside the GRM as a result of shortages in the system. This has allowed people to build new houses without a license. Since the war, people prefer to buy housing units in the center of urban areas and to live in apartment buildings. This is because town centers are considered safer and new building on urban land with planning permission tends to be very expensive.

Table 6. Repairs and reconstruction of the housing units damaged and destroyed during the 2014 War.

	# Units*	Completed	In progress	Funded	Gap
Totally destroyed	11,000	937	591	3,479	5,993
Severe damage	6,800	2,034	3,027	1,097	642
Major damage	5,700	119	1,075	1,747	2,759
Minor damage	147,500	69,428	9,936	10,060	58,076

Source: Shelter Cluster Palestine (February, 2016)

According to the 2007 Census, there were 241,873 housing units in the Gaza Strip, and according to the projected number of households and housing units in the Gaza Strip using the hypothesis of average number of households per year (PCBS 2009), about 15,529 housing units were required in 2015 and 16,284 in 2016. The amount of cement that entered the Gaza Strip in the previous period was enough for normal urban growth but there were problems for reconstructing the destroyed buildings due to a shortage of donor finance. Around 10-15% of the destroyed housing units were reconstructed in the 15 months between September 2014 and February 2016. International donors at the Cairo Donor Conference on 12th October 2014 pledged over USD 5.4 billion to support the plan to rebuild the Gaza Strip.

Reconstruction of the Gaza Strip is a priority for the Palestinian Authority, and all the destroyed buildings during war 2014 are entitled to financial support. The reconstruction efforts however depend on financial support from the donors, and also on Israel allowing construction materials to enter the Gaza Strip. Since the shortage of building materials due to the blockade affects both reconstruction efforts and natural urban growth, if the blockade ended, the Gaza Strip would return to its previous natural urban growth rate. The fact is however that there is no guarantee that Israel will not repeat past behavior and launch new wars on the Gaza Strip, and there is no expectation of the economic blockade coming to an end soon.

This study tries to answer questions about the future of the Gaza Strip and the impacts on its environment. This information is useful for decision-makers and politicians, who are regularly faced with questions about the complicated situation in the Gaza Strip as a result of its weak economic resources, and the lack of donor support from countries concerned by other conflicts such as in Syria. Most of the houses destroyed during the war belong to poor people who are waiting for financial support to rebuild their houses. Many urban areas were destroyed during the war and their reconstruction would be harder without modeling exercises such as the one presented here.

6 Conclusions

This paper presents, analyses, evaluates, and simulates urban expansion for the years 1972 to 2014 to 2023, using the historical free Landsat data and the free UNITAR/UNOSAT Geodatabase for the areas attacked during the 2014 war. These simulations are based on the continuity of observed past trends and are not exact predictions. Instead they are plausible scenarios of a future state assuming the maintenance of macro-political and social conditions.

The following conclusions were drawn from the results of this research in which we performed a simulation of urban growth in the Gaza Strip for the year 2023 using five scenarios and the Land Change Modeler:

- Around 57.13% of the Gaza Strip will be urban land.
- Around 10-15% of the buildings and infrastructure damaged during the war had been rebuilt and returned to their previous state of natural growth by February 2016.
- The amount of building materials entering the Gaza Strip must be increased and additional support must be given to the people who lost their houses during the 2014 War.
- There is an inverse relationship between the predicted urban area for 2023 and the length of the calibration period.
- Urbanization in the Gaza Strip is increasing dramatically because of natural population growth. This is placing more stress on agricultural areas, causing soil erosion and impairing water quality and quantity.
- Urban planners should take into account that in the near future the three main urban areas will merge into one.
- Urban sprawl increases over time at the expense of agricultural land, above all due to an increase in population.

- The reduction in agricultural land in the Gaza Strip and the pressure placed on natural resources will contribute to local and global climate change.

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PART III. Results and Discussion: Land Change impact on the environment

7. Assessment of aquifer vulnerability to contamination in Khanyounis Governorate, Gaza Strip—Palestine, using the DRASTIC model within GIS environment

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ORIGINAL PAPER

Assessment of aquifer vulnerability to contamination in Khanyounis Governorate, Gaza Strip—Palestine, using the DRASTIC model within GIS environment

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Abstract Groundwater is a very important natural resource in Khanyounis Governorate (the study area) for water supply and development. Historically, the exploitation of aquifers in Khanyounis Governorate has been undertaken without proper concern for environmental impact. In view of the importance of quality groundwater, it might be expected that aquifer protection to prevent groundwater quality deterioration would have received due attention. In the long term, however, protection of groundwater resources is of direct practical importance because, once pollution of groundwater has been allowed to occur, the scale and persistence of such pollution makes restoration technically difficult and costly. In order to maintain basin aquifer as a source of water for the area, it is necessary to find out, whether certain locations in this groundwater basin are susceptible to receive and transmit contamination. This study aims to: (1) assess the vulnerability of the aquifer to contamination in Khanyounis governorate, (2) find out the groundwater vulnerable zones to contamination in the aquifer of the study area, and (3) provide a spatial analysis of the parameters and conditions under which groundwater may become contaminate. To achieve that, DRASTIC model within geographic information system (GIS) environment was applied. The model uses seven environmental parameters: depth of water table, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity to evaluate aquifer vulnerability. Based on this model and by using ArcGIS 9.3 software, an attempt was made to create vulnerability maps for the study area. According to the DRASTIC model index, the study has shown that in the western part of the study area the vulnerability to contamination ranges between high and very high due to the relatively shallow water table with moderate to high recharge potential, and permeable soils. To the east of the previous part and in the south-eastern part, vulnerability to contamination is moderate. In the central and the eastern part, vulnerability to contamination is low due to depth of water table. Vulnerability analysis of the DRASTIC Model indicates that the highest risk of contamination of groundwater in the study area originates from the soil media. The impact of vadose zone, depth to water level, and hydraulic conductivity imply moderate risks of contamination, while net recharge, aquifer media, and topography impose a low risk of aquifer contamination. The coefficient of variation indicates that a high contribution to the variation of vulnerability index is made by the topography. Moderate contribution is made by the depth to water level, and net recharge, while impact of vadose zone, hydraulic conductivity, soil media, and Aquifer media are the least variable parameters. The low variability of the parameters implies a smaller contribution to the variation of the vulnerability index across the study area. Moreover, the "effective" weights of the DRASTIC parameters obtained in this study exhibited some deviation from that of the "theoretical" weights. Soil media and the impact of vadose zone were the most effective parameters in the vulnerability assessment because their mean "effective" weights were higher than their respective "theoretical" weights. The depth of water table showed that both "effective" and "theoretical" weights were equal. The rest of the parameters

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exhibit lower "effective" weights compared with the "theoretical" weights. This explains the importance of soil media and vadose layers in the DRASTIC model. Therefore, it is important to get the accurate and detailed information of these two specific parameters. The GIS technique has provided an efficient environment for analysis and high capabilities of handling large spatial data. Considering these results, DRASTIC model highlights as a useful tool that can be used by national authorities and decision makers especially in the agricultural areas applying chemicals and pesticides which are most likely to contaminate groundwater resources.

Keywords Groundwater vulnerability · Contamination · DRASTIC model · GIS · Khanyounis Governorate

Introduction

Groundwater is a very important source for water supply and development in Gaza Strip, and in Khanyounis Governorate in particular. The quality of groundwater plays an important role in the water scarcity regions, especially for drinking water supply. Therefore, it needs to be protected from the increasing threats of surface contamination, where the quality of groundwater is generally under a considerable potential of contamination especially in agriculture-dominated areas with intense activities that involve the use of fertilizers and pesticides (Lake et al. 2003; Thapinta and Hudak 2003; Chae et al. 2004).

The growth of Khanyounis population has doubled about four times since 1960s. Therefore, the demand of safe drinking water is increasing, while the average domestic water consumption is less than 25 m^2 per capita per year, which is one of the lowest rates in the world (Al Hallaq 2002). The intensive utilization of aquifers has changed the groundwater chemical quality. Vulnerability maps became an essential tool for groundwater protection and environmental management (Vias et al. 2005). These maps could be used for activities such as land use planning, decision making, groundwater resources management, and groundwater quality monitoring (Samey et al. 2008). Maps of aquifer vulnerability to contamination are becoming more in demand because of (a) groundwater represents the main source of drinking water and (b) concentrations of human/economic activities, e.g., industrial, agricultural, and domestic represent real or potential sources of groundwater contamination (Rahman 2008).

The concept of groundwater vulnerability to contamination is based on the assumption that the physical environment may provide some degree of protection to groundwater against natural and human impacts with respect to contaminants entering the subsurface environment. Consequently, some land areas are more vulnerable to groundwater contamination than others (Baalousha 2006; Napolitano and Fabbri 1996). In 1968, Margat was the first one to use the term vulnerability in hydrogeology, and thereafter the concept was adopted worldwide. He used the term "vulnerability" to mean the degree of protection that the natural environment provides against the ingress of pollutants to groundwater (Albinet and Margat 1970). Up to date, several propositions have been given by scientists to define groundwater vulnerability, many are quite similar, however, there is no recognized and accepted common definition that has been developed.

Another studies showed that the concept of groundwater vulnerability is a cornerstone in the evaluation of the risk of groundwater contamination and in the development of management options to preserve the quality of groundwater (Fobe and Goossens 1990; Worrall et al. 2002; Worrall and Besien 2005). Vulnerability assessment has been recognized for its ability to delineate areas that are more likely than others to become contaminated as a result of anthropogenic activities at/or near the earth's surface (Babiker et al. 2005). Groundwater vulnerability to contamination might be defined based on the conclusion and recommendation of the international conference on "Vulnerability of Soil and Groundwater to Pollution", held in 1987, as "The sensitivity of groundwater quality to an imposed contaminant load, which is determined by the intrinsic characteristics of the aquifer" (Van Duijvenbooden and van Waegening 1987). According to National Research Council (NRC), groundwater vulnerability to contamination is the tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some locations above the uppermost aquifer (NRC 1993). Shukla and others suggest that "All groundwater is vulnerable." This is a relative property rather than an absolute measure. The probability of contamination is a function of time and therefore the potential for contamination of groundwater resources must be inferred from surrogate data that is quantifiable (e.g., chemical and physical factors affecting the leaching potential of contaminants; Shukla et al. 1998). Groundwater is most vulnerable where it is present in significant quantities and regularly recharged. Therefore, rock units that have high permeability and porosity are more at risk than those with negligible permeability and porosity. This is the basis on which groundwater vulnerability maps are generally constructed. (NRC 1993). Piscopo suggest that the fundamental concept of groundwater vulnerability is that some land areas are more vulnerable to groundwater contamination than others (Piscopo 2001). Vibra and Zoporozec defined groundwater vulnerability as the possibility of percolation and diffusion of contaminants from the ground surface into the groundwater system. Vulnerability is usually considered as an intrinsic property of a groundwater system that depends on its sensitivity to human and/or natural impacts. Specific or integrated vulnerability, on the other hand, combines intrinsic vulnerability with the risk of the groundwater being exposed to the loading of pollutants from certain sources (Vrba and Zaporozec 1994). As can be inferred from the above definition and studies, groundwater vulnerability is not an absolute or measurable property, but an indication of the relative possibility with which contamination of groundwater resources will occur. This understanding implies a very basic vulnerability concept that all groundwater is vulnerable.

The assessment of groundwater vulnerability has been undertaken in case studies that have reflected wide ranging circumstances. The global concern for evaluating the conditions under which groundwater may become contaminated is apparent by numerous investigations that include: a study of Kaçaroglu (1999) which titled “review groundwater pollution and protection in Karst areas.” This study concluded to that protection measures are required to preserve the quality and quantity of karst groundwater that specifically consider the vulnerability of the karst environment. In order to preserve karst groundwater, the geological, hydrological and hydrogeological characteristics of the karst area must be investigated and information on polluting activities and sources must be collected.

A study of Ibe et al. (2001), “Assessment of Ground Water Vulnerability and Its Application to the Development of Protection Strategy for the Water Supply Aquifer in Owerri, Southeastern Nigeria”, showed that the Owerri metropolis and the southwest area of Owerri have high vulnerability, indicating groundwater pollution.

Similar studies have been conducted by Thirumalaivasan et al. (2003) in India. This study indicated that all wells in low and high vulnerability category have concentrations of nitrates less than 10 ppm and more than 10 ppm, respectively. The results of the study have shown strong relationship between DRASTIC Specific Vulnerability Index and nitrate concentrations with a correlation coefficient of 0.84 at 0.01 level.

Another study conducted in Mexico by Tovar and Rodriguez (2004) in Mexico. It concluded that the main potential sources of aquifer pollution were included in the territorial ordering analysis. The vulnerability tendencies and land uses were analyzed. The urban expansion tendencies were revised taking into account the aquifer vulnerability zoning. Vulnerability areas were restricted for urban development.

A study of Vias et al. (2005) in Spain shows the results of a comparative study involving application of the vulnerability mapping methods known as AVI, GOD, DRASTIC, and EPIK to a pilot carbonate massif in southern Spain, namely the Torremolinos aquifer. The main objectives of the study were to determine which methods are most suitable for diffuse flow carbonate aquifers such as in southern Spain, and to evaluate variations in the degree of vulnerability associated to the rainfall variations that normally occur in a Mediterranean climate. According to three of the above methods, the aquifer is moderately vulnerable, but the AVI method evaluated it as highly vulnerable—this, however, is improbable.

In the United States, examples of groundwater vulnerability studies accomplished under varying groundwater vulnerability conditions include Evans and Myers (1990) in Delaware, Runquist et al. (1991) in Nebraska, Hatchitt and Maddox (1993) in Florida, Merchant (1994) in Kansas, Loague and Corwin (1998) in California, Wade et al. (1998) in North Carolina, and Fritch et al. (2000) in Texas.

Many approaches have been developed to evaluate aquifer vulnerability. They include process based methods, statistical methods, and overlay and index methods (Tesoriero et al. 1998)

This study aims to: (1) assess the vulnerability of the aquifer to contamination in Khanyounis governorate, (2) find out the groundwater vulnerable zones to contamination in the aquifer of the study area, and (3) provide a spatial analysis of the parameters and conditions under which groundwater may become contaminated by applying the DRASTIC model within geographic information system (GIS) environment. In this study an attempt was made to create a vulnerability map for Khanyounis Governorate area in Gaza Strip, Palestine, based on DRASTIC model.

Materials and methods

DRASTIC model

DRASTIC model of groundwater vulnerability falls into the category of overlay and an index method, which is one of the most commonly used categorical rating methods and was among the earliest used methods. It was developed by US Environmental Protection Agency (US EPA) as a standardized system for evaluating groundwater pollution potential due to hydrogeologic setting (Aller et al. 1987; US EPA 1993; Vrba and Zaporozec 1994). The DRASTIC model is used to prepare a vulnerability map for the area of study. The name DRASTIC is taken from initial letters of seven environmental parameters, used to evaluate intrinsic vulnerability of aquifer systems. These seven parameters are: (Aller et al. 1987; Babiker et al. 2005; and Baalousha 2010).

- Depth (D) to water table: the more depth to water, the lesser the chance for the contaminant to reach it as compared with shallow water table.

- Net (R) recharge: it represents the total quantity of water that reaches the water table. It is the process through which the contaminants are transported to the aquifer. The more the recharge is, the more vulnerable the aquifer is (Aller et al. 1987).
- Aquifer (A) media (geology): it reflects the attenuation characteristic of the aquifer material reflecting the mobility of the contaminants through the aquifer material. For example, the larger the grain size is and more fractures or openings within the aquifer are, the higher the permeability, and thus vulnerability of the aquifer.
- Soil (S) media (texture): soil of different types have differing water holding capacity and influence the travel time of the contaminants.
- Topography (T; slope): it refers to the slope of the land surface. High degree of slope increase runoff and erosion which is composed of the contaminants.
- Impact (I) of vadose zone: it is the unsaturated zone above the water table. It reflects the texture of the vadose zone. The texture determines the time of travel of the contaminants through it.
- Hydraulic conductivity (C): refers to the ability of an aquifer to transmit water. With a higher hydraulic conductivity, there exists a greater potential for contamination because contaminants can move easily through the aquifer.

This model produces a numerical value called DRASTIC INDEX which is derived from the rating and weights assigned to the parameters used in the model. Using the seven DRASTIC parameters (Table 1), a numerical ranking system of weights, ranges, and ratings has been devised to evaluate the potential of groundwater contamination (Aller et al. 1987).

Weights A relative parameter value ranging from 1 to 5, where one represents the least significant factor and five represents the most significant factor. DRASTIC model assumes that all the contaminants move vertically downwards with the water and are introduced at the soil surface. A combination of variable weights has been evaluated and based on the results obtained a specific weight has been assigned to each DRASTIC parameter on the basis that each weight determines the relative significance with respect to pollution potential (Table 1).

- ***Ranges:*** each of the DRASTIC parameters has been divided into either ranges or significant media types that have an impact on contamination potential.
- ***Ratings:*** each of the DRASTIC parameters is assigned a rating from 1 to 10 based on a range of values, and based on its relative effect on the aquifer vulnerability (Almasri 2008). Ratings are taken from USPEA 1993 since the ratings depend on the physical character of the parameters which are more or less constant.

Determination of the DRASTIC INDEX value (pollution potential) for a given area involves multiplying each factor rating by its weight and adding together the resulting values. The total impact factor score of the DRASTIC INDEX can be calculated as: (Aller et al. 1987; Hammouri and El-Naqa 2008).

$$\text{DRASTIC Index} = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w$$

where: D, R, A, S, T, I, and C are the seven hydrogeologic parameters; r is the rating for the area being evaluated (1–10); w is theimportance weight for the factor (1–5). The resulting DRASTIC index represents a relative measure of groundwater vulnerability. The higher the DRASTIC index means the greater the vulnerability of the aquifer to contamination. A site with a low DRASTIC index is not free from groundwater contamination, but it is less susceptible to contamination compared with the sites with high DRASTIC indices. The DRASTIC index can be converted into qualitative risk categories of low, moderate, high, and very high.

Table 1 Weights of DRASTIC parameters

Parameters	DRASTIC weight
Depth to water table	5
Net recharge	4
Aquifer media	3
Soil media	2
Topography	1
Impact of vadose zone	5
Hydraulic conductivity	3

Source: (Aller et al. 1987)

The study area

Khanyounis Governorate is a part of the Gaza Strip, located in the south of the Gaza Strip, (Fig. 1), bound by Deir al Balah to the north (9 km distance between Khan Younis and Deir al Balah cities) and Rafah in the south (9 km distance between Khanyounis and Rafah cities). It covers an area of about 111 km^2 (about 31% of the Gaza Strip total area). According to the Palestinian Central Bureau of Statistics (PCBS 2008), the population of Khanyounis in 2007 was 270,979 inhabitants (about 19.1% of the Gaza Strip total population).

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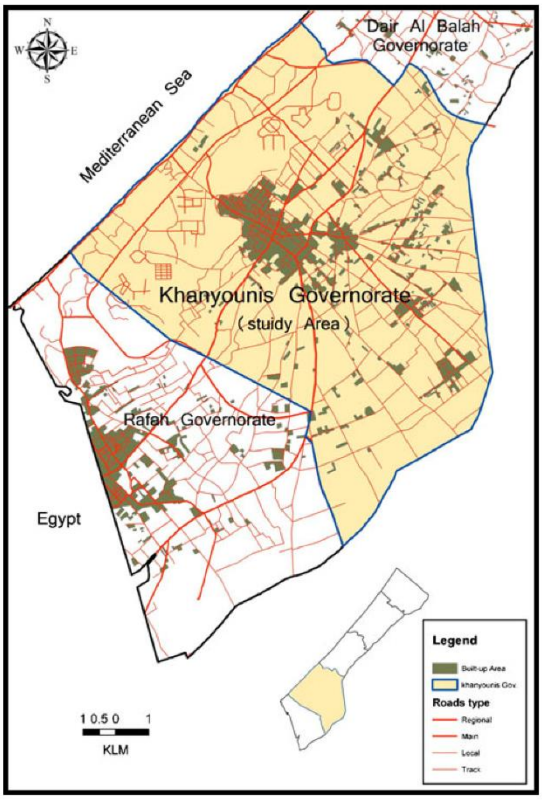

Fig. 1 Location map of Khanyounis Governorate (the study area)

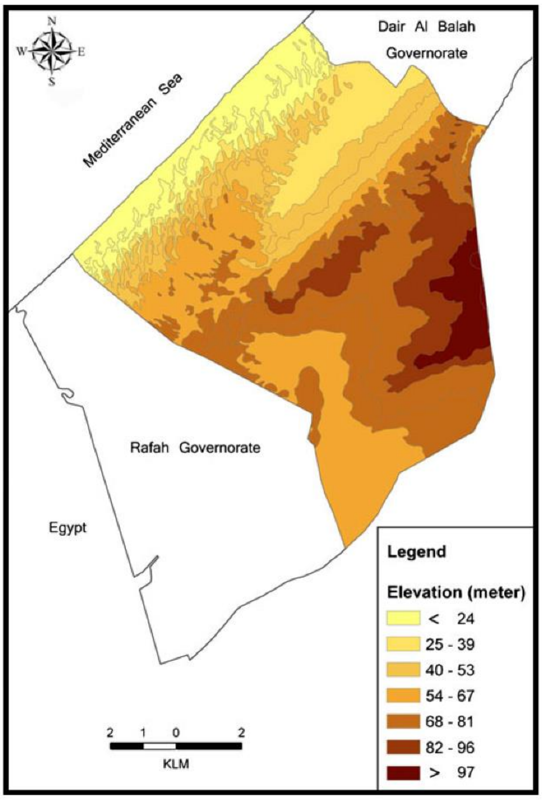

Fig. 2 Topography of the study area

The built-up area occupies an area of about 17.57 km^2, while the agricultural lands cover an area of about 63 km^2. The area is generally flat with topographic elevation ranging from mean sea level (MSL) in the west to about 100 m above MSL in the east (Fig. 2). The annual average rainfall in the Governorate is more than 300 mm. There is a 5 months period in winter (November–March) with a rainfall surplus. On an average there are less than 30 rainy days in the year. The rest of the year, evaporation greatly exceeds the rainfall.

The aquifer of Khanyounis is a part of the Gaza Strip Pleistocene coastal aquifer. Its average thickness ranges from 60 m in the east to about 140 m at the coastline (Fig. 3). The aquifer is mainly composed of gravel, calcareous sandstone, clay and unconsolidated sands (sand dunes). Near the coast, coastal clays extend about 2–4 km inland, and divide the aquifer sequence into three sub-aquifers (A, B, and C). Towards the east, the clay pinch out and the aquifer is largely unconfined (Palestinian Water Authority (PWA) 2001). In fact, the natural conditions (Unconfined condition and shallow water table near the coast) allow the entry of contaminants through the surface. Thus, the groundwater vulnerability will be evaluated for the Pleistocene aquifer. This aquifer represents the most important water bearing formation.

Methodology and data

Groundwater vulnerability maps are designed to show areas of greatest potential for groundwater contamination on the basis of hydrogeologic and anthropogenic (human) factors. The maps are developed by using computer mapping hardware and any GIS package to combine data layers such as soils and depth of water table. Usually, groundwater vulnerability is determined by assigning point ratings to the individual data layers and then adding the point ratings together when those layers are combined into a vulnerability map. The seven maps needed for the DRASTIC model were prepared and built using available hydrogeological data with the help of ArcGIS 9.3. The methodology flow chart is shown in Fig. 4.

The required data were obtained from different sources, including the PWA, contour map for the study area,

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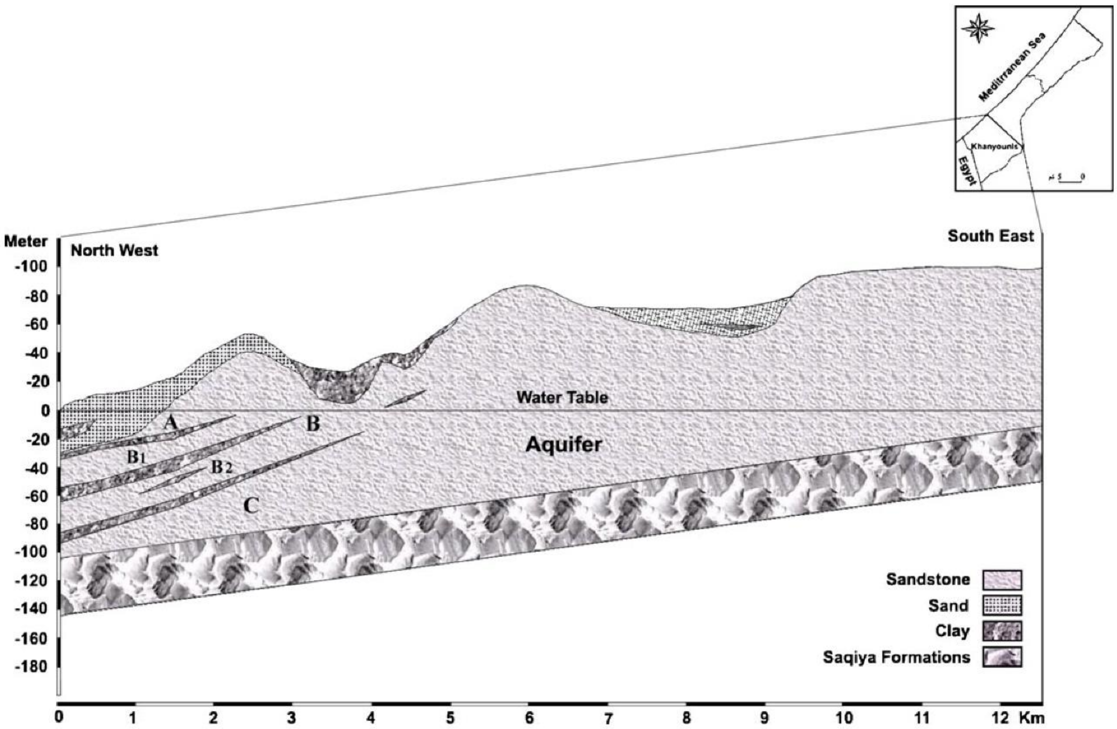

Fig. 3 Hydrogeological cross section of Khanyounis Governorate aquifer. Adapted from PWA (2001)

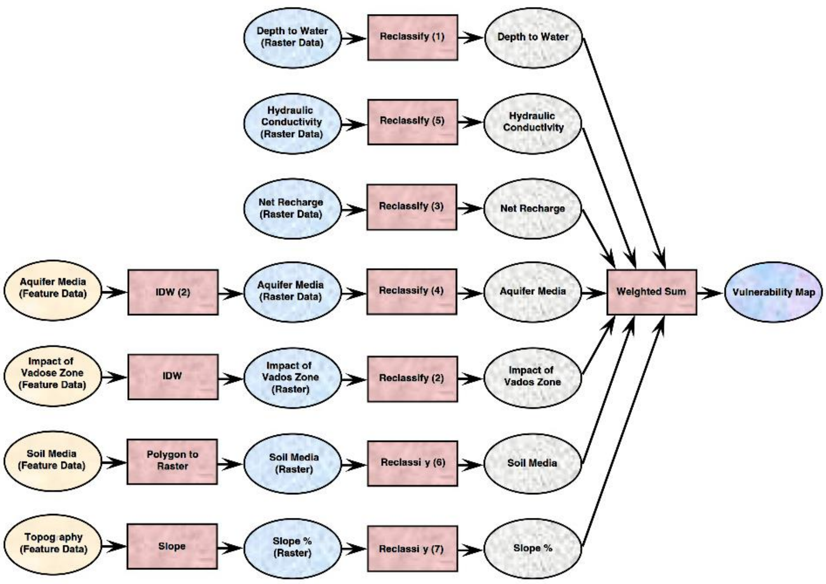

Fig. 4 Flow chart for groundwater vulnerability analysis using DRASTIC model in GIS

Ministry of Agriculture, and Ministry of Planning and International Cooperation.

Results and discussion

Depth to water table

Depth to water table is a significant parameter of the DRASTIC model controlling the ability of contaminants to reach the groundwater. A shallow depth to water table will lead to a higher vulnerability rating.

Depth to water data (for 199 drinking and agricultural water wells) was obtained from a summary of Palestinian hydrologic data report; vol. 2 Gaza (PWA 2000). Depth to water table in the study area varies between 3 m in the west to 96 m in the east. Range values of depth to water table are divided into ten levels from <12 m to a depth of >92 m (Table 2). Piezometric map of the Khanyounis Governorate was used to provide the depth to water map (Fig. 5).

The depth to water table index value (D_r D_w) ranges from a value of 5, representing the deepest and least vulnerable water level, to 50 where the water table is near the surface. Whereas the greatest percentage of wells (24.6%) falls within <12 m range and makes up about 15% of the total area, water that is from 63 to 72 m below the surface accounts for over 22% of the total area and the predominant depth to water index value (20) impacting the DRASTIC model. Overall, about 95% of the area has water levels less than 92 m. The deepest water levels, those over 92 m, make up the remaining 5% of the study area. The greatest depth to water values is predominantly found in the east of Khanyounis. In general, the aquifer potential protection increases with depth to water.

Table 2 Range, rating and weight for depth of water in Khanyounis aquifer

Range (m)	Percent of wells	Rating	Index	Area (%)
<12	24.62	10	50	14.89
13–22	1.51	9	45	3.88
23–32	11.06	8	40	3.35
33–42	11.06	7	35	9.49
43–52	11.06	6	30	4.96
53–62	14.57	5	25	8.79
63–72	10.05	4	20	22.18
73–82	9.05	3	15	15.41
83–92	5.53	2	10	12.19
>92	1.51	1	5	4.85

DRASTIC weight=5

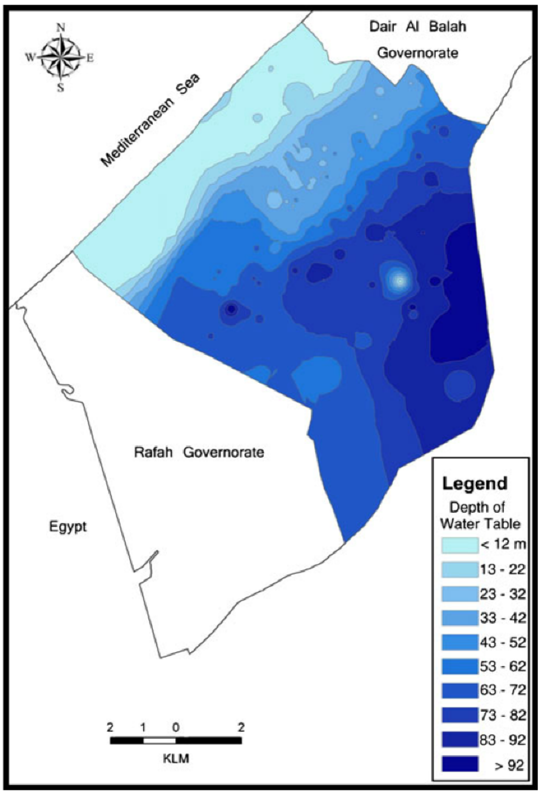

Fig. 5 Depth to water table map of the study area

Net recharge

Net recharge is the total amount of water reaching the land surface that infiltrates into the soil and then continues to percolate through the vadose zone (unsaturated zone) into the groundwater, measured in centimeters per year. Recharge represents the primary contaminant transport mechanism into the aquifer and depends on the soil characteristics. A sand or loamy sand will have the maximum infiltration capacity, while clay or clay loam may allow a very small amount of infiltration. The prevailing soils in the study area are sand, sandy loam and loamy sand.

The primary source of groundwater recharge in the study area is rainfall. Rainfall data is derived from Khanyounis climatic station with 27 years records (1980–2007), and were used for computing net recharge (Ministry of Agriculture 2008). The annual average rainfall of the study area is 310 mm/year.

According to the Isohyetal map of the study area, the average rate of rainfall varies in its value during this period from 295 mm/year in the South to 335 mm/year in the

North. Estimation of annual recharge was accomplished by using Williams and Kissel's equation (Jha and Sabastian 2005):

$$PI = (P - 10.28)^2/(P + 15.43) \text{for hydrologic soil gravel and sand}$$

$$PI = (P - 15.05)^2/(P + 22.57) \text{for hydrologic soil sandy loam and loamy sand}$$

where, PI is the percolation index, and P is the annual average rainfall.

According to the rainfall values, and by using previous equations, which allow for a minimum and maximum recharge value, the rate of recharge of the study area is ranging between 1.7 mm per year in the south of the study area and 8.8 mm per year in the north. Combining rainfall with soil permeability, rating values are created that are used to compute the recharge index value (R_r R_w) and show recharge variation over the study area using the above recharge equations. An ascending range and rating scale is devised from which an index value can be assigned. The net recharge index is weighted at a value of four. Table 3 and Fig. 6 illustrate the recharge values.

The areas of vulnerability for this parameter are identified by recharge index values (R_r R_w) from 4 to 40, representing the ranges of recharge vulnerability from lowest to highest respectively. The vulnerability index value 12 represents about 33% of the study area, distributed across all directions of the study area (Fig. 5). The higher and the lowest recharge values are mostly associated with soil type and with amount of rainfall. In general, the greater recharge, the greater the potential for groundwater contamination (Piscopo 2001). These higher recharge areas combined nearly, 25% of the total area.

Aquifer media

The aquifer media has been identified from available geological map and cross sections of the study area. The aquifer media refers to the portion of soil matrix capable to yield water in pores or to the saturated zone material properties. Therefore, the aquifer media affect the flow within aquifer which controls the rate of contaminant contact within the aquifer. The larger grain size and the higher porosity within the aquifer are the higher the permeability, and thus vulnerability of the aquifer. The aquifer media in the study area comprised mainly of unconsolidated formations such as sand, and consolidated rock such as sandstone (locally, sandstone is called Kurkar). According to DRASTIC standards, the rating of aquifer media in the study area varies between four for clay and sandstone, and five for sand, sandstone and clay (Table 4). The weight assigned for aquifer media is three.

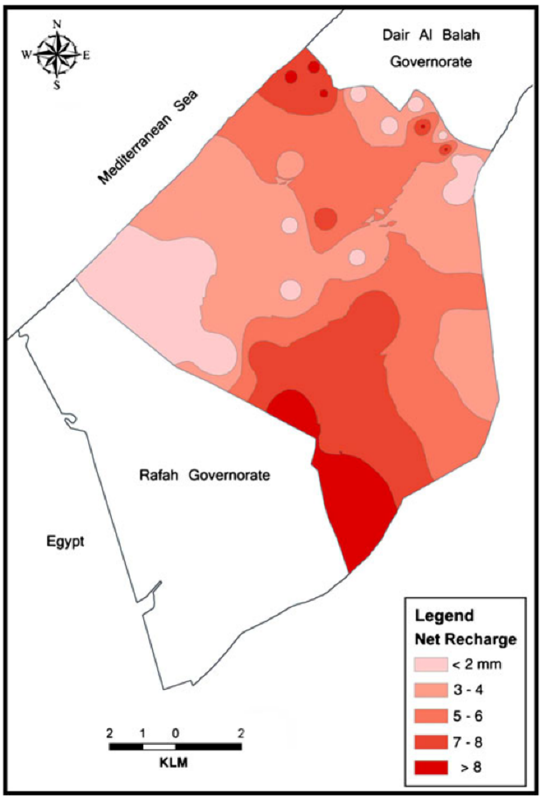

Fig. 6 Spatial distribution of net recharge rate (millimeters) of the study area

Table 3 Range, rating and weight for net recharge in Khanyounis governorate

Range (mm)	Rating	Index	Area (%)
<2	1	4	13.54
3–4	3	12	32.94
5–6	5	20	28.98
7–8	7	28	17.91
>8	10	40	6.63

DRASTIC weight=4

Table 4 Range, rating, and weight for aquifer media in Khanyounis Governorate

Range	Rating	Index	Area (%)
Clay and sandstone	4	12	62.64
Sand, sandstone, and clay	5	15	37.36

DRASTIC weight=3

The aquifer media index value (A_r A_w) is moderately low, 12 in areas comprised of clay and sandstone, and is moderate, 15 in the areas with sand, sandstone and clay. The lowest percent of the study area where the aquifer media is partially exposed at the surface consists of sand, sandstone and clay at 37%. Clay and sandstone predominate within the study area and make up about 63% of it (Fig. 7). In general, as the index value increases, vulnerability increases.

Soil media

Soil media is the upper and weathered portion of the unsaturated zone. The characteristics of the soil influence the amount of recharge infiltrating into the aquifer, the amount of pollutant dispersion and purifying process of contaminant. A number of soil characteristics controls the capacity of contaminants to move into the groundwater. The thickness of soils determines the length of time contaminants reside within the media. The texture and structure influence the rate at which water percolates through the soil profile.

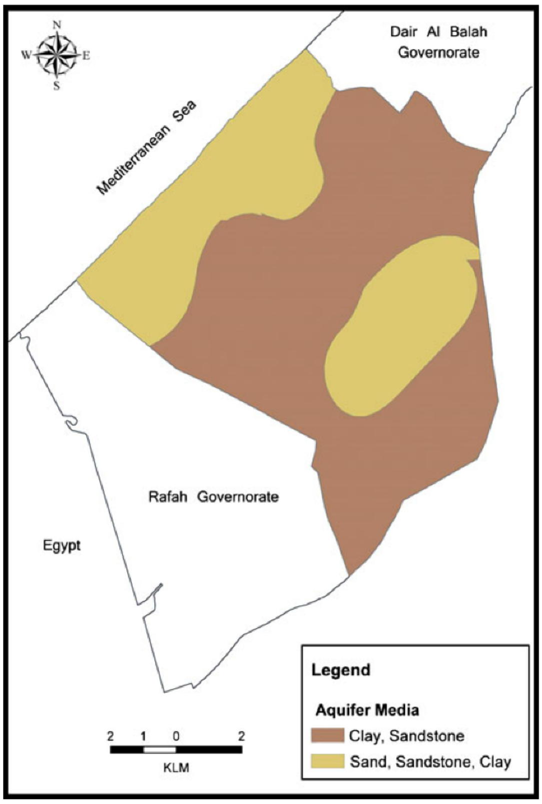

Fig. 7 Aquifer media (geology) of the study area

The soil data of the study area were derived from the results of the mechanical analysis of soil which was done by the central laboratory for soil which belongs to the Ministry of Agriculture (Ministry of Agriculture 2000). This study depended on the results of 36 samples of soil distributed within the study area. Textural classification of a soil type provides the necessary information for evaluating the rating value that is assigned for the range of soil media, reflecting the greatest impact to vulnerability. Referring to soil data for the study area, and according to the US Department of Agriculture (USDA) texture triangle software which is used to obtain the soil texture class (USDA 2008), there are three types of soil: sand, sandy loam and loamy sand. The ratings, and DRASTIC weight of two, are used to determine the final index value (S_r S_w). The rating values of soil vary from 9 for sand to 6 for sandy loam and loamy sand (Table 5).

Sand soil, rated high (18) in terms of the soil media index value is the predominant textural type comprising about 54% of the study area. This soil type can be found along the study area from west to east, but it is particularly prevalent west of it in form of sand dunes. Loamy sand and sandy loam follow at about 35 and 11% respectively, with moderate index value (seven and six). These soil types spread east and southeast of the study area (Fig. 8).

Topography

Topography refers to the slope of the land surface. Topography indicates whether a contaminant will run off or remains on the surface long enough to infiltrate into the groundwater (Aller et al. 1987). Areas with low slope tend to retain water for a longer period of time. This allows greater infiltration or recharge of water and a greater potential for contaminant migration.

To obtain the slope map, a contour map of the study area is used to extract the slope percentage map using ArcGIS 9.3 options. As mentioned above, the study area is generally flat with topographic elevation ranging from mean sea level (MSL) in the west to about 100 m above MSL in the east. The slope variation is moderate (<4% to more than 32%), but most of the study area has a gentle slope (Table 6). Flat area was assigned high rate because in

Table 5 Range, rating, and weight for soil media in the study area

Range	Rating	Index	Area (%)
Sand	9	18	54.25
Loamy sand	7	14	35.13
Sandy loam	6	12	10.62

DRASTIC weight=2

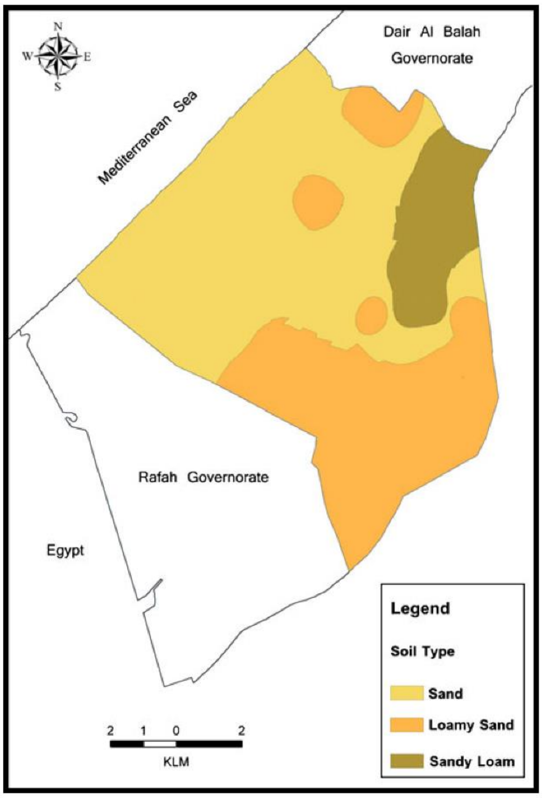

Fig. 8 Soil media of the study area

flat area the runoff rate is less, so more percolation of contaminants to the groundwater.

Ratings corresponding to >32% slope have a value of one, and for <4% slope, a value of ten. The DRASTIC weight assigned for topography is one. At <4% slope, the greatest potential exists for contaminant infiltration. At >32% slope, little potential exists for infiltration. Distribution of categories across the study area is divided nearly equally. It is noticed that the <4% slope range represents about 88% of the study area, while the remaining range categories make up 12% of the area (Fig. 9).

Table 6 Range, rating and weight for topography in the study area

Range (slope %)	Rating	Index	Area (%)
<4	10	10	87.860
4–7	9	9	3.391
7–11	8	8	0.137
11–14	7	7	0.015
14–18	6	6	2.339
18–21	5	5	6.245
21–25	4	4	0.003
25–28	3	3	0.005
28–32	2	2	0.002
>32	1	1	0.002

DRASTIC Weight=1

The topography index value (T_r T_w) in this case is just as prevalent as the value for less than 4%. So, this area which represents 88% of the study area has more potential for contaminant retention and less potential for infiltration of contaminants. The nine categories that comprise the >4% through >32% slope range are distributed throughout the remaining of the study area.

Impact of the vadose zone media

Vadose zone is defined as that zone above the water table which is unsaturated or discontinuously saturated, lying between soil layer and water table (Kabera and Zhaohui 2008). The vadose zone influences aquifer contamination potential is similar to that of aquifer media, depending on its permeability and on the attenuation characteristics of the media (Added and Hamza 2000). If vadose zone is highly

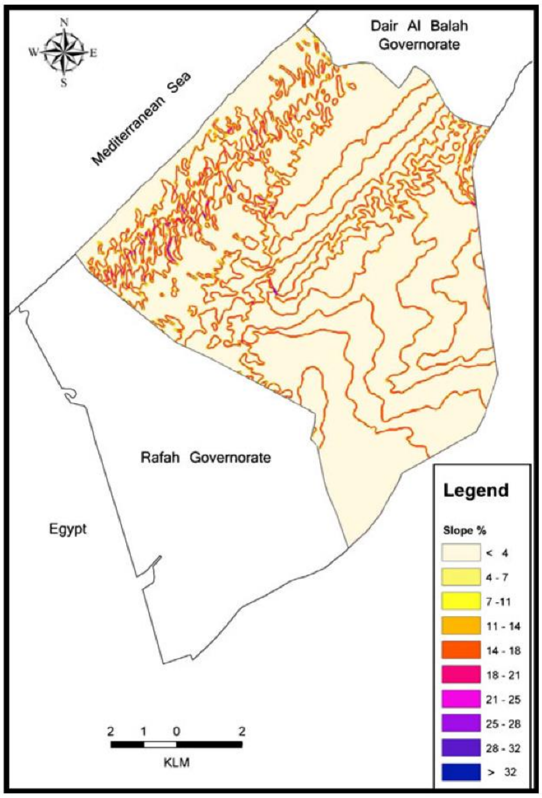

Fig. 9 Slope of the study area

permeable, then this leads to a high vulnerable rating (Corwin et al. 1997). The vadose zone has been identified from the available geological map and cross sections of the study area. The vadose zone is composed of sand, sandstone (Kurkar), and clay. From Table 7, the typical ratings and DRASTIC weight of five were used to determine the final index values (I_r I_w)

The vadose zone media is evaluated with about 50% of the study area controlled by sandstone layer. The sand and sandstone account about 32% of the study area. Clay and sandstone make up the remaining area (about 19%). The sandstone (rating=6), and clay and sandstone (rating=4) are moderate vulnerability index value (I_r I_w) and present the two thirds of the study area, while the sand and sandstone formations (rating=7) are relatively high vulnerability index value and present about the remaining one third of the area (Fig. 10).

Hydraulic conductivity

The hydraulic conductivity is described in terms of aquifer material and its ability to transmit water for a given hydraulic gradient. The rate of groundwater flow within the aquifer media also controls the rate of contaminant movement. Based on PWA data, the hydraulic conductivity in the study area varies between 40 and 51 m/day (PWA 2000). According to DRASTIC standard rating (Aller et al. 1987), these values fall in the same category and have the same rating. Therefore, a local scale was assigned for the rating as shown in Table 8. A higher rating is indicative of higher hydraulic conductivity. Weighting criteria is (3) for the regular DRASTIC model. The product of rating and weight are the final index value (C_r C_w).

Data shows that there are four categories of hydraulic conductivity index values (C_r C_w) for all aquifers. A range of 45–48 (rating=5 and 15) is the most prevalent value covering more than a half of the study area (Fig. 11). This is followed by 23.7% of the area ranging from 43 to 45 m/day (rating=4 and 12). According to DRASTIC model, high hydraulic conductivity is associated with high contamination potential (Aller et al. 1987). In the study area, the hydraulic conductivity index value is moderate (9 and 18)

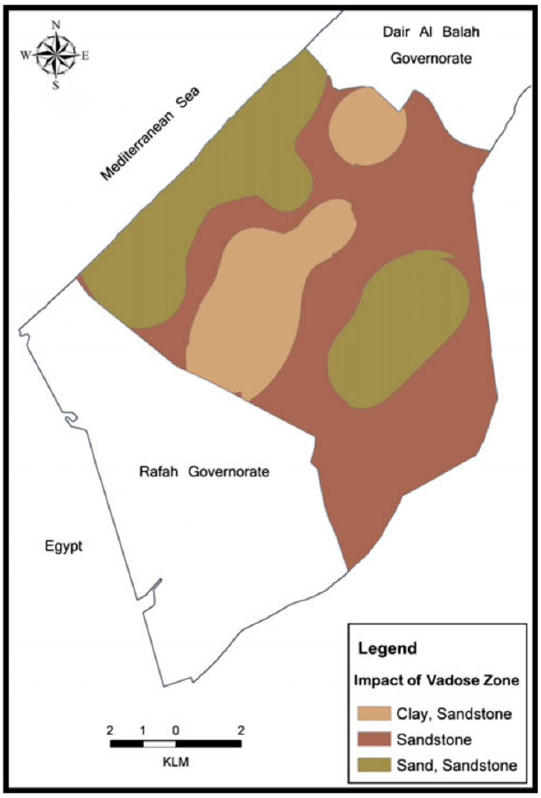

Fig. 10 Vadose zone of the study area

Aquifer vulnerability

Aquifer vulnerability analysis was carried out as described in DRASTIC model section. Combining the hydrogeological setting parameters results in a range of numerical values termed the DRASTIC index. Derived by combining the seven DRASTIC parameters index values, a range of values are developed that have been classified to present groundwater vulnerability. Using the DRASTIC model index a composite layer representing the study area has

Table 7 Range, rating, and weight for vadose zone in Khanyounis Governorate

Range	Rating	Index	Area (%)
Clay and sandstone	4	20	18.51
Sandstone	6	30	49.91
Sand and sandstone	7	35	31.58

DRASTIC Weight=5

Table 8 Range, rating, and weight for hydraulic conductivity in Khanyounis Governorate

Range (m/day)	Rating	Index	Area (%)
40–43	3	9	3.06
43–45	4	12	23.76
45–48	5	15	56.76
48–51	6	18	16.42

DRASTIC weight=3

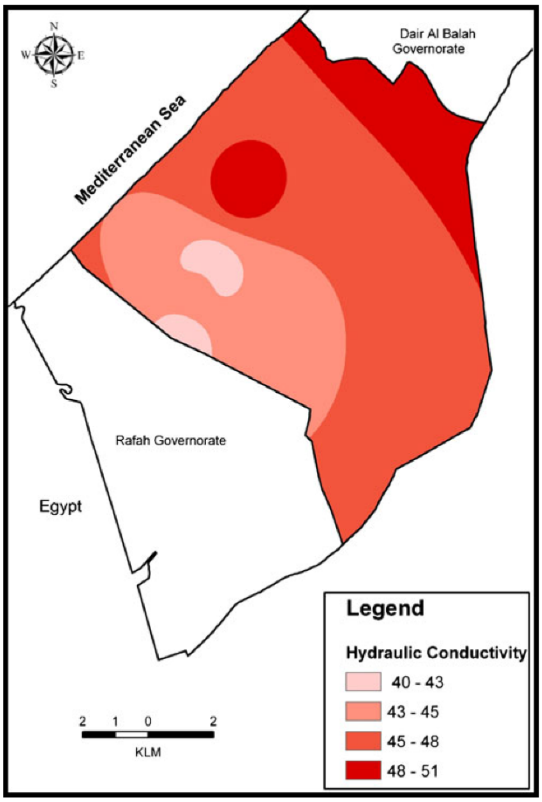

Fig. 11 Hydraulic conductivity of the study area

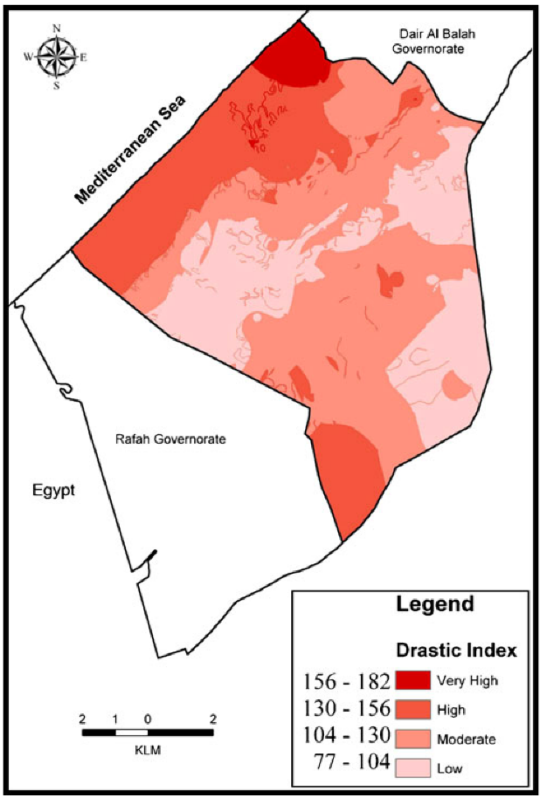

Fig. 12 The map of vulnerability to contamination for Khanyounis Governorate

been created combining the grid files described in Figs. 4, 5, 6, 7, 8, 9, and 10 and Tables 2, 3, 4, 5, 6, 7, and 8.

According to DRASTIC model index, the aquifer vulnerability ranges from 88 to 190. The values were categorized into four classes. They are low (77–104), moderate (104–130), high (130–156), and very high (156–182) groundwater vulnerability. Table 9 shows the total area covered by each class.

Figure 12 indicates that in the western part of the study area has the vulnerability to contamination in ranges between high (26.16%) and very high (3.14% of the total area). These classes are found in the sand dunes area with moderate–high recharge potential, shallow water table and permeable soils. These areas require a particular attention in regard to future land use decisions. To the east of the previous part and in the south-eastern part, vulnerability to contamination is moderate (43.44%). In the central and the eastern part, vulnerability to contamination is low (27.24% of the total area).

Table 9 DRASTIC index values in Khanyounis Governorate

DRASTIC index value	Area (%)	Vulnerability zone
77–104	27.24	Low
104–130	43.44	Moderate
130–156	26.16	High
156–182	3.14	Very high

Given these results, the model that has emerged can be used as a tool for making decisions on where agricultural chemical applications pose the greatest potential for contaminating the groundwater resources. For example, in these regions, pesticides should not be used in the agricultural fields and orchards, since the contaminants may easily leach into the groundwater through the vadose zone. The most critical hydrogeologic parameters that contribute to groundwater vulnerability in this study are found to be a combination of shallow depth to water, high net recharge, soil type (sandy soil rate=9) and topography with low percent slope.

Table 10 A statistical summary of the DRASTIC parameter maps

	D	R	A	S	T	I	C
Minimum	1	1	4	6	1	4	3
Maximum	10	10	5	9	10	7	6
Mean	5.15	4.49	4.37	7.98	1.44	5.95	4.87
SD	2.79	2.37	0.48	1.15	1.33	1.03	0.71
CV (%)	54.17	52.78	10.98	14.41	92.63	17.31	14.58

Sensitivity analysis of the DRASTIC model

Table 10 presents a statistical summary of the seven rated parameters of the DRASTIC model that workout the vulnerability of groundwater in Khanyounis Governorate. An examination of the means of the parameters reveals that the highest risk of contamination of groundwater in the study area originates from the soil media (mean value is 7.98). The impact of vadose zone, depth to water level, and hydraulic conductivity imply moderate risks of contamination (mean values are 5.95, 5.15, and 4.87, respectively), while net recharge, aquifer media, and topography impose a low risk of aquifer contamination (mean values are 4.49, 4.37, and 1.44, respectively).

The coefficient of variation (CV) indicates that a high contribution to the variation of vulnerability index is made by the topography (92.63%). Moderate contribution is made by the depth to water level (54.17%), and net recharge (52.78%), while impact of vadose zone (17.31%), hydraulic conductivity (14.58%), soil media (14.41%), and aquifer media (10.98%) are the least variable parameters. The low variability of the parameters implies a smaller contribution to the variation of the vulnerability index across the study area.

Single parameter sensitivity analysis

The single parameter sensitivity measure was developed to evaluate the impact of each of the DRASTIC parameters on the vulnerability index. The single parameter sensitivity analysis is normally used to compare the "theoretical" weight of each input parameter in each polygon with their "effective" weight assigned by the analytical model. The "effective" weight is a function of the value of the single parameter with regard to the other six parameters as well as the weight assigned to it by the DRASTIC model (Atiqur 2007). The "effective" weight of each polygon is obtained using the following formula (Hasiniaina et al. 2010):

$$W = 100*(P_r P_w / V)$$

Where W refers to the "effective" weight of each parameter, P_r and P_w are the rating value and weight of each parameter, and V is the overall vulnerability index.

The "effective" weights of the DRASTIC parameters obtained in this study exhibited some deviation from that of the "theoretical" weights. Table 11 reveals that the soil media and the impact of vadose zone were the most effective parameters in the vulnerability assessment because their mean "effective" weight, 13.5% and 25.1%, respectively, were higher than their respective "theoretical" weight.

The depth to water table showed that its "effective" weight (21.7%) and its "theoretical" weight (21.7%) were equal. The rest of the parameters exhibit lower "effective" weights compared with the "theoretical" weights. The significance of soil media and vadose zone layers highlights the importance of obtaining accurate, detailed, and representative information about these factors.

Conclusions

In this paper, an attempt has been made to assess groundwater vulnerability to contamination in Khanyounis Governorate. This task was accomplished using DRASTIC model. Based on the vulnerability analysis and according to DRASTIC

Table 11 Statistics of the single parameter sensitivity analysis

Parameter	Theoretical weight	Theoretical weight (%)	Effective weight (%)	SD
D	5	21.7	21.7	13.93
R	4	17.4	15.1	9.46
A	3	13.0	11.1	1.45
S	2	8.7	13.5	2.30
T	1	4.3	1.2	1.33
I	5	21.7	25.1	5.13
C	3	13.0	12.3	2.13

index values, it was found that about 26% and 3% of the study area is under high and very high vulnerability of groundwater contamination, respectively, while more than 43% and 27% of the study area can be classified as an area of moderate and low vulnerability, respectively.

It is noticed that the western part of the study area was dominated by high and very high vulnerability classes, while the east of the previous part and in the south-eastern part, vulnerability to contamination is moderate. In the central and the eastern part, vulnerability to contamination is low. In these regions, pesticides should not be used in the agricultural fields and orchards, since the contaminants may easily leach into the aquifer through the vadose zone.

The study also showed that the highest risk of contamination of groundwater in the study area originates from the soil media (mean value is 7.98). The impact of vadose zone, depth to water level, and hydraulic conductivity imply moderate risks of contamination (mean values are 5.95, 5.15, and 4.87, respectively), while net recharge, aquifer media and topography impose a low risk of aquifer contamination (mean values are 4.49, 4.37, and 1.44, respectively). The single parameter sensitivity analysis has indicated that the soil media and the impact of vadose zone were the most effective parameters in the vulnerability assessment. The significance of soil media and vadose zone layers highlights the importance of obtaining accurate, detailed, and representative information about these factors.

The GIS technique has provided an efficient tool for assessing and analyzing the vulnerability to groundwater contamination. The study suggests that this model can be an effective tool for local authorities, water authority and decision makers who are responsible for managing groundwater resources.

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8. GIS as a tool to analyze groundwater salinity: The Gaza Strip as a case study

GIS as a tool to analyze groundwater salinity: The Gaza Strip as a case study

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Resumen

La Franja de Gaza sufre un grave problema relacionado con la calidad y cantidad del agua. El agua subterránea se utiliza como agua potable, para usos agrícolas y para procesos industriales. La salinidad del agua está aumentando en la Franja de Gaza, siendo la intrusión de agua de mar la principal fuente de salinidad. En este trabajo, los iones selectivos de cloruro se utilizan, como indicador de la salinidad, para el análisis y modelización de la salinidad del agua subterránea en la Franja de Gaza para 2023. Tres modelos, Forecasting, regresión lineal y regresión multiple, son utilizados para el escenario del año 2023. El resultado de estos tres modelos muestra que la salinidad del agua aumentará en todas las áreas de la Franja de Gaza para el año 2023. Solo una pequeña zona en la provincia del norte tendrá menos de 250 mg / l de concentración de cloruro en agua dulce, lo que representa 4.56% del total del área de la Franja de Gaza. La intrusión de agua de mar se pone de manifiesto en los cortes transversales a lo largo de la costa, extendiéndose desde el Mar Mediterráneo hasta el este de la Franja de Gaza.

Palabras clave: Aguas Subterráneas, Salinidad, Intrusión de agua de mar, Modelización, SIG

Résumé

La bande de Gaza souffre d'un problème aigu de la qualité et de la quantité de l'eau. Les eaux souterraines sont utilisées comme eau potable, à des fins agricoles et à des procédés industriels. La salinité augmente dans les eaux souterraines dans la bande de Gaza. L'intrusion d'eau de mer est la principale source de salinité. Un isolant ionique par chlorure est utilisé comme indicateur de salinité pour l'analyse et la modélisation de la salinité des eaux souterraines dans la bande de Gaza d'ici 2023. La recherche dépend de trois modèles de prédiction de la concentration de chlorure dans les eaux souterraines: régression linéaire, régression multiple et Prévisions pour l'année 2023. Le résultat de trois modèles a montré que la salinité de l'eau augmenterait dans toutes les zones de la bande de Gaza d'ici l'an 2023. Une petite superficie dans le gouvernorat du Nord conserverait moins de 250 mg / L de concentration de chlorure dans l'eau douce, ce qui représente 4,56% du total de la bande de Gaza. L'analyse de l'intrusion d'eau de mer dans les sections transversales est claire le long du littoral et dépasse de la mer Méditerranée vers la partie est de la bande de Gaza.

Mots-clés: Eau souterraine, salinité, intrusion d'eau de mer, modélisation, SIG

Abstract

The Gaza Strip suffers from an acute problem in the water quality and quantity. Groundwater is used as drinking water, for agricultural uses, and industrial processes. Salinity is increasing in groundwater in the Gaza Strip. Seawater intrusion is the main source of salinity. A chloride ion-selective is used as indicator of salinity for analysis and modelling of salinity of groundwater in the Gaza Strip by 2023. Research depends on three models for prediction of chloride concentration in groundwater: Linear regression, Multiple regression, and Forecasting for year 2023. The result of three models showed water salinity will increase in all areas in the Gaza Strip by the year 2023.Only a small area in the North Governorate will keep less than 250 mg/L of chloride concentration in fresh water, which represents 4.56 % of the total of the Gaza Strip area. The analysis of seawater intrusion within the cross sections is clear along the coastline and outspreads from the Mediterranean Sea to the East part of the Gaza Strip.

Keywords: Groundwater, Salinity, Seawater intrusion, Modelling, GIS

1 Introduction

The Gaza Strip suffers from an acute problem in the water quality and quantity that will affect the future of the population in the Gaza Strip that was around 1.8 in 2014 in an area of around 365 Km^2.The estimated population in 2023 is of 2.4 million (PCBS, 2014). In Gaza Strip, the water crisis is a function of population growth, an agriculturally intensive, economy, a fragile water ecosystem and a highly inequitable distribution of resources (Kelly and Homer-Dixon, 1995).

Groundwater is considered the main and only water supply source for all kinds of human usages in the Gaza Strip (domestic, agricultural and industrial) and this aquifer can only be fed by rainfall and lateral flow from the east (Hamad et al., 2012). Salinity is increasing in many ground water areas in the Gaza Strip, which is the main reason of soil salinity and changes of agriculture systems in the Gaza strip. Seawater intrusion is the main source of sodium chloride in groundwater in the Gaza Strip. Therefore chloride is considered an indicator of salinity (Al-Agha, 1995; Qahman et al., 2006; Baalousha, 2011).

Seawater intrusion is the movement of seawater into fresh water aquifers due to natural processes or human activities. Seawater intrusion is caused by decreases in groundwater levels or by rises in seawater levels (Al-Agha, 1995; Qahman, et al., 2006; Mogheir et al., 2014). In coastal areas, chloride from saltwater aquifers can find its way into freshwater waters. Salinity is an ecological factor of considerable importance, influencing the types of organisms that live in a body of water (Peñalver et al., 2010). As well, salinity influences the kinds of plants that will grow either in a water body, or irrigated by a groundwater. Chlorides are widely distributed in nature as salts of Chloride sodium (NaCl), Chloride potassium (KCl), and chloride calcium ($CaCl_2$) (WHO, 2003). Seawater has a natural chloride of about 19,400 mg/L (ppt) combined with sodium. The salinity level in seawater is fairly constant, at about 35,000 mg/L, while brackish has chloride levels of between 500 and 5,000 mg/L and may have salinity levels between 1 and 10 ppt. When Chloride concentrations exceed 250 mg/L, it can give detectable salinity taste in water; salinity can be determined from chloride concentration. The following formula is used (WHO, 2003): Salinity (ppt) = 0.0018066 X Cl^- (mg/L) can be used to determine the salinity, which chloride ion selective electrode can be converted to a salinity value.

There is no health-based guideline value in the WHO organization to be proposed for chloride in drinking-water. Water Salinity can have significant impacts on Agricultural production, public health, Terrestrial biodiversity, and Soil erosion. The accumulation of salts (often sodium chloride) occurs from water irrigation in soil and water to levels that impact on human and natural. Water moves into plant roots by a process known as osmosis which is controlled by the water contained in the plant and the level of salts in the soil water. Salinity is one of the most important abiotic stresses, limiting crop production in arid and semi-arid regions, where soil salt content is naturally high and precipitation can be insufficient for leaching (Zhao et al., 2007).

Increasing of population number and urban expansion has raised concern about water use and potential for degradation of water Quality in the Gaza Strip. Urbanization in the Gaza Strip is increasing dramatically and is placing more stress on the agricultural areas, causing soil erosion, and affecting water quality and quantity, because of the natural growth of the population (Abuelaish, in press) and will affect food security (Abuelaish and Camacho Olmedo, 2016).

As we mentioned before, the population of the Gaza Strip will grow over 2.4 million by 2023 and the growth population rate is 3.44 in 2013 (PCBS, 2013). The demands of drinking water will place additional stress on water quantity and quality, Land cover and other environmental themes unless appropriate integrated planning and management actions are instituted immediately.

The water currently pumped from the coastal aquifer in the Gaza Strip is divided into 92.8 million cubic meter (mcm) for urban and domestic use and 86 mcm for agricultural use, average water consumption per person is 70 to 90 liters a day, most residents buy their drinking water from door-to-door salespeople (btselem, 2014), who sell water that has been treated by own Water Desalination Plants.

In Qahman (2006), the evaluation and numerical modeling of seawater intrusion in the Gaza aquifer, shows an increase in the salinity groundwater of the Gaza Strip within two cross sections in the north of the Gaza Strip near the Jabalia area and in the South near Khanyounis from the Mediterranean Sea to the east. The study used the Modflow software depending on the historical data from 1969 to 2003 for the estimation year 2020. The study has not details about the spatial distribution of salinity, and the trends of salinity were in two sections only.

Seyam and Moghier (2011) study the influence of the input variables on chloride concentration using ANN model. It proved that chloride concentration in groundwater is reduced by decreasing abstraction, abstraction average rate and life time. Furthermore, it is reduced by increasing recharge rate and aquifer thickness. In this research, data were extracted from 56 wells, most of them are municipal wells covering the total area of the Gaza Strip.

Alhalaq and Abuelaish (2012) study and assess of the ground water vulnerability to contamination in Khanyounis Governorate in Gaza Strip using the DRASTIC model within GIS environment, then find out the groundwater vulnerable zones to contamination in the aquifer of the study area, and provide a spatial analysis of the parameters and conditions under which groundwater may become contaminate.

The aim of our research is to analyze, simulate and model the salinity in the ground water of the Gaza Strip for the year 2023 in the highlight of urban expansion, through temporal mapping between 1972 to 2013, i.e., to show the decision makers in the future of the Gaza Strip and the real dangers of the future of water. For that the research process and provide detailed information on the trends of seawater intrusion flow through six cross sections and presents three simple models that have not been applied in the study area.

2. Study Area

The Gaza Strip is a narrow area that occupies the southern region of the Palestinian coast on the Mediterranean Sea, and gained its name from the largest city of Gaza. The Gaza Strip extends to 365 square kilometers, and a length of 41 kilometers, and varies in width between 6.5 and 12.5 kilometers. It is bound from the north and east by Israel; the Mediterranean Sea is to the west as shown in Figure 1, while bordered by Egypt to the south-west (Abuelaish and Camacho Olmedo, 2016).

The Gaza Strip has a temperate climate, with mild winters and dry, hot summers subject to drought. Average rainfall is of about 300 mm. The terrain is flat or rolling, with dunes near the coast. The highest point is 105 m above sea level. There are no permanent water bodies in the Gaza Strip (MOAg, 2013).

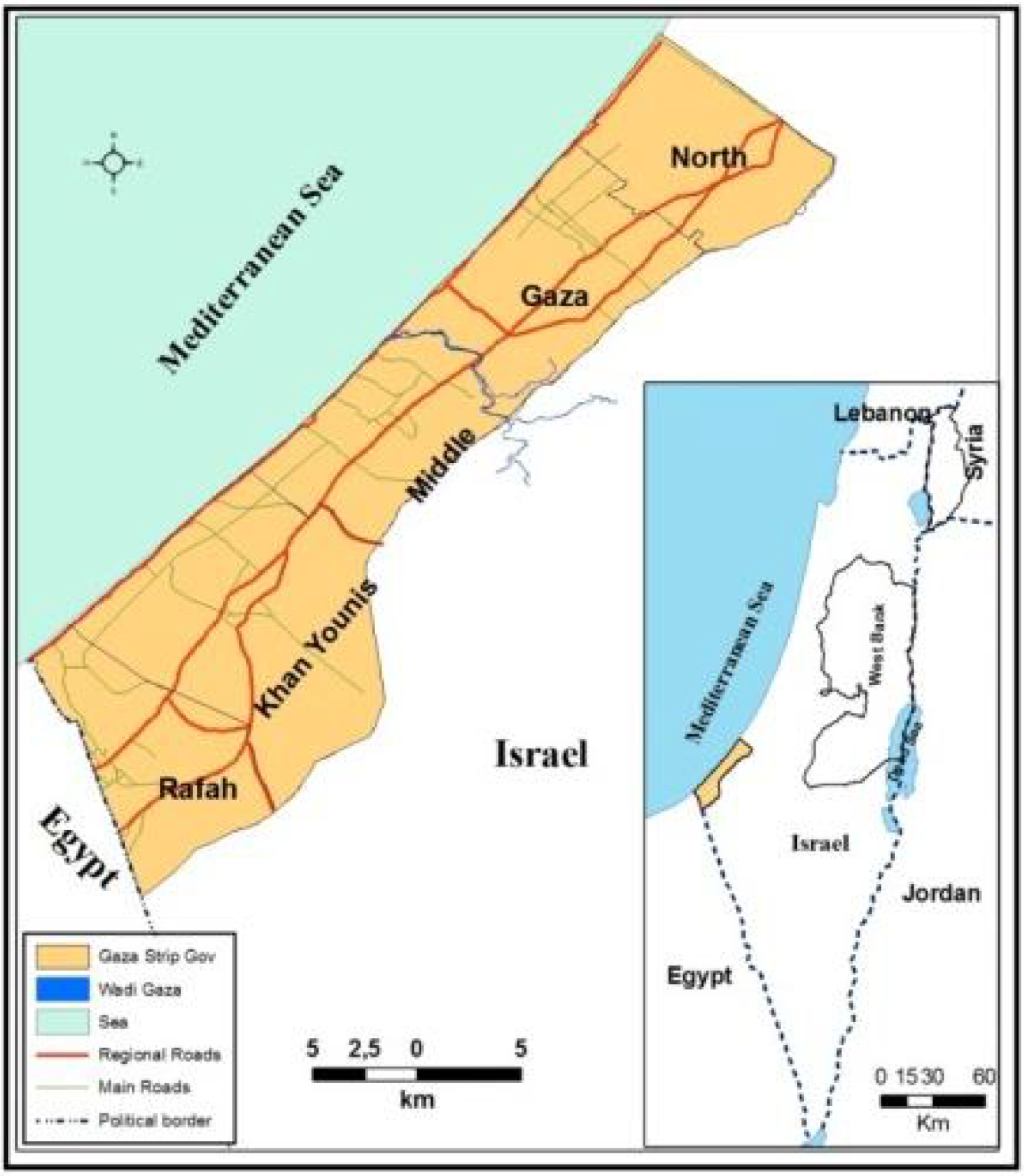

Figure 1. Location of the Gaza Strip

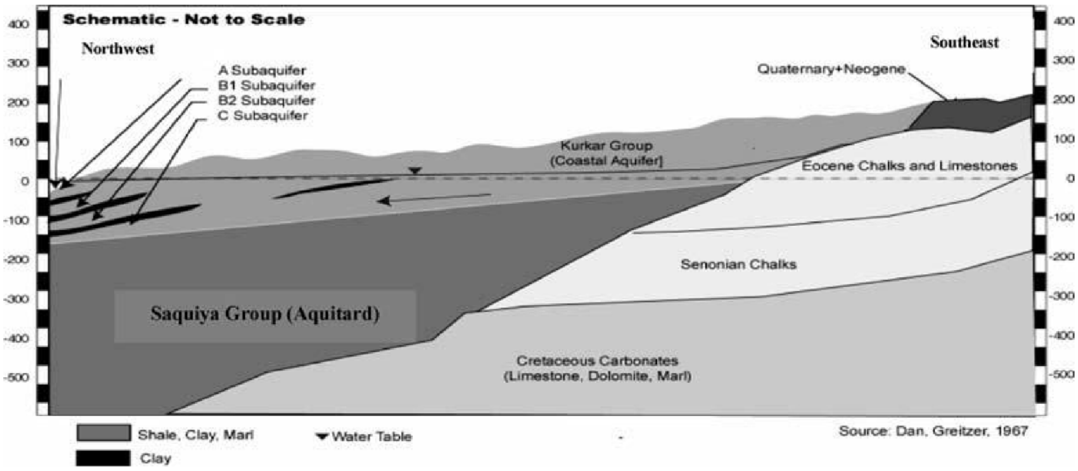

Figure 2. The hydrogeological cross-section of the aquifer of Gaza Strip (Source: PWA/USAID 2000); vertical scale in meters.

The coastal aquifer of the Gaza strip extends 41 km along the Mediterranean Sea, which is a part of the Gaza Strip Pleistocene coastal aquifer. Its average thickness ranges from 60 m in the eastern margins to about 200 m in the west along the coastline to a few meters (Vengosh et al., 1999; Zaineldeen, 2014). The aquifer is mainly composed of gravel, calcareous sandstone, clay and unconsolidated sands (sand dunes). Near the coast, coastal clays extend about 2-4 km inland, and divide the aquifer sequence into three sub aquifers (A, B, and C). Towards the east, the clay pinch out and the aquifer is largely unconfined as shown in Figure 2 (PWA, 2001; Al halaq et al., 2012; Zaineldeen, 2014).

3. Methodology

The methodology based on the aims to analyze chloride concentration and the future scenario by 2023 in the aspect of raising of chloride in the ground water of Gaza Strip, urban expansion and the high population rate which will lead to increase the water abstraction from the groundwater wells. Scenarios are used depending on the historical data of wells. One past trend scenario was evaluated using the input parameters within three models: the Forecasting, Linear, and Multiple linear regression models as shown in Figure 3.

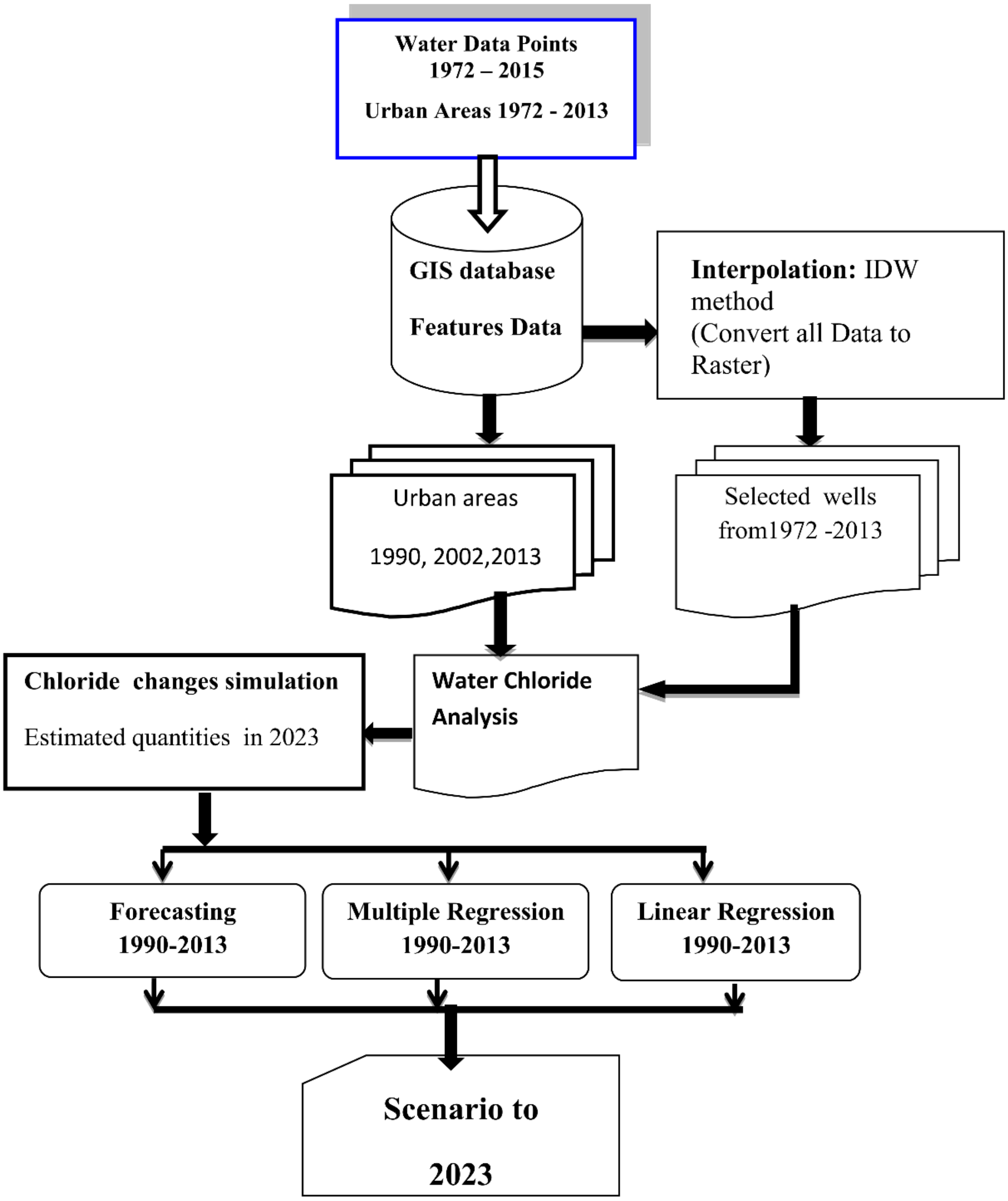

Figure 3. Methodology flow chart of water chloride analysis

3.1 GIS Database

The available data of agriculture and municipals wells are collected from the Palestinian Water Authority and Ministry of Agriculture as series time data for the years 1972 to 2015, and all data are converted from Microsoft excel to Shapefiles using ArcGIS 10.3 that have coordinates for all wells. The chloride ions are selected only for analysis and simulation. The number of wells varies according to the year but normally increases with early years. It was a number of 486 wells in 2013. It was filtered to 180 wells depending on the all selected years from 1990 to 2013 as series time data for modelling and scenario by the year 2023 using three models. The selected year 2015 is used for validity of models. The urban GIS database was used to analyze the effect of urban expansion on water salinity for year 1993, 2003 and 2013.

3.2 Interpolation

There are many methods of interpolation algorithms of data to create surface maps. Inverse Distance weighted (or Inverse Distance Weighted), denoted IDW (Tolosana-Delgado et al., 2011), is a method for interpolation of irregularly-spaced data. It is one of the most popular methods adopted by geoscientists and geographers (Lu et al., 2008; Mather et al., 2011).

Interpolation of all points is based on the IDW method for estimation of the unknown cells in the space that are using the ArcGIS10.3 software. The formulation of IDW method is used as follows. The value u at a given point X interpolated from a set of known samples ui=u(Xi)ui=u(Xi) for i=0,1,…,Ni=0,1,…,N can be calculated by

Equation (1)

$$u(X) = \sum_{i=0}^{N} \frac{w_i(X) u_i}{\sum_{j=0}^{N} w_j(X)}, \quad R(i) = \left[\sum_{a=1}^{A} W_a P_a^{(i)}\right] / \left[\sum_{a=1}^{A} W_a\right] \qquad (1)$$

where $w_i(X)=1/d(X, X_i)^p$, wi(X)=1/d(X, Xi)p is a simple IDW weighting function, as defined by Shepard (1968). d(X, Xi) is the distance function from unknown points X to known point X_i with positive power parameter p, and N is the number of known points included in the calculation.

From Eq. (1), it can be concluded that the points, which are further from the unknown point X, will get smaller weights in the interpolation process. Greater values of p assign greater influence to values closest to the interpolated point.

3.3 Water chloride analysis

The analysis of water chloride concentration depends on classification of data using the main ArcGis10.3 software based on the following concepts:

1) Classification of the chloride concentration to six classes, taking into consideration the salinity above 250 mg\L of the WHO parameter and the maximum value of chloride concentration.
2) Analysis of chloride concentration transition from class to others during the time series to show the changes clearly.

Analysis of chloride concentration profiles within six cross sections depending on the “Stack Profile” tool in the ArcGIS 10.3 software for the selected layers from 1972, 1982, 1993, 2003, 2013 and 2023 that are estimated by three models. It creates a table and optional graph denoting the profile of line features over one or more multipatch, raster, TIN, or terrain (ArcGIS 10.3 help, 2016). Chloride changes map is a continuous surface raster data such as a terrain. A terrain profile is a cross sectional view along a line drawn through a landform. Cross sections, that are valuable tools for visualizing structures (Radford University, 2014), show the terrain of a vertical plane below the earth’s surface.

3.4 Water chloride changes modeling

The research depends on three models for prediction of chloride concentration for the year 2023: Forecasting, linear regressions, and multiple regression. The three models process the chloride concentration as dependent variable. Forecasting and linear regression are determined on the time series (years) only as independent variables, but multiple regression are determined by time series, population, water level, the precipitation and the Pumping from groundwater (production). The RMSE is used to assess goodness-of-fit in models depending on the results of the three models and the real data for the year 2015.

3.4.1 Forecasting

Forecasting is the process of making predictions of the future based on past and present data and analysis of trends. Forecasting estimates values at certain specific future times Forecasting methods can be classified as qualitative or quantitative. It is assumed that the pattern of the past will continue into the future- This can be developed using a time series method or a causal method.

The time series forecasting refers to the historical data as a time series, i.e. to discover a pattern in the historical data and then extrapolate the pattern into the future. The forecast is based solely on past values of the variable and/or on past forecast errors. Causal forecasting methods are based on the assumption that the variable we are forecasting has a cause-effect relationship with one or more other variables (Camm et al., 2015).

The forecast time series modeling the study are produced within Microsoft Excel depending on the Forecasting Function which takes the form: The FORECAST (x, known y's, known x's) function returns the predicted value of the dependent variable (represented in the data by known y's) for the specific value ‘x’ of the independent variable (represented in the data by known x's) by using a best fit (least squares) linear regression to predict y values from x values (Microsoft, n.d.). The dependent variable is the chloride concentration, and the independent variable is only the time series as years from 1990 to 2013.

The equation (2) for FORECAST is a+ bX (2)

where:

$$a = \overline{Y} - b\overline{X} \tag{3}$$

and

$$b = \frac{\sum(X - \overline{X})(Y - \overline{Y})}{\sum(X + \overline{X})^2} \tag{4}$$

where $\overline{X}$ and $\overline{Y}$ are the average (known X's) and average(known Y's).

3.4.2 Linear regression

Linear regression is used when we want to predict the value of a variable based on the value of another variable. If plots of data versus time suggest a simple linear increase or decrease over time, a linear regression of the water quality variable Y against time T may be fit to the data (Gilbert, 1987). Linear regression analysis is the most widely used of all statistical techniques that are used for the modeling and analysis of numerical data. It exploits the relationship between two or more variables so that we can gain information about one of them through knowing values of the other. In addition, the regression can be used for prediction, estimation, hypothesis testing, and modeling causal relationships.

A linear regression line has an equation (5) of the form:

$$Y = b_0 + b_1X + c \tag{5}$$

where X is the explanatory variable and Y is the dependent variable, b_0 and b_1, are constants, called the model regression coefficients or parameters (i.e. b_0 called the intercept or constant coefficient, and b_1 called the slope of the least squares regression line), and c is a random disturbance or error in the approximation of Y. It is assumed that in the range of the observations studied, the linear equation provides an acceptable approximation to the true relation between Y and X, is the predicted value of Y when X = 0.
The y-intercept (b_0) and the slope (b_1) of the line are recognized by the equation 6 and 7

$$b_0 = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2} \tag{6}$$

$$b_1 = \frac{(\sum y)(\sum x^2) - (\sum x)(\sum xy)}{n(\sum x^2) - (\sum x)^2} \quad (7)$$

In the study, The IBM SPSS statistics software is used to run the model where the chloride concentration is the dependent variable and the year from 1990-2013 is the independent variable.

3.4.3 Multiple Linear regression

Multiple linear regression is the most common form of linear regression analysis. As a predictive analysis, the multiple linear regression is used to explain the relationship between one continuous dependent variable (criterion or endogenous or regress variable) and two or more independent variables (predictor or regressors variables). Multiple linear regression analysis is the task of fitting a single line through a scatter plot. More specifically, the multiple linear regression fits a line through a multi-dimensional cloud of data points. The simplest form has one dependent and two independent variables, the general form of the multiple linear regression (Montgomery et al., 2006).

A dependent variable is modeled as a function of several independent variables with corresponding coefficients, along with the constant term. Multiple regression requires two or more predictor variables, and this is why it is called multiple regression. The multiple regression model explained by the following form (8):

$$Y = b_1 x_1 + b_2 X_2 + \ldots + b_n X_n + c. \quad (8)$$

The response variable, indicated by Y , is measured along with a set of predictor variables, symbolized by X_1 ; X_2 ; : : : ; X_n, where n is the number of predictor variables, for b_i (i=1,2,...n) are the regression coefficients, which represent the value at which the criterion variable changes when the predictor variable changes., c is error term.

When selecting the model for the multiple linear regression analysis another important consideration is the model fit. Adding independent variables to a multiple linear regression model will always increase its statistical validity and essentially of the model fit, because it will always explain a bit more variance.

In the study, the IBM SPSS statistics software is used to run the multiple regression model where the dependent variable is the chloride concentration, and the independent variables are the population, water level, the rainfall in the whole Gaza Strip, and the production of each well in a time series, that is using Stepwise linear regression, method of variables while simultaneously removing those that aren't important. Stepwise regression essentially does multiple regression a number of times, each time removing the weakest correlated variable. At the end you are left with the variables that explain the distribution best.

3.4.4 Root Mean Square Error (RMSE)

The root mean square error (RMSE), also called the root mean square deviation (RMSD), is a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modeled. These individual differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power. The RMSE of a model prediction with respect to the estimated variable X_{model} is defined as the square root of the mean squared error (9):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}} \qquad (9)$$

where X_{obs} is observed values and X_{model} is modeled values at time/place i. The RMSE values can be used to distinguish model performance in a calibration period with that of a validation period as well as to compare the individual model performance to that of other predictive models (Fujita et al., 2014) otherwise the RMSE is used to assess goodness-of-fit in models.

4. The results

4.1 Water chloride analysis

Water analysis depends on the behavior of chloride concentration in the ground water in a time series of each well. Figure 4 shows variation from 1972-2013 for eleven sample wells in different places of the Gaza Strip.

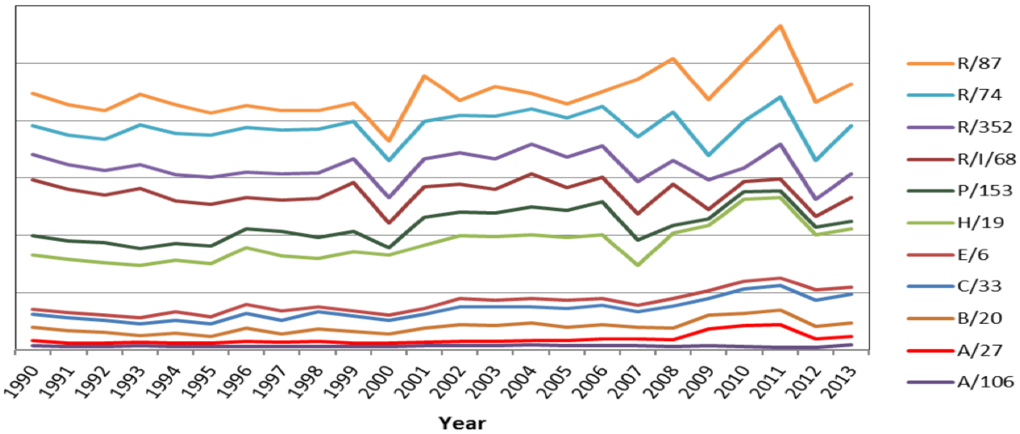

Figure 4. Behaviors of chloride concentration in the sample selected wells from 1990 to 2013

The simulation of chloride concentration for the years 1972, 1982, 1993, 2003 and 2013 (Figure 5), shows clearly an increase and demonstrate the positive relationship with the increase in urban areas.

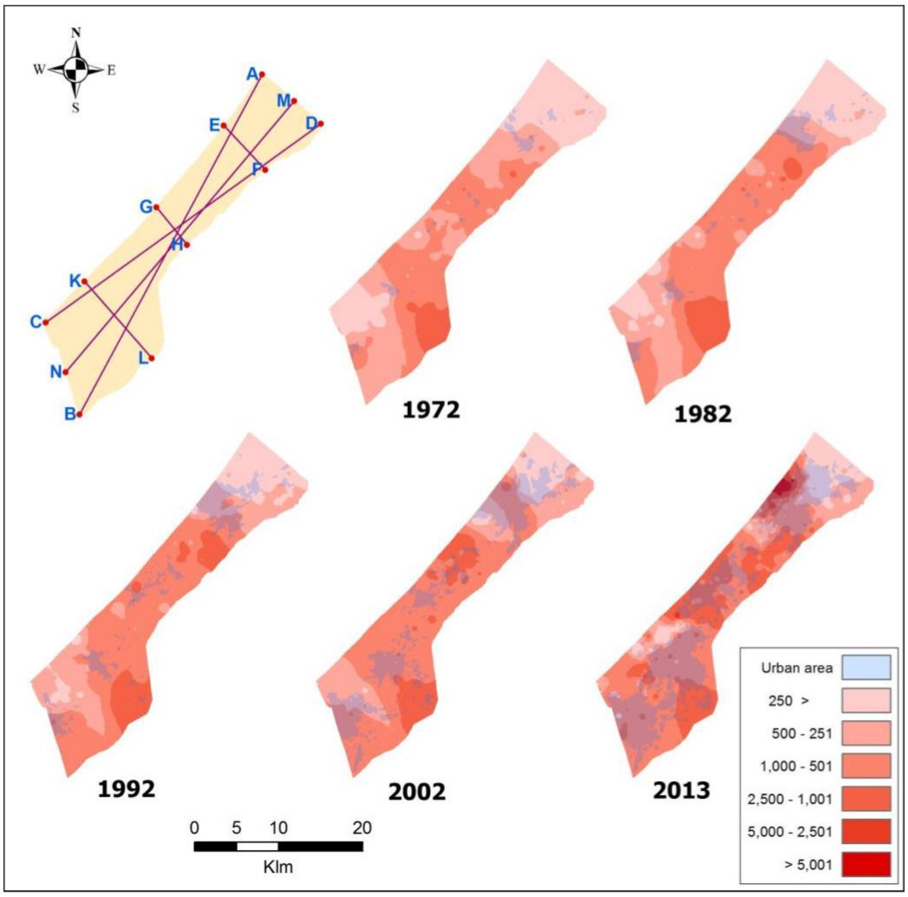

Figure 5. Chloride concentration (mg/L) and urban areas for the years 1972, 1982, 1993, 2003 and 2013, and locations of cross sections.

Six chloride profiles (Figure 5) were selected to extract the chloride concentration. Figure 6 illustrates the chloride concentrations in the ground water within elaborated six cross sections for year 1993, 2003 and 2013 that are focused over the urban areas and other non-urban areas equal zero. The chloride concentration of ground water in the whole of the Gaza strip was classified to six classes for the years 1972, 1982, 1993, 2003 and 2013 as shown in Table 1.

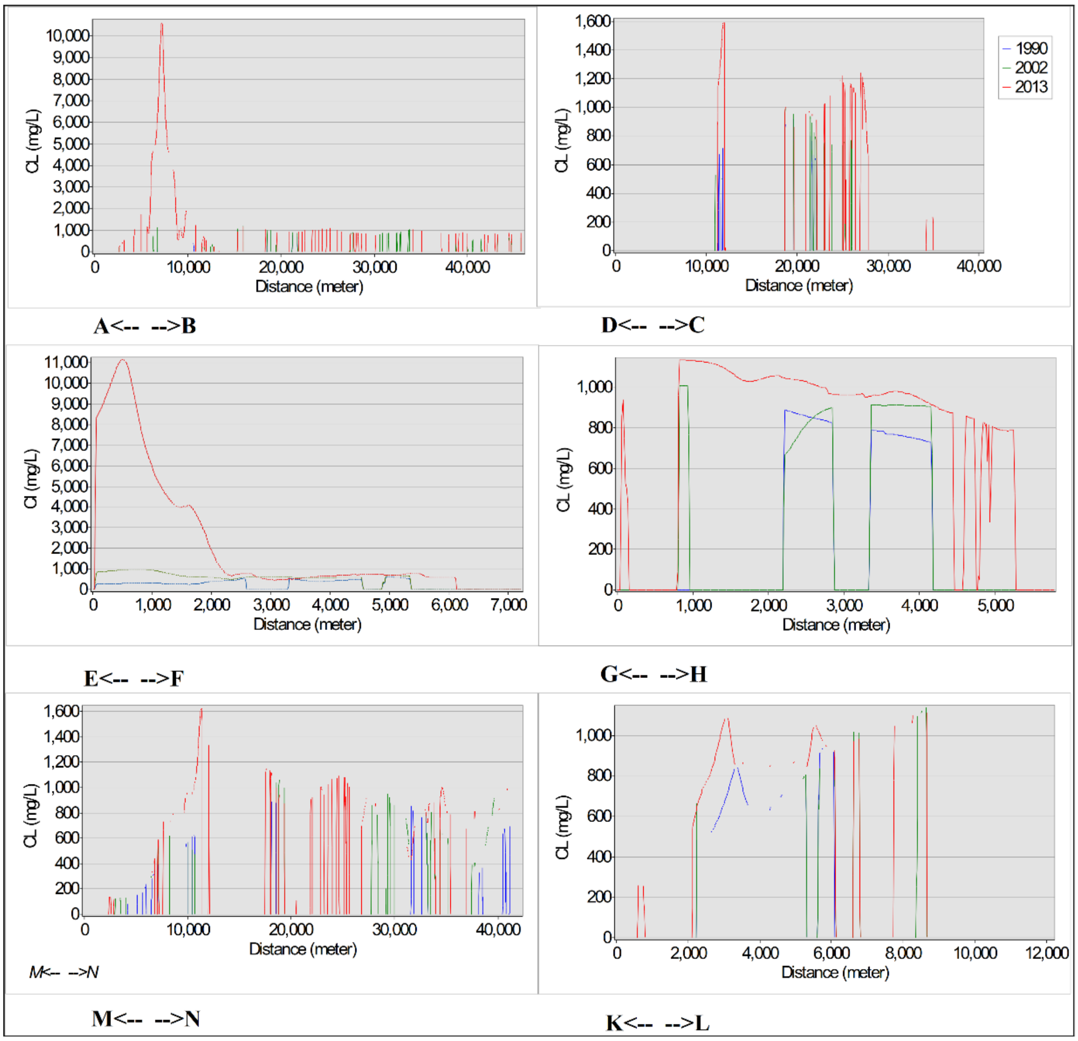

Figure 6. The selected profiles focused over urban areas: A-B, C-D, E-F, G-H, M-N, and K-L.

Table 1. Chloride concentration in ground water according to classification

CL (mg/L)	1972 (Km²)	1972 %	1982 (Km²)	1982 %	1993 (Km²)	1993 %	2003 (Km²)	2003 %	2013 (Km²)	2013 %
0 – 250	97.5	27.01	77.4	21.4	57.01	15.8	38.1	10.5	40.4	11.2
250 -500	118.7	32.9	85.8	23.8	84.2	23.3	76.9	21.3	45.1	12.5
500 -1000	124.6	34.4	165.7	45.9	179.1	49.6	202.5	56.1	170.9	47.3
1000 -2500	20.6	5.7	32.1	8.9	40.8	11.3	43.7	12.1	97.3	27.0
2500 -5000	0	0	0	0	0	0	0	0	4.6	1.3
> 5000	0	0	0	0	0	0	0	0	2.8	0.8

4.2 Water chloride changes modeling

The results of water chloride changes modeling are shown in Figure 7. Three maps are produced that represent three simulations for the year 2023. There are some differences in the results of the three models that are classified to six classes as shown in Table 2.

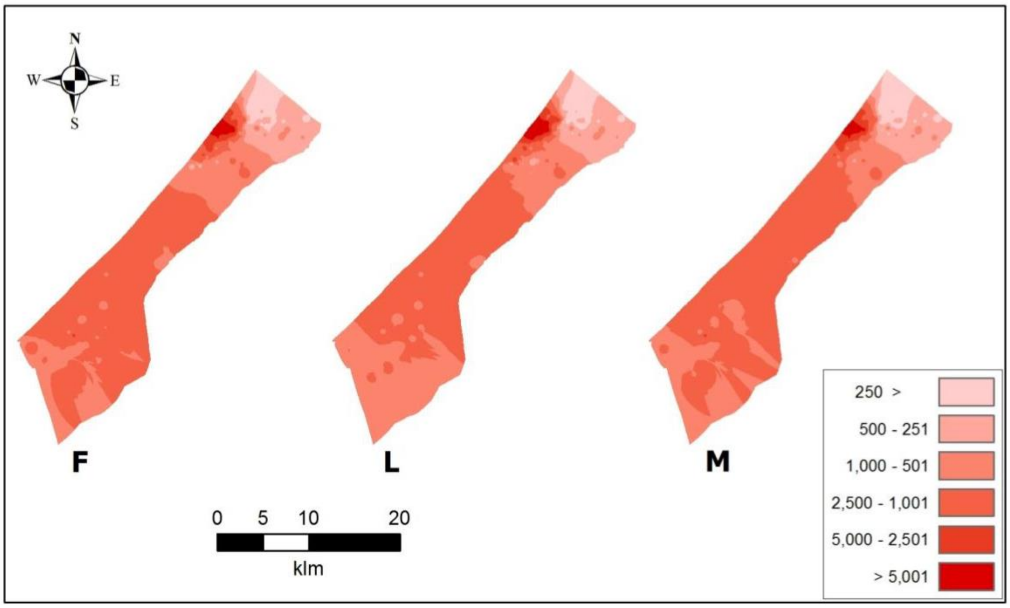

Figure 7. Simulated chloride concentration (mg/L) for the year 2023 as results of F) Forecasting Model, L) Linear Regression Model, and M) Multiple Linear Regression Model

Table 2. Area and percentage of simulated chloride concentration for the year 2023 as results of F) Forecasting Model, L) Linear Regression Model, and M) Multiple Linear Regression Model

CL (mg/L)	F (Km^2)	F %	L (Km^2)	L %	M (Km^2)	M %	Average (Km^2)	Average %
0 – 250	15.90	4.40	15.58	4.31	17.90	4.96	16.46	4.56
250 -500	36.27	10.05	36.50	10.11	34.00	9.41	35.59	9.86
500 -1000	95.09	26.33	134.02	37.11	93.66	25.94	107.59	29.80
1000 -2500	205.68	56.96	166.49	46.11	207.71	57.52	193.29	53.53
2500 -5000	5.09	1.41	4.41	1.22	5.41	1.50	4.97	1.38
> 5000	3.07	0.85	4.11	1.14	2.41	0.67	3.20	0.89

Figure 8 presents the chloride concentration profiles which illustrate increases of water chloride along the cross sections that come from the imported data, which are the chloride concentration in mg/L on the y-axis and the distance from point to other on the cross section (horizontal line) in meters along the x-axis.

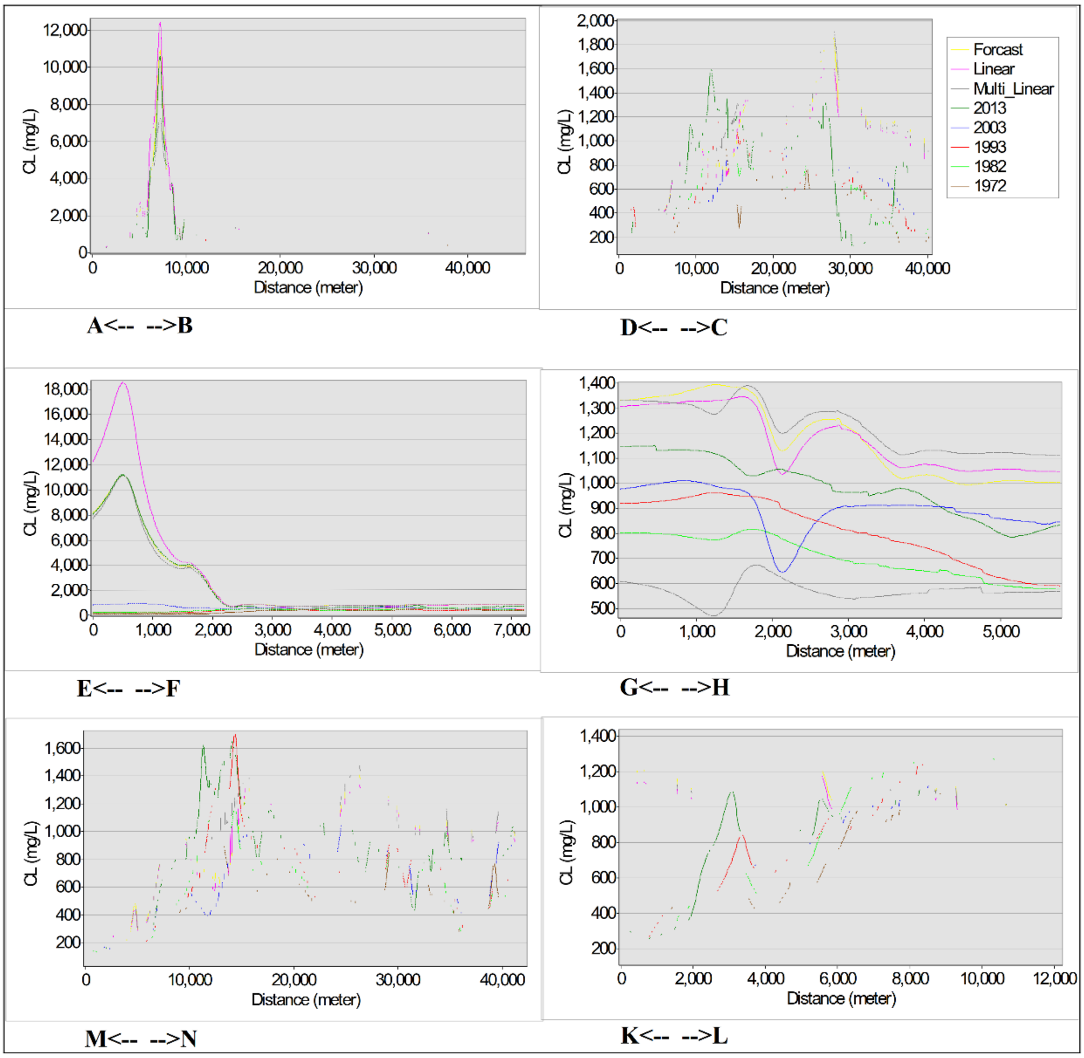

Figure 8. The selected profiles: A-B, C-D, E-F, G-H, M-N, and K-L

Calculation of the RMSE values as predictive power shows that the Linear regression has more value 1668.3, second being Forecasting 1656.9, and then the Multiple Linear regression 1631.723.

Scatter plots in Figure 9 represent the real data of the chloride concentration on the *x*- axes and the predicted chloride concentration on the *y*-axes that shows how the scatter diagram points of Forecasting and Multiple Linear are closely being on a line predictor while the Linear regression is far from them.

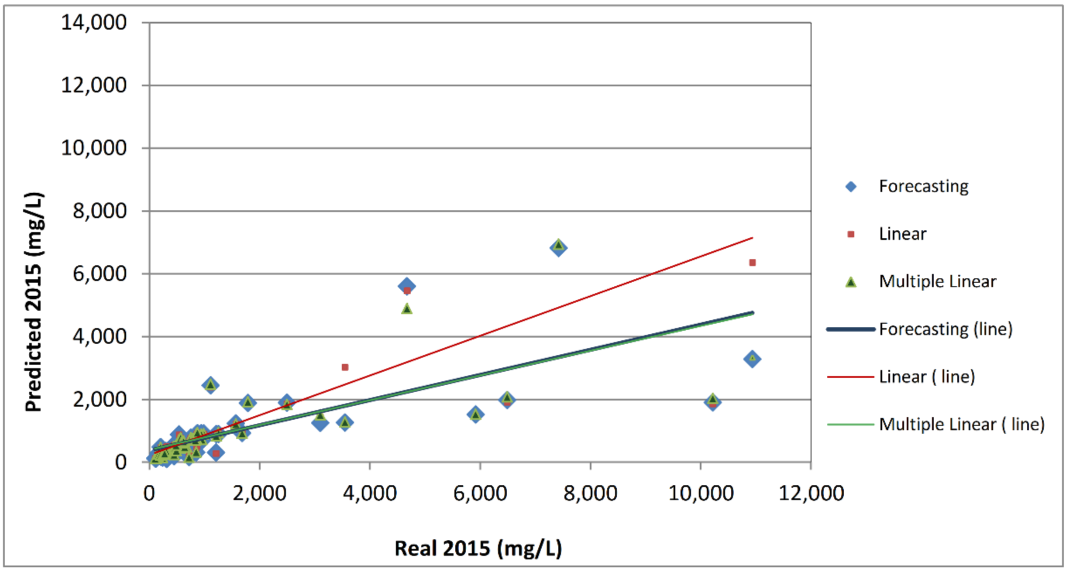

Figure 9. The scatter plot for chloride concentration (mg/L) Real data 2015 versus predicted data models 2015 of Forecasting, Linear, and Multiple linear regression.

The data inputs and output for the chloride concentration from 1972-2013 and 2023 represented the severe change in water chloride that is showed clearly in 2008 in the Gaza Strip as shown in Figure 10. Chloride expanding is shown in the whole area of the Gaza Strip. The area of chloride concentration of less than 250 mg/L will become less than 10% for the Gaza Strip by the year 2023.

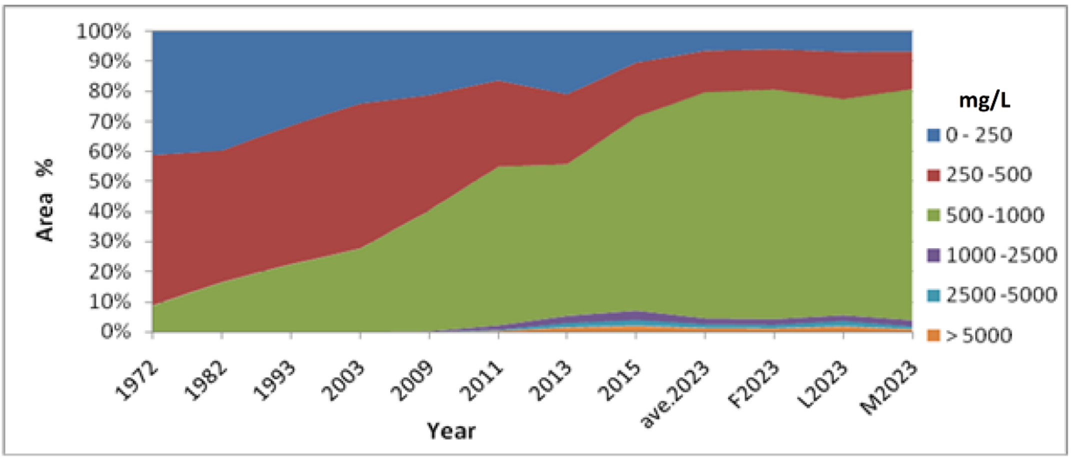

Figure 10. Increase area of chloride concentration from 1972 to 2023

5 DISCUSSION

Groundwater is an important source of fresh water in the Gaza Strip for domestic and irrigation use. Groundwater quality is influenced by geological formation and anthropogenic activities, e.g. changes in land use, urbanization, intensive irrigated agriculture, mining activities, disposal of untreated sewage in river, lack of rational management, etc. (Voudouris, 2009). Ground water contamination may cause severe threaten on public health due to human activities.

During the analysis of chloride concentration in each well, we found some problems in some years, which changed suddenly due to many reasons, as the discharge rate, the rainfall weight per year; because at a given location the amount of infiltrating water depends on geomorphology, water conductivity of superficial rocks, air temperature, amount, duration and physical state of precipitation, and also vegetation and many other factor (Kovács et. al., 2012), in addition to the error of chloride analysis or readings or registering, and the changing the depth of well to get to brackish water.

Figure 11 demonstrates chloride concentrations in 1993, 2003 and 2013 inside the urban area 2013 and non-urban areas are masked, therefore the figure are focused on chloride concentrations inside urban areas only. This shows that the urban areas suffered more than others, where the chloride concentrations is increased clearly from the early year to the higher concentration rate in the late years.

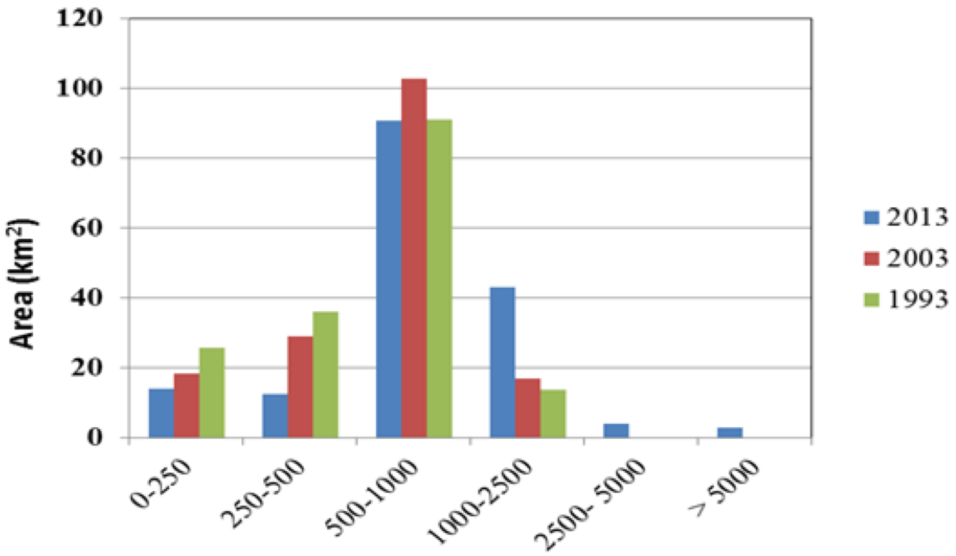

Figure 11. The area of classified chloride concentrations (mg/L) by years 1993, 2003 and 2013, within the urban area 2013.

As mentioned before, Figure 6 illustrated the positive relationship with the increasing of urban areas in all cross sections. It was highlighted higher concentrations of chloride concentrations in urban areas in 2013 than in previous years in 1993 and 2002. The visual analysis of cross sections is based on the water data analysis profiles which describe how the chloride is increasing to continue everywhere in the Gaza Strip along the time series from 1972 to2023.

Figure 8 shows chloride expansion in the whole of the Gaza strip and the increase from early year to late years for 1972, 1982, 1990, 2002, 2013 and by 2023 in the three models. The trend of expansion from the west to the east due to the seawater intrusion is evident in all cross section as following:

Along the cross section A-B chloride is above 250 mg/L. After 5,000 meters from point A near the Mediterranean Sea chloride increases to 2,500 mg/L and at a distance of 7,500 meters it reaches 7,500 mg/L in 2013 and 11,500 to 12,500 by the year 2023 which considers the center of the Gaza city. It decreases 1,500 -2000 mg/L at a distance of 10,000 meters at point B. The cross section D-C shows the area from the north at Biet Hanoun town (C) to the south at Rafah city (D). We noticed time series increased in chloride, while Biet Hanoun along time has the best water quality in the Gaza Strip, which will get chloride to reach 1100 mg/L by the year 2023.

The across section drawn from the transect E-F starts from the coast of the city of Gaza with highest population density at point E to get to around 11,000 mg/L at the coastal area. Chloride in the years from 1972 to 1993 was of around 1000mg/L along the cross section, which is an evidence of increase in 2013 and will get more increased by the year 2023. The cross section G-H intersects Alnusairat town at point G and H point at the east of the Gaza Strip. During the time series from 1972 to 2023, the chloride concentration increased with rate 150-200 mg/L per ten years. In the cross section K-L, there is evidence of an increase of chloride concentration at point K in the Almauasi area which is considered an agricultural land and a sensitive area near the Mediterranean Sea. The chloride concentration increases from K to L in the east during the time series from 1972 to 2023.

The cross section M-N intersects the Gaza Strip from the northern border at point M to the southern border at point N. Point M at the Biet Lahia has the best water quality in the Gaza Strip during the time series from 1972 to 2013, but the area that has the chloride concentration below 250 mg/L will be reduced by the year 2023. We noticed from the cross sections E-F, G-H, and K-L clearly, that water salinity moved toward the coastal zone eastwards. Hence, sea water intrusion has an effect on all areas; therefore, this will have an effect on the agricultural systems, and consequently many agricultures types and trees will change to others with salt tolerance to water salinity.

Figure 12 shows that the chloride concentration increases in each governorate in most classes.

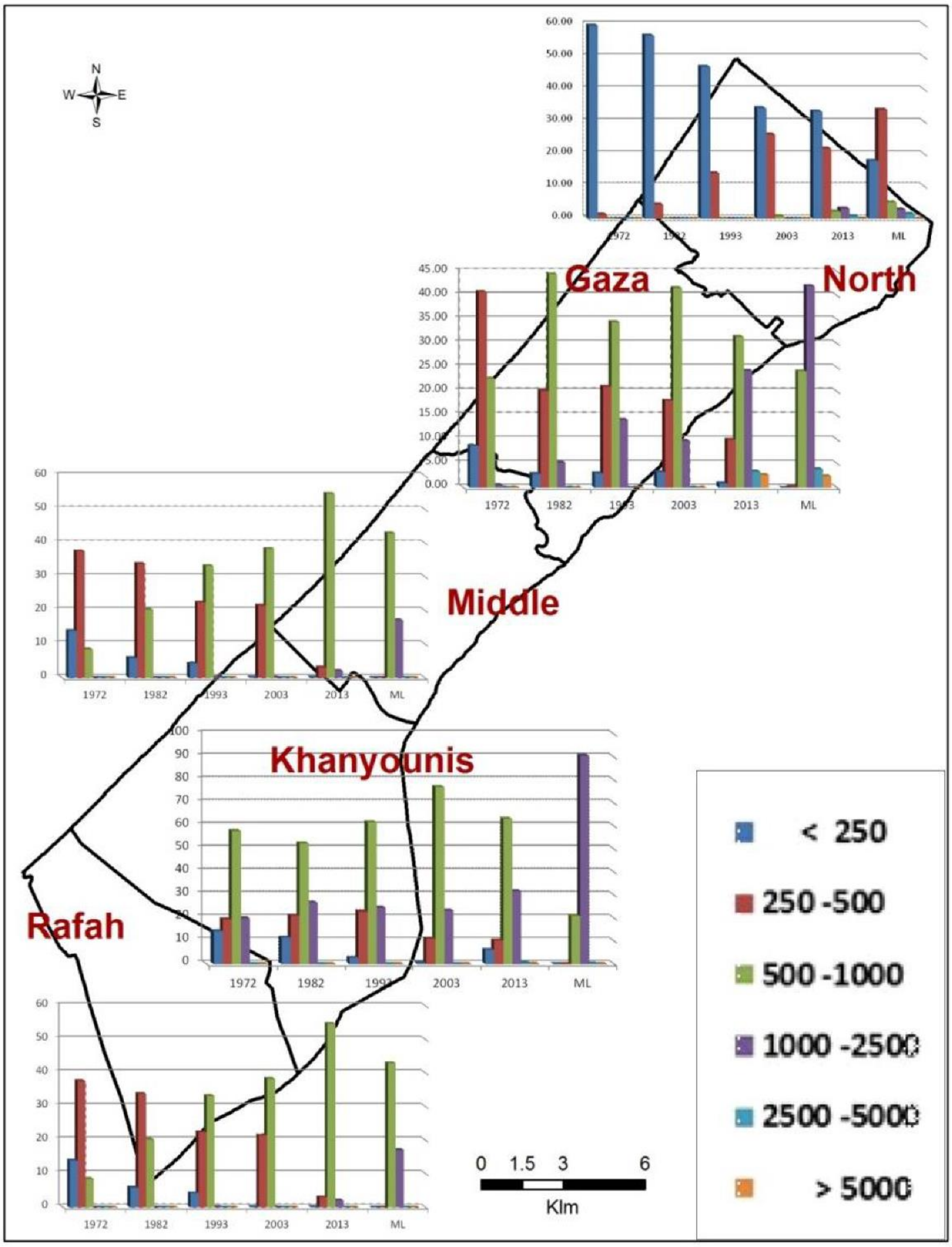

Figure 12. Increase of chloride concentration (mg/L) in each Governorate

20

Multiple Linear regression is considered the best model in our study according to the Root Mean Square Error (RMSE), then the Forecasting model and then Linear regression in order of importance. When the stepwise method in Multiple Linear regression is used by SPSS, the wells are affected by all input variables at a different rate; the year has more effectiveness, around 45%, population 35 %, production 10 %, rainfall 10 % and water level 10%.

In this study, one scenario of chloride concentration increase as indicator of salinity by 2023 is presented. There is another scenario to be envisaged that is to create a big desalination plant in the Gaza Strip. The EU has invested EUR 10 million during this phase which, when fully operational, will produce 6,000 m^3 of potable water daily. This will provide over 75,000 Palestinians with safe drinking water—approximately 35,000 people in Khan Younis and 40,000 people in Rafah, southern Gaza Strip. EU Commissioner Johannes Hahn announced an additional funding of EUR 10 Million for the second phase of the desalination plant to start in mid-June 2016, which is expected to be completed within 36 months. Then the plant will produce a total of 12,000 m^3 of safe drinkable water, each day (IMEMC, 2016). The annually increasing rate of the required water in the Gaza strip is 2,240,437 m^3 per year from 2016 to 2023. Hence the desalination plant will reduce the problem of drinking water. If the EU plant worked, it would produce 4,380,000 m^3 annually after 36 months.

6 Conclusions

This paper presents the analysis and modeling of chloride concentration in the ground water of the Gaza Strip using the historical data from 1972 to 2015. Three models are used for the estimation of chloride concentration by the year 2023 depending on the data from 1990 to 2013 based on the one past trend scenario.

The following conclusions were drawn from results and analysis of this research:

- Water salinity will increase in all areas in the Gaza Strip by the year 2023.
- The north governorate will keep only the fresh water that has a chloride concentration of less than 250mg/L, which represents a percentage of 4.56% of the Gaza Strip area by the year 2023.
- Water salinity will cover the area 95% of the Gaza Strip that have an effect on the agricultural systems and salt tolerance of vegetables and trees to water salinity. In addition to the main reason of soil degradation that will have an effect on the soil capability and productivity.

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Conclusions and Perspectives

Conclusions

Land use and land cover changes, and increasing urban growth as a result of population growth, have very clear environmental impacts on the surrounding ecosystems, water quality and quantity, land resources in the urban area and by extension on the quality of life in general. The Gaza Strip, the study area for this research, is a very small part of the world, situated at the eastern end of the Mediterranean Sea, which has been a theatre of conflict for decades. Each of these conflicts has left its mark, and a significant environmental footprint has developed in the Gaza Strip over time (UNEP, 2009).

The results of the study have confirmed the initial hypotheses and highlight the need to understand the implications of these changes: (1) The models were set up to evaluate changes in different land use and land cover data for more periods as a function of the changes, that tested for different calibration periods to show the normal urban growth. (2) Parts of the aquifer in the study area are vulnerable to contamination, and the groundwater may become polluted. (3) The salinity of groundwater has increased in recent years and will continue to do so in most areas of the Gaza Strip due to high fresh water extraction and high population growth.

The principal objective of this thesis was to identify and analyze land use and land cover change (LUCC) in the Gaza Strip, with a view to creating scenarios and models to help predict future LUCC, in the light of climate change.

The thesis presents a better understanding of potential options for urban land use expansion and highlights some of the key drivers behind LUCC in the Gaza Strip, for example population, socioeconomic forces, the political situation and the Israeli occupation. It also assesses the effect of urban expansion on environmental issues such as water quality and climate change.

In terms of structure, the thesis follows a methodology aimed at achieving the objectives and reaching the results and conclusions in five phases: (1) defining the problem of land use and land cover change and stating the research objectives, (2) data collection, classification, analysis and validating, (3) processing and analysis of the data from the GIS-produced database, urban simulation, then detecting and measuring urban expansion; (4) scenarios, projecting urban land use for the year 2023, and (5) Impacts of land change on the environment within a study of groundwater vulnerability to pollution and water salinity.

The following main conclusions can be drawn from this thesis:

- Around 57.13 to 58.8% % of the Gaza Strip will be urban land by 2023.
- There are differences in the spatial distribution of land change between the different models used (Geomod, CA_Markov and LCM).
- There is an inverse relationship between the predicted urban area for 2023 and the length of the calibration period, as tested using five scenarios and the Land Change Modeler.
- Urbanization in the Gaza Strip is increasing dramatically because of natural population growth. This is placing more stress on agricultural areas, causing soil erosion and impairing water quality and quantity.
- Urban sprawl is increasing over time at the expense of agricultural land, above all due to an increase in population.
- An increase in the agricultural land in the Gaza Strip will put pressure on natural resources and contribute to local and global climate change.
- Urban planners should take into account that in the near future the three main urban areas will merge into one, and population should be directed to vertical constructions to reduce further sprawl.
- The Gaza Strip can help mitigate its contributions to climate change and has potential for adapting its land cover.
- Urban expansion affects water quality and quantity, air quality, coastal zone management, and marine environment. Within cities, the nature of urban growth is an important determinant of the vulnerability of urban dwellers to environmental stress (Güneralp and Seto, 2008).
- Urban planners and decision-makers should take into account the vulnerability of the groundwater in the aquifer to pollution. For this purpose the DRASTIC model can be an effective tool for local authorities and water authorities responsible for managing groundwater resources.
- Groundwater salinity has extended to most parts of the Gaza Strip as a result of rapid population growth and urban expansion. This process will continue up to 2023.
- The study can help those that take decisions about land-use management, city planning, the environmental situation and future scenarios for the people of Gaza.

Perspectives

This study aspires to provide a starting point for other researchers on land use and land cover changes. It recommends that future studies should pay particular attention to the following research topics in the Gaza Strip:

Providing further assistance for environmentalists and planners to consider the impacts of urban land use development by identifying urban expansion.

- Using high resolution satellite images to produce accurate data for monitoring and analysis, scenarios, modelling and projection of LUCC and other environmental indicators for the Gaza Strip.
- Planners and decision makers should develop a strategic plan to prevent the decline of agricultural lands.
- Updating and upgrading of the LUCC GIS database within periodic data collection.
- In order to ensure sustainable urban developments, Environmental Impact Assessment (EIA) should be carried out for all future projects in the Gaza Strip, so as to reduce negative environmental impacts.
- Future research must consider all these limitations and apply an advanced modelling approach that would enable long-term forecasting.
- Future studies should focus on the impacts of land-use changes on climate change and environmental elements such as air pollution, coastal erosion related to harbors, urban heat islands, decreasing numbers of flora and fauna, land capability and productivity, etc.

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ABBREVIATIONS

Btselem	The Israeli Information Center for Human Rights in the Occupied Territories
EPA	United States Environmental Protection Agency
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization of the United Nations
IMEMC	International Middle East Media Center
LCCS	Land Cover Classification System
PARC	Palestinian Agricultural Development Association
PCBS	Palestinian Central Bureau of Statistics
PWA	Palestinian Water Authority
UNCTAD	United Nations Conference on Trade and Development, United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	The United Nations Educational, Scientific and Cultural Organization
UNITAR	The United Nations Institute for Training and Research
UNOSAT	Operational Satellite Applications Programme of the UNITAR
WHO	World Health Organization
GIS	Geographic Information System
RMS	Root Mean Square
LULCC	Land use and land cover changes

ANNEXES

Annex I – Impact factor and quality analysis of contributions (chapter 7, chapter 5, chapter 6)

Chapter 7

Al Hallaq, A. H., & Abuelaish, B. S. (2012). Assessment of aquifer vulnerability to contamination in Khanyounis Governorate, Gaza Strip—Palestine, using the DRASTIC model within GIS environment. *Arabian Journal of Geosciences*, *5*(4), 833-847.

I.1. The Journal

The highest Impact Factor for the *Arabian Journal of Geosciences* in the Journal Citation Report (JCR) published by Thomson Reuters was in 2014, when it achieved an impact of 1.224, as illustrated in Table A1.

Table A1. Journal Citation Report (JCR) and 5-Year Impact Factor for the Arabian Journal of Geosciences

	Journal Citation Report (JCR)	5-Year Impact Factor
2014	1.224	1.439
2013	1.152	1.265
2012	0.74	0.741
2011	1.141	1
2010	0.538	0.538

Source: the Journal Citation Report (JCR) Thomson Reuters, 2014

According to the Scimago Journal & Country Rank powered by Scopus Data, the *Arabian Journal of Geosciences* was classified as seen in Table A2.

Earth and Planetary Sciences (miscellaneous)	2015	Q2
Environmental Science (miscellaneous	2015	Q2

The *h*-index is based on the highest number of papers included that have had at least the same number of citations.

H Index for the *Arabian Journal of Geosciences*: 16

Table A2. CiteScore metrics calculated on 23 May, 2017.

Title	CiteScore	Highest CiteScore Percentile	CiteScore Rank	Citations 2016	Documents 2013-15	% Cited
Arabian Journal of Geosciences	1.00	58%	70/169	1,522	1,521	44%

Source: Scopus Journal metric, https://www.scopus.com/sourceid/17400154823

The Scimago Journal & Country Rank (SJR) is a size-independent prestige indicator that ranks journals by their 'average prestige per article'. It is based on the idea that 'all citations are not created equal'. SJR is a measure of the scientific influence of journals that takes into account both the number of citations received by a journal and the importance or prestige of the journals in which these citations appear. It measures the scientific influence of the average article in a journal, and expresses how central it is to the global scientific discussion. Results are set out in Table A3.

Table A3. Arabian Journal of Geosciences SJR Rank by year.

Year	SJR
2009	0.110
2010	0.137
2011	0.202
2012	0.272
2013	0.315
2014	0.350
2015	0.417

Source: Scopus Journal metric, https://www.scopus.com/sourceid/17400154823

I.2. The article

I.2.1. Springer citation service

The Springer publishing house has a service for tracking the number of times the articles published in its journals are cited. My article was cited 17 times altogether, 16 times in journals and once in a book, as seen in Table A4 and Table A5.

Citation rank - 93rdpercentile.

Table A4. Journals that cite the Article (Springer citation service).

Journal	Citations	JCR	SJR
Arabian Journal of Geosciences	6	2014 - 2015	2014 – 2015
Environmental Earth Sciences	3	1.224	0.350 – 0.417
Applied Water Science	2	1.765	0.717- 0.755
Earth Sciences Research Journal	1	-	-
Environmental Science and Pollution Research	1	0.243 - 0.302	0.122 – 0.155
International Journal of Geosciences	1	2.828 - 0.760	0.958 - 0.886
Journal of Maps	1	-	-
Journal of the Indian Society of Remote Sensing	1	1.193 – 1.435	0.519 – 0.596

Table A5. Citations per year.

Year	Citation
2014	3
2015	6
2016	6
2017	2

1. Adhikary, P.P., Chandrasekharan, H., Trivedi, S.M. et al.(2015). GIS applicability to assess spatio-temporal variation of groundwater quality and sustainable use for irrigation, Arab J Geosci. 8: 2699. Springer. doi:10.1007/s12517-014-1415-x
2. Colins, J, Sashikkumar, MC, Anas PA, and Kirubakaran M (2016). GIS-based assessment of aquifer vulnerability using DRASTIC Model: A case study on Kodaganar basin. *Earth Sciences Research Journal* 20(1), H1-H8. doi:http://dx.doi.org/10.15446/esrj.v20n1.52469
3. Hamza SM,Ahsan A, Imteaz MA, and Rahman A(2015).Accomplishment and subjectivity of GIS-based DRASTIC groundwater vulnerability assessment method: a review, Environmental Earth sci., 73: 3063. doi:10.1007/s12665-014-3601-2.
4. Hamza SM, Ahsan A , Imteaz MA , and Ghazali AH(2017). GIS-based FRASTIC model for pollution vulnerability assessment of fractured-rock aquifer systems, Environmental Earth ,76: 197, Springer-Verlag. doi:10.1007/s12665-017-6520-1.
5. Hussain Y, Ullah SF, and Hussain MB(2016). Protective capacity assessment of Vadose Zone material by geo-electrical method: A case study of Pakistan, International Journal of Geosciences, Vol.07, No.05. Doi:10.4236/ijg.2016.75055.

6. Iqbal J, Pathak G, and Gorai AK(2015). Development of hierarchical fuzzy model for groundwater vulnerability to pollution assessment, Arab J Geosci (2015) 8: 2713. Springer, doi:10.1007/s12517-014-1417-8.
7. Kura NU, Ramli MF, Ibrahim S, and Sulaiman WNA(2015).Assessment of groundwater vulnerability to anthropogenic pollution and seawater intrusion in a small tropical island using index-based methods, Environmental Science and Pollution Research22: 1512- Springer, doi:10.1007/s11356-014-3444-0.
8. Nasir MS, Nasir A, Rashid H and Shah SHH(2016). Spatial variability and long-term analysis of groundwater quality of Faisalabad industrial zone, Applied Water Science, pp.1-9.Springer.doi:10.1007/s13201-016-0467-3
9. Nasri N, Chebil M, Guellouz L,and Bouhlila R (2015).Modelling nonpoint source pollution by nitrate of soil in the Mateur plain, northeast of Tunisia, Arab J Geosci, Vol.8, Iss 2, Springer. doi:10.1007/s12517-013-1215-8.
10. Neshat A, Pradhan B, and Shafri HZM (2014) An integrated GIS based statistical model to compute groundwater vulnerability index for decision maker in agricultural area, Journal of the Indian Society of Remote Sensing, Vol. 42, Iss. 4.
11. Sahoo S, Dhar A, Kar A, and Chakraborty D (2016).Index-based groundwater vulnerability mapping using quantitative parameters,Environ Earth Sci (2016) 75: 522.Springer. doi:10.1007/s12665-016-5395-x
12. Shekhar S, Pandey AC, and Tirkey AS (2015).A GIS-based DRASTIC model for assessing groundwater vulnerability in hard rock granitic aquifer, Arabian Journal of Geosciences, Vol.8, Iss. 3. DOI: 10.1007/s12517-014-1285-2.
13. Verma, D.K., Bhunia, G.S., Shit, P.K. et al. (2016). Spatial variability of groundwater quality of Sabour block, Bhagalpur district (Bihar, India), Appl. Water Sci. Springer, pp 1–12.doi:10.1007/s13201-016-0380-9
14. Vidal Montes R, Martinez-Graña AM, Martínez Catalán J R, Ayarza ArribasP, and Sánchez San Román F J (2016). Vulnerability to groundwater contamination, SW Salamanca, Spain, Journal of Maps Vol. 12-2016, Taylor & Francis. Do:http://dx.doi.org/10.1080/17445647.2016.1172271.
15. Wan S, Lei TC, and Chou TY(2014). Optimized object-based image classification: development of landslide knowledge decision support system, Arabian Journal of Geosciences – Vol.7, No.5, Springer. DOI: 10.1007/s12517-013-0952-z
16. Zaineldeen U , Qahman K and Al-Dasht J(2014). Geological structure of the coastal aquifer in the southern part of the Gaza Strip, Palestine, Arabian Journal of Geosciences, 7: 4343.Springer. doi:10.1007/s12517-013-1082-3

EuroKarst 2016 *Book*

17. Taheri K, Taheri M, and Komail MS (2017). Sin-DRASTIC: A Modified Vulnerability Mapping Method for Alluvial Aquifer Hosted by Karst in the North of Hamadan Province, West of Iran. In: Renard P., Bertrand C. (eds) EuroKarst 2016, Neuchâtel. Advances in Karst Science. Springer, Cham, pp 255-271

I.2.2. Google Scholar

According to Google Scholar, the article has been cited 34 times, the same 17 citations recorded by the Springer citation service,3 repeated citations and 14 cited in different journals in Table A6, making a total of 31 citations.

Table A6. Journal citations not recorded by Springer

Journal	Cite	Impact Factor:
Journal of Risk Research:	1	2015, JCR:1.027
Open Engineering	1	-
Journal of African Earth Sciences:	1	2015, JCR:1.652
Arabian Journal of Geosciences:	1	2014, JCR:1.224
Journal of Health:	1	-
International Journal of Innovation and Applied Studies	2	2015 SJIF: 3.92
Stochastic Environmental Research and Risk Assessment	1	JCR: 2.237
Physics and Chemistry of the Earth	1	JCR : 1.7
Academia S. Nacional De Ciencias Ambientales	1	-
Geociências	1	-
Iberoamericana de Ciencias	1	-
环境科学研究	1	-

Source: Google Scholar

The citations in the following articles were not recorded by Springer:

18. Al-Rawabdeh A, Al-Ansari N, Al-Taani A (2014). Modeling the risk of groundwater contamination using modified DRASTIC and GIS in Amman-Zerqa Basin, Jordan, Open Engineering.https://doi.org/10.2478/s13531-013-0163-0.

19. Árcega, I., Otazo, E., Galindo, E., Acevedo, O., & Romo, C. (2015). Determinación del índice de vulnerabilidad mediante el método DRASTIC. Revista: Caso: Acuífero del Valle de Tulancingo, Hidalgo, México.Iberoamericana de Ciencias. ISSN 2334-2501

20. Baghapour MA , Talebbeydokhti N(2014). Assessment of Groundwater Nitrate Pollution and Determination of Groundwater Protection Zones Using DRASTIC

and Composite DRASTIC (CD) Models: The Case of Shiraz Unconfined Aquifer, Journal of Health, Vol 2, No 2,- jhsss.sums.ac.ir

21. Brou, D., Lazare, K. K., Innocent, K. K., Seraphin, K. K., Moussa, S., Brice, K. W. A., & Dago, G. (2013). Evaluation de la Vulnérabilité à la Pollution des Aquifères des Formations Altérites à Partir des Méthodes DRASTIC et SYNTACS: Cas de la ville de M'bahiakro, Centre de la Côte d'Ivoire. International Journal of Innovation and Applied Studies, 2(4), 464-476.
22. Chandoul IR, Bouaziz S,and Dhia HB(2015). Groundwater vulnerability assessment using GIS-based DRASTIC models in shallow aquifer of Gabes North (South East Tunisia), Arabian Journal of Geosciences, 8: 7619,Springer. doi:10.1007/s12517-014-1702-6.
23. de Souza MIRANDA, C., MIOTO, C. L., LASTORIA, G., GABAS, S. G., & PARANHOS FILHO, A. C. (2016). USO DE SISTEMAS DE INFORMAÇÃO GEOGRÁFICA (SIG) NA MODELAGEM DA VULNERABILIDADE DE AQUÍFERO LIVRE: COMPARAÇÃO ENTRE OS MÉTODOS GOD E EKv NA BACIA DO RIO COXIM, SÃO GABRIEL DO OESTE, MS, BRASIL. Geociências (São Paulo), 34(2), 312-322.
24. Hamutoko JT, Wanke H and Voigt HJ(2016). Estimation of groundwater vulnerability to pollution based on DRASTIC in the Niipele sub-basin of the Cuvelai Etosha Basin, Namibia, Physics and Chemistry of the Earth., Volume 93-2016, pp. 46–54, Elsevier.https://doi.org/10.1016/j.pce.2015.12.007.
25. Neh AV, Ako AA, Ayuk AR, and Hosono T (2015). DRASTIC-GIS model for assessing vulnerability to pollution of the phreatic aquiferous formations in Douala–Cameroon,Journal of African Earth Sciences, Vol. 102, Pp. 180–190 – Elsevier. https://doi.org/10.1016/j.jafrearsci.2014.11.001
26. Rezaei, F, Ahmadzadeh M R, and Safavi, H.R. (2016). SOM-DRASTIC: using self-organizing map for evaluating groundwater potential to pollution,Stoch Environ Res Risk Assess,1-16. Springer-Verlag. doi:10.1007/s00477-016-1334-3.
27. Rosas, M. L. S., Acevedo, J. L. R., & Almazán, M. S.(2014).ACADEMIA NACIONAL DE CIENCIAS AMBIENTALES.
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Chapter 5

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SJR: 0.417 Q2

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Valera, C. A., Pissarra, T. C. T., Martins Filho, M. V., Junior, R. V., Fernandes, L. S., & Pacheco, F. A. L. (2017). A legal framework with scientific basis for applying the 'polluter pays principle' to soil conservation in rural watersheds in Brazil. Land Use Policy, 66, *61-71. DOI: 10.1016/j.landusepol.2017.04.036 JCR Impact factor:2.77*

Chapter 6

Abuelaish, Basheer (2018). "Urban land use change analysis and modelling: a case study of the Gaza Strip". In: Camacho Olmedo, Maria Teresa; Paegelow, Martin; Mas, Jean-Françoisand Escobar, Francisco J (Eds.) Geomatic approaches for modeling land change scenarios. Lecture Notes in Geoinformation and Cartography LNGC series (http://www.springer.com/series/7418) Series Editors: Cartwright, W., Gartner, G., Meng, L., Peterson, M.P. ISSN: 1863-2246. Springer Verlag. Berlin, Heidelberg, New York. ISBN: 978-3-319-60800-6

The chapter entitled "Urban land use change analysis and modelling: a case study of the Gaza Strip" appears in the forthcoming "Geomatic Approaches for Modeling Land Change Scenarios -A Review and Comparison of Modeling Techniques", which is scheduled to be published by Springer in 2018.

This book provides a detailed overview of the concepts, techniques, applications, and methodological approaches involved in land use and cover change (LUCC) modeling, also known simply as land change modelling. More than 40 international experts in this field have participated in this book, which illustrates recent advances in LUCC modelling with examples from North and South America, the Middle East, and Europe. Given the broad range of geomatic approaches available, it helps readers select the approach that best meets their needs. The book is structured into three parts preceded by a foreword written by Roger White and a general introduction. Part A consists of four chapters, each of which focuses on a specific stage in the modelling process: calibration, simulation, validation, and scenarios. It presents and explains the fundamental ideas and concepts underlying LUCC modelling. This is complemented by a comparative analysis of the selected software packages, practically applied in various case studies in Part B and described in Part C. Part B is subdivided into two sections: the first discusses recently proposed methodological developments that have enhanced modelling procedures and results, while the second offers case studies as well as interesting, innovative methodological proposals. Part C includes two extensive chapters with technical notes on the different techniques used in LUCC modelling and the best-known software packages used in the applications presented in Parts A and B.

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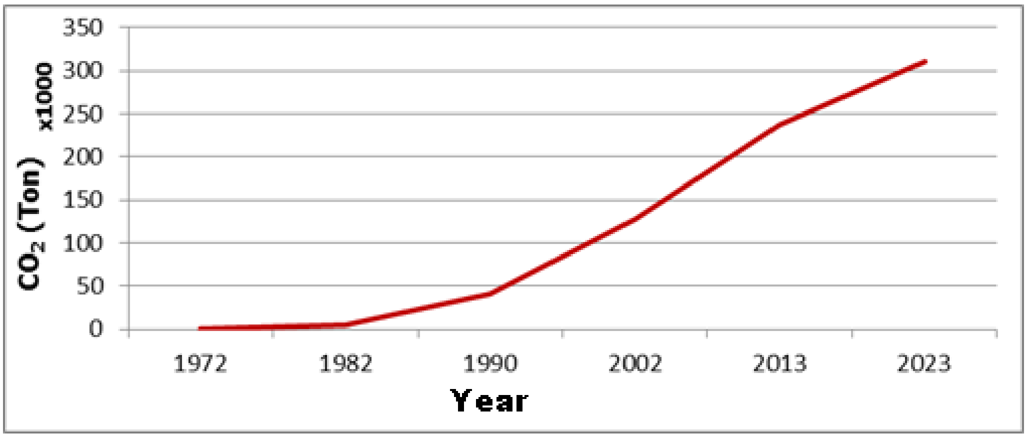
Annex II - CO_2 emissions in the Gaza Strip

Figure A1 illustrates a simple scenario for CO2 emissions for the year 2023 based on a fall in total agricultural area. 1972 is used as the base year. We then show the contribution to the change in emissions.

Figure A1. CO_2 emissions 1972-2013 and the scenario for year 2023.



Source: estimated by student

Carbon dioxide emissions are analyzed within a calculation of the decline in agricultural areas, detecting the effects of CO_2 emissions on climate change for the whole study area.

The data analysis shows an increase in annual CO_2emissions from 2,354 (1972-1982) to 4,427 (1982-1990), 7,293 (1990-2002), 9,851(2002-2013), and 7,383 (2013-2023) ton per year. Table A7 illustrates the increase in the CO_2 emission rate in the Gaza Strip.

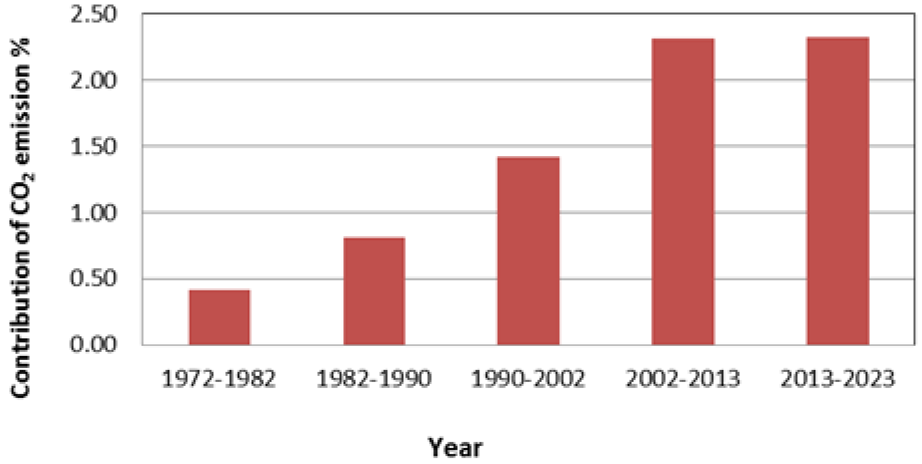
Table A7. Average annual CO_2 emissions (Ton) by periods.

Period	Annual CO_2 (Ton/Year)
1972-1982	2,354
1982-1990	4,427
1990-2002	7,293
2002-2013	9,851
2013-2023	7,383

Source: estimated by student

Using 1972 as the base year, Gaza Strip emissions grew annually (0.41% per year) between 1972 and 1982 in line with population growth and the decline in agriculture. Over the period 1982-1990 the Gaza Strip produced about 0.81% of the world's CO2 emissions. This trend continued over the successive periods 1990-2002, 2002-2013 and 2013 -2023, with consequent increases in emissions to 1.42%, 2.31% and 2.32% of the total. This is likely to continue due to the decline in agricultural areas, as shown in Figure A2.

Figure A2- The annual rate of CO_2 emissions by periods



Source: estimated by student

Earlier we presented an overview of CO_2emissions showing the annual increase in carbon dioxide emission due to the decline in agricultural areas.

There are other reasons for CO_2emissions in the Gaza Strip and the resulting contribution to climate change such as fossil fuel combustion, waste water and soil degradation.

Table A8 illustrates increasing CO_2 emission due to rising consumption of fossil fuels in the Gaza Strip according to data from the Palestinian Central Bureau of Statistics from 1996-2006 (PCBS, 1998, 2002, 2009). The amounts of fossil fuel consumed in the Gaza Strip are converted into carbon dioxide using the International Carbon Bank and Exchange website http://www.icbe.com/carbondatabase/volumeconverter.asp. Table A8 illustrates the annual increase in CO_2 emissions due to rising fossil fuel consumption.

Table A8. CO_2emissions (Ton) due to fossil fuel combustion (1996-2006).

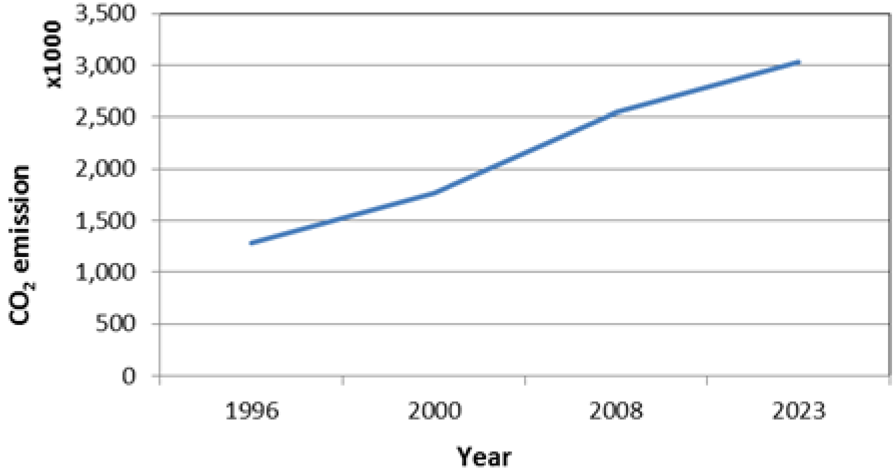
Year	Wood and Coal (Ton)	LPG (Ton)	Diesel (Ton)	Kerosene (Ton)	Gasoline (Ton)
1996	1,229,988	2,751	28,764	7,653	15,706
2000	1,709,964	3,644	41,498	660	10,261
2008	2,119,979	66,790	354,463	1,298	9,677

Source: estimated by student

Figure A3 shows the sharp rise in fossil fuel based CO_2 emission from 1,284,860 Tons in 1996 to 2,552,206 Tons in 2008. The predicted scenario for 2023 is 3,028,751 Tons.

Another means of assessing increases in fossil fuel consumption and CO_2 emission is by studying the increasing number of cars and their consumption of fuel, from around 46,898 vehicles in 1998 to 59,147 in 2006, 60,901 in 2010 and 70,000 in 2017.

Figure A3. Fossil Fuel CO_2 emissions in the Gaza Strip (1996-2023)



Source: estimated by student

Waste water treatment Plants (WWTPs) also produce greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) during the biological wastewater treatment processes. CO_2 is also emitted during the production of the energy required for operating the plant. The CO_2 released due to energy demand can be directly reduced by enhancing the energy efficiency of the WWTPs (Campos et al., 2016). The Gaza Strip produces around 120,000 cubic meters of wastewater everyday. About three quarters of this amount (90,000 cubic meters) has to be discharged into the sea, as the WWTPs do not have sufficient capacity to process such large quantities.