# مجلة العلوم الاجتماعية

فصلية علمية محكمة - تصدر عن مجلس النشر العلمي - جامعة الكويت

## محاكاة تأثير انهيار الاقتصاد النفطي في دولة الكويت بين عامي 2020-2050 لدى السكان باستخدام نظم المعلومات الجغرافية.

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# محاكاة تأثير انهيار الاقتصاد النفطي في دولة الكويت بين عامي 2020–2050 لدى السكان باستخدام نظم المعلومات الجغرافية

سعد مفلح الغريب
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**ملخص:**

**هدف الدراسة:** تركز هذه الدراسة على العلاقة بين عدد المهاجرين وانخفاض عدد السكان في الكويت؛ نتيجة هبوط عائدات النفط؛ إذ إن الناتج الإجمالي المحلي لدولة الكويت يعتمد على الصناعات النفطية بنسبة 90%. ومن المتوقع أن يكون لانخفاض عدد السكان تأثيرات كبيرة في الخطط المستقبلية وصنع القرار في الدولة. **المنهجية:** استخدم في هذه الدراسة نموذج جيومكاني، يعتمد على نظم المعلومات الجغرافية والنمذجة بالاعتماد على الوكلاء لمحاكاة مدى انخفاض عدد السكان وتأثيرات ذلك في المناطق السكنية والاستثمارية في الكويت في حال حدوث أزمة بأسعار النفط بين عامي 2020 – 2050، وذلك وفقاً لستة سيناريوهات مختلفة. **النتائج:** وجدت الدراسة أن المناطق التي ستشهد انخفاضاً حاداً في عدد السكان ستكون هي المناطق الاستثمارية، ويعود سبب ذلك إلى أن أغلب قاطنيها هم من الوافدين الذين يعتبرون أول من سيهاجر خلال الأزمة. **الخلاصة:** يجب على حكومة دولة الكويت أن تعيد توزيع السكان بحسب الجنسية في المناطق الاستثمارية، كما أنه يجب عليها وضع خطة للطوارئ في حال انهيار أسعار النفط في المستقبل؛ مثل وقف إنشاء المدن الجديدة.

**المصطلحات الأساسية:** دولة الكويت، السكان، النفط، نظم المعلومات الجغرافية، النمذجة باستخدام الوكلاء.

# Simulation of the Impact of Oil Crisis on Population Decline in Kuwait between 2020-2050 by Using GIS

***Saad Algharib*** (*)
***Nayef Alghais*** (**)

**Abstract:**

**Objective:** This research paper examines the relationship that holds between the number of emigrants and population decline in Kuwait because of dropping oil revenue as Kuwait's GDP is 90% dependent on oil industry; population decline is expected to have severe impacts on future planning and policy making decisions. **Methods:** This paper applied an Agent Based Model (ABM) in ArcGIS to simulate the extent of the population decline and its impacts on specific suburbs around the State of Kuwait in case the oil crisis eventuates between 2020-2050 according to six possible scenarios. **Results:** The study found that districts expected to experience sharp population decline shall be in the commercial areas since they comprise the majority of non--Kuwaiti residents in Kuwait, who shall be the first to emigrate during a crisis. **Conclusion:** the Kuwaiti government should re--evaluate the distribution of its population based on nationality in commercial areas; also, it should prepare a contingency plan in case of a probable oil price collapse in future such as considering a halt on the process of new cities establishments.

**Keywords:** Kuwait, Population, Oil economy, GIS, Agent Based Modelling.

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# Introduction

Research on population geography and demographics is important to identify complex patterns pertaining to behavioral, social, environmental and economic phenomena in a particular region. The findings from such work are necessary for policy makers to secure future needs of the populace, like food supply and housing. Population geographers and demographers include age, gender ratios, population density, migration rates, birth and death rates and labor force characteristics in their attempt to detect underlying patterns and extract useful predictions about the national and local societies and economies (Newbold, 2017). Researching the effects of population geography on the economy is of particular significance; it has been established that one of the driving forces of economic growth and planning policy is population growth (Jonge, 2010). The three main factors that influence population growth rate are birth rate, mortality, and migration (Clarke, 1978; Newbold, 2017). In this article, the correlation of these population growth factors will be examined in relation to oil economy in Kuwait.

## 1. Kuwait background

The State of Kuwait is a small country located in the north west of the Arabian Gulf that faced profound transformations over the last century. Kuwait's transformation has been evident since 1946, when the oil industry set hold in the country. At the time, there was no planning at all for urban development and accommodating any notable population growth. The discovery of oil in Kuwait had a huge impact on the population of Kuwait City. The size of the city increased rapidly due to the domestic migration and immigrants arriving from foreign countries seeking better opportunities. Kuwait City became one of the fastest expanding cities in the world, but the capacity of the city could not meet the demand of accommodating all new immigrants. For these reasons, the government has adopted three master plans since 1952 that have transformed Kuwait City from unplanned small coastal town to a modern city.

## 2. The history of population in Kuwait

Before the development of oil industry, the population of Kuwait was not as diverse. During the 18th and 19th centuries, Kuwait City was a small fishing village, primarily populated by fishermen and pearl divers. In 1938, just before the oil boom, the population was around 150,000 (Al-Damkhi et al., 2008). The first official census after the commercial oil explorations began in 1946, was carried out in 1957 and showed that the Kuwaiti population (citizens) was around 206,000 whereas non-Kuwaitis (non-citizens) were around 93,000 persons. This represented an almost doubling of the population from just years ago. Since 1965, regular censuses have been conducted, and the population reached 2,151,680 in 1990 consisting of 72% non-citizens (PACI, 2020).

During the Iraqi invasion in the early 1990s, the population of Kuwait decreased to 1,600,000, as around 400,000 Kuwaitis and several hundred thousand of non-citizens fled the country (Human Rights Watch, 1991). Notably, the Indian government implemented the largest civilian evacuation in history (more than 170,000 persons in 488 flights) (Venkataramakrishnan, 2014). After the liberation of Kuwait, the population started to increase dramatically again and reached 2,200,000 in 1998. According to the central statistics office, the population of Kuwait was estimated to be 4,776,407 in 2020, out of which 1,432,045 were citizens, while the rest were expatriates (3,344,362) (PACI, 2020). Thus, non-citizens are twice as much as the citizens in Kuwait which is considered a huge demographic challenge in Kuwait (Al-Ramadan, 2009). The variation of the population of Kuwait can be seen in (Fig. 1) (Populationof.net, 2019). Furthermore, (Fig. 2) shows the land use zones in Kuwait City as of 2020.

**Figure 1.** *Population growth in Kuwait 1955-2020 (Population of.net, 2019)*

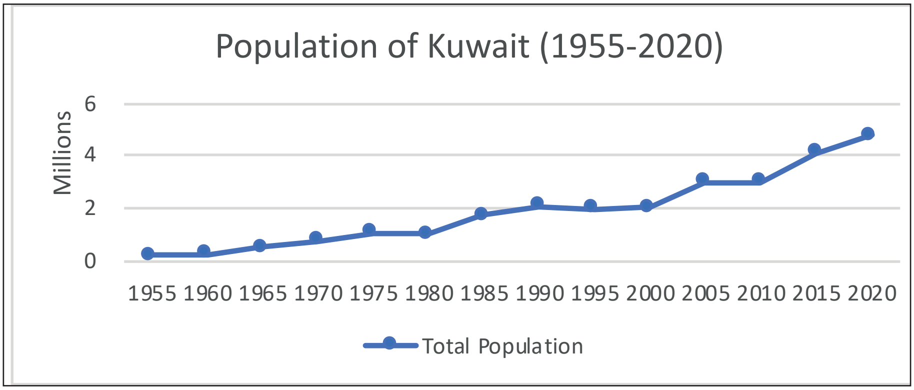
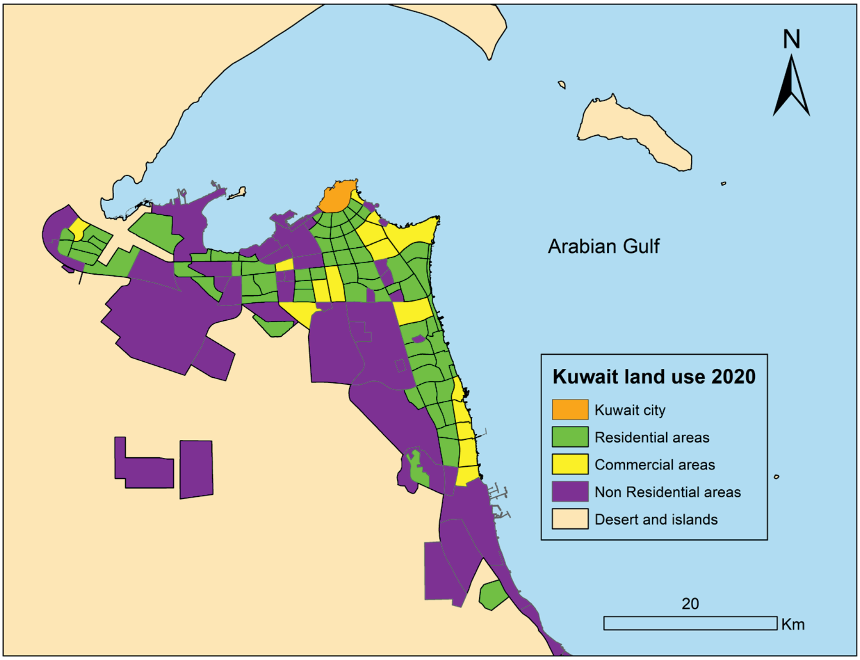



**Figure 2.** *Kuwait land use in 2020*.




## 3. Reliance on oil

According to the World Bank (2016), oil industry contributes more than 90% to Kuwait's Gross Domestic Product (GDP). As of 2015, Kuwait had the biggest fiscal surplus of any country in the GCC. However, in 2015, Kuwait experienced a shortfall of 3.6% in GDP due to a slump in oil revenues of about 15 billion dollars (World Bank, 2016). Oil prices declined significantly in the second half of 2014 and caused that significant economic contraction. Since then, oil prices have never recovered to pre-2014 levels. For instance, in the second half of 2019, the average oil price was $57 per barrel compared to $100 per barrel during the period of 2011- 2014 (Macrotrends, 2019). As such, any macroscopic trend that causes future slump in oil prices shall impose a significant risk of economic collapse in Kuwait.

## 4. Potential triggers for oil price collapse

### 4.1. Renewable sources

Renewable energy sources have been gaining ground over the years, as a response to global warming that is broadly believed to be associated with human activities, predominantly the use of fossil fuels. The adoption of renewable energy sources has been accelerated by falling costs of wind and solar powers (The Economist, 2017). It is believed that soon renewable energy will continue to displace significant parts of fossil fuel generation and result in a decline in the demand for fossil fuels.

### 4.2. War

According to (Colgan, 2013) oil was among the leading causes of war and it has been responsible for more than 50% of all interstate wars since 1973. Resource wars may occur when states or individuals attempt to acquire oil reserves by force, as was the case with Saddam Hussein when Iraq invaded Kuwait. Oil revenues are valuable in order to finance insurgencies and conflicts triggered by prospects of regional domination. Naturally, war creates an unstable environment for the drilling and transportation of oil and as such has the potential to cause the collapse of economies that are reliant on it.

### 4.3. Shale oil

Shale oil production in the United States has expanded at a fast rate since 2011 and now rivals the crude oil production of OPEC member countries, which have been slow to adapt to this new disruption in supply. Shale oil has affected the structure of oil market and influenced the decision of OPEC whether to target stabilization of prices or protecting market share. A period of prolonged oversupply of oil resulting in low oil prices between the end of 2014 and the end of 2019 was the result of interplay of these factors (Alvarez & Di Nino, 2017).

## 5. Economic collapse case studies

### 5.1. Shrinking cities in Germany

According to (Franz, 2004) shrinking cities from the standpoint of urban development are characterized by a faltering economic momentum exacerbated by a loss of population. The rate of growth of population is, therefore, regarded as a proxy indicator of economic growth (Franz, 2004). A decline in population figures indicates stagnation or contraction of the economy. For instance, after the fall of the Berlin Wall in 1989, the public started leaving former East Germany, whose economy was dependent on obsolete industries; particularly, the younger demographic moved in masse to the West resulting in the shrinking of East German cities and laying further burden on their economy as there were significant shortages of labor (Delken, 2008).

The repercussions of these events are evident even today, as cities in Germany are facing a near irreversible decline, and it is predicted that two in every five Germans will be over the age of 60 by 2050. Additionally, the population of the country is expected to shrink from 82 million to 75 million people. As a result of the declining population in Germany's shrinking cities most houses and shops have been left empty. This could happen in Kuwait in case oil economy collapsed and most young citizens and non-citizens decided to emigrate.

## 5.2. Detroit in US

Detroit was once among the wealthiest cities in United States, but today it is a decrepit and dwindling place. In the 1950s, Detroit had the highest rate of residence ownership, as well as the highest median income in the US. However, the city experienced white flight and the collapse of its auto industry manufacturing base. The white flight was a result of a series of class conflicts coupled with racial conflicts, which resulted in mass migration. The manufacturing companies moved their production bases to other places in an attempt to access cheaper labor and tap into emerging markets. As a result, the population of the city shrunk from 2 million people in the 2000s to 900,000. Detroit suburbs presently contain rows of dilapidated houses, empty apartment buildings and factories, while the unemployment rate is close to 29% (Harris, 2009). The city's tax revenue has consequently been on the decline, with a deficit of $326 million as of 2012. Detroit declared bankruptcy in 2013 and is the biggest municipality to do so in the US (Schindler, 2014). In worst case scenario, this situation can be seen in Kuwait if its oil economy collapsed.

## 6. Using GIS in population decline studies:

Population changes and the respective planning responses can be investigated using Geographic Information System (GIS). Ayeni and Adewale (2002) stated that GIS is a fundamental tool in planning, development, and management of the human population. For example, GIS and mobile phone data has been utilized to determine and map population changes through observation of temporal variations in certain cities in Lisbon and Paris (Deville et al., 2014). Jonge (2010) used GIS to analyze the reasons behind population changes; he attempted to identify the spatial factors behind the population decline in the province of Fryslan in the Netherlands over the years 2000-2008. In that study, two GIS applications for visualization of spatial patterns and spatial analysis were used, and the average nearest neighbor function was utilized to find out the distribution of feature over space. It was found that the spatial distribution of cores over space was random.

## Research questions and objectives:

The research focus of this paper is on studying the relationship between the number of emigrants and population decline in Kuwait. In Kuwait, the main risk of major emigration is a notable drop in oil revenue, followed by the risk of geopolitical tensions and/or war in the region. Regardless of the reason, population decline is expected to have severe impacts on future planning and policy making decisions. In this paper, population decline in Kuwait will be modeled by using GIS and Agent Based Model (ABM), and the research questions investigated are the following:

1- What would be the population growth rate in case of an oil economy collapse in Kuwait?

2- What would be the spatial emigration patterns in case of an oil economy collapse in Kuwait?

3- How may the future population change and how to model the distribution ?

## Thus, the study objectives are:

1- To identify the future population growth rate under the worst-case scenario in Kuwait.

2- To predict the most affected districts by emigration in Kuwait by GIS and ABM.

3- To simulate the future distribution of population in Kuwait by GIS and ABM.

It is important to mention that this research is a part of a larger project that involves further varying scenarios based on different inputs and variables. Thus, this paper will be a foundation for this larger project.

# Methodology

## 1. Data sources and preparation

Various sources were used to collect necessary data for the model proposed in this study, as seen in Table 1. The data was prepared to be used in ArcMap and ABM as follows:

**Table 1.** *Data sources*

| Data | Type/ format | Sources |
|---|---|---|
| Kuwait's current districts | GIS ready data (Polygon (feature class | Vision International), (2020 |
| Kuwait's road network | GIS ready data (Line fea- (ture class | Vision International), (2020 |
| District population on 31st Dec 2019 | Excel tables | (PACI, 2020) |
| Future cities locations | Images | Kuwait Municipality), (2020 |
| Future road network | Images | Kuwait Municipality), (2020 |
| Future cities capacities and open dates | PDF and online texts | (PAHW, 2020) |
| Population projections 2020-2050 | Tables | (KISR, 2019) |

– Future cities and future streets were added / drawn with the Georeferencing tool as polygon and line feature classes.

– All new cities were divided as districts manually according to the master plan where possible.

- Tables were manually imported in the attribute tables of districts layers as new fields for citizen population, non-citizens population, total population, future city capacities and open dates for each district. Both current and future districts were classified as residential, commercial, and non-residential.

After the data preparation, the following spatial data analysis tasks were completed:

- Distance calculation of each district to Kuwait Capital: Polygon to Point Tool and Near Tool.

- Distance calculation of each district to the main street network: Polygon to point Tool and Near Tool.

- Distance calculation of all residential districts to the nearest commercial district: Near Tool.

- Distance calculation of all future cities to the current urban area: Near Tool.

- Distance calculation of all future cities' districts to the center of their own cities: Near Tool.

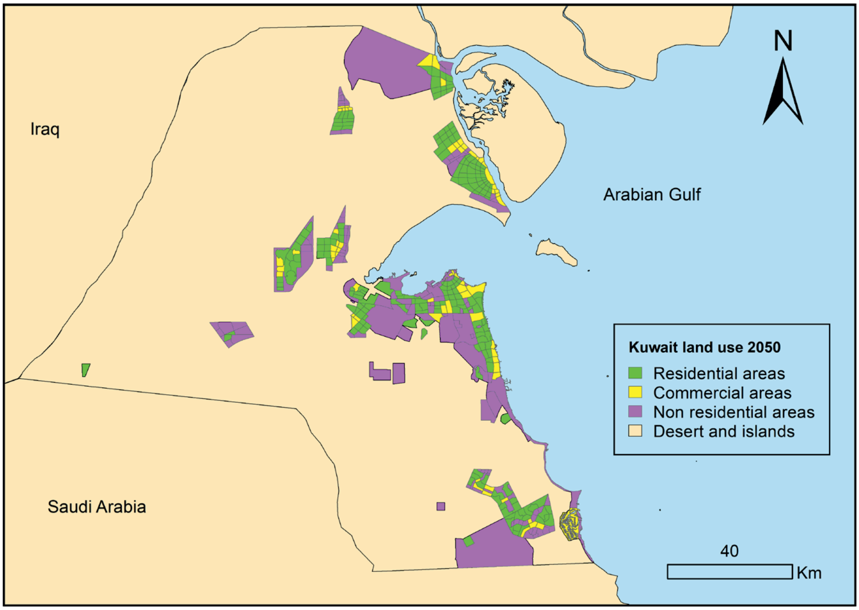
Analysis of historical data was also conducted in two recently opened cities (Jaber Al-Ahmed City and Sabah Al-Ahmed City) to understand the district capacity fill rate within a period of 5 years. It was found that 40% of their maximum capacity was filled in 5 years. This percentage was used in moving to future cities action. Additionally, the current ratio of citizens to non-citizens based on districts type was analyzed and it was found that:

- Residential districts have a citizen to non-citizen ratio of approximately 50%: 50%.

- Commercial districts have a citizen to non-citizen ratio of approximately 10%: 90%.

Finally, population projection data was entered as two .txt files (for both citizens and non-citizens) for six future time points (2025, 2030, 2035, 2040, 2045 and 2050). Figure 3 shows the land use of Kuwait for 2050 as an outcome of the preparation step (can be compared with Figure 2).

**Figure 3.** *Kuwait land use in 2050*




## 2. Agent Based Modelling

### 2.1. Background

An increase in applications of Agent Based Modelling (ABM) in simulation of geographical system dynamics has been evident in recent years. ABM enables the analysis of systems via the interactions of individuals (or groups of individuals) with unique characteristics and rule sets. Interactions between agents such as cities and humans or agents and the environment may vary through time and space. Application of ABM pertains to various matters including social issues, such as people's behavior based on their needs, desires and patterns of health, culture, conflict, diseases, etc. (El-Sayed et al., 2012).

Traditional models have been beneficial and produced reliable results; nevertheless, the treatment of all geographical elements in homogeneity is an inherent limitation that cannot be ignored (Johnston, 2013). The development of the automata approach has helped address the homogeneity issue and increased the use of ABM. Macal and North (2014), refer to automata as a processing mechanism with elements (like the ABM agents) that change over time, due to influence of internal aspects, external elements, and rules.

In ABM models, an agent may be a representation of entities such as people, insects, and pieces of land etc. Several features identify an agent including autonomy, heterogeneity, and the ability to interact with other agents and their environment under certain rules. A rule may be applied to all agents, each agent separately or to groups of agents (Lee & Malkawi, 2014). Johnston (2013) identifies various circumstances where ABM can be suitable including where interactions between agents are discontinuous, where heterogeneity is imperative, and where agents portray complex behavior. One such field is urban modeling, which involves analysis of land use, planning in urban centers or planning for the location of residential homes. The major limitation of ABM is its computational complexity, due to the utilization of multiple variables.

### *2.2. Model design*

In this study, the ABM extension “Agent Analyst extension ArcGIS” (Johnston, 2013) was used in ArcMap to model the population decline in case of oil economy collapse in Kuwait. The model simulates the population decline in a worst-case scenario, like the Iraqi invasion in 1990, where approximately 70% of population left Kuwait (Human Rights Watch, 1991). The model simulates six 5-year intervals from 2020 to 2050 and six different scenarios and it assumes that the collapse may happen during any of these intervals:

1- Scenario 1 assumes that oil economy shall collapse between 2020-2025

2- Scenario 2 assumes that oil economy shall collapse between 2025-2030

3- Scenario 3 assumes that oil economy shall collapse between 2030-2035

4- Scenario 4 assumes that oil economy shall collapse between 2035-2040

5- Scenario 5 assumes that oil economy shall collapse between 2040-2045

6- Scenario 6 assumes that oil economy shall collapse between 2045-2050

**The model consists of the following components:**

1. Agents and respective traits:

a. Citizens or Kuwaitis, who mostly live in residential districts.

b. Non-Citizens or non-Kuwaitis, who mostly live in commercial districts.

c. Planning authorities: Kuwait Municipality and Public Authority of Housing Welfare (PAHW) which open the future cities.

2. Environment: Districts where citizens and non-citizens live.

3. Actions and rules based on agents (Table 2).

**Table 2.** *Actions and rules for the model's agents*

| Action | Agent | Rule/explanation |
|---|---|---|
| Open future cities | Planning authorities | Based on official planned open date. |
| Moving to future cities | Citizens & Non-citizens | After opening a future city, citizens and non-citizens will move in until 40% of the future city's .capacity is reached |
| Distributing | Citizens & Non-citizens | Distributing new population in old districts based on population projection data:<br>- Add newborn citizens and non-citizens.<br>- Add new incoming immigrants (non-citizens).<br>- Remove deceased and departing immigrants (both citizens and non-citizens). |

| Action | Agent | Rule/explanation |
|---|---|---|
| Internal migration | Citizens & Non-citizens | Random movement of 5% citizens and non-citi-.zens between the old districts |
| Declining | Citizens & Non-citizens | Decline the population in the collapse period by .up to 70% of total population |
| Correction | Citizens & Non-citizens | - Add all remaining population that are less than 1000 person randomly in districts.<br>- Merge all numbers of population that are less than 1 person (i.e. decimal number) and then add them randomly in districts. If there are remainder less than 1 after that, delete them.<br>- Ensure that the total population ratio is correct for both citizens and non-citizens. |

## 3. Model parameters

Several parameters were used in the model, and they were summarized in Table 3.

**Table 3.** *Model's parameters*

| Parameter | Description | Steps application |
|---|---|---|
| Population addition | Adding new population (newborn & new immigrants) or moving population by 1000 person each period | Moving to future city<br>Distributing<br>Internal migration |
| Residential districts percentage for citizens | Ensures that each residential district will hold citizens and non-citizens in the correct ratio of 50%-50%. | Moving to future city<br>Distributing<br>Internal migration |
| Residential districts percentage for non-citizens | | |
| Commercial districts percentage for citizens | Ensures that each commercial district holds 10% citizens. | Moving to future city<br>Distributing<br>Internal migration |
| Commercial districts percentage for non-citizens | Ensures that each commercial district holds 90% non-citizens. | |
| Internal migration percentage | 5% of all population moves randomly between districts. | Internal migration |
| End year | The end year of the model: 1 to 6, with each interval representing 5 years (i.e., 1 = 2025, 6 = 2050) | Start the model<br>Open future cities<br>End the model |

| Parameter | Description | Steps application |
|---|---|---|
| Citizens declining percentage | Set to 70% of all citizens across all districts. | Declining |
| Non-citizens declining percentage | Set to 70% of all non-citizens across all districts. | |
| Maximum capacity of future cities percentage | 40% of each district capacity to be filled with new residents in each period | Moving to future city |
| Suitability parameters weight percentages | For 5 parameters to equal 100%. | Moving to future city<br>Distributing<br>Internal migration |

## 4. Model assumptions

Due to lack of real data as the model simulates future scenarios from 2020 to 2050, some assumptions were necessary:

- Declining population percentage of 70% on total, as per the worst-case scenario of population decline during the Iraqi invasion in 1990-1991.
- Declining percentage of 70% for both citizens and non-citizens. This assumption was based on unofficial data and by comparing the citizens and non-citizens departures from Kuwait during the Iraqi invasion.
- The internal migration percentage was estimated to be 5%, as there is no available data; however, based on the authors' knowledge, it is a reliable forecast for 5-year periods.

- Suitability parameters and weights were estimated by the authors' knowledge, as they are Kuwaitis living in Kuwait and understand the local society.
- Citizens and non-citizens percentage distribution on different district types was estimated based on historical trends.
- New population was added in chunks of 1,000 instead of single residents at a time to reduce computational time.

## 5. Suitability model

Citizens and non-citizens perform three main actions in the model: movement (i.e., ving to future cities), distribution, and internal migration. These actions are dictated by certain parameters with weights. These parameters and their weights were:

1- Nearness to current urban area: 30%

2- Nearness to Kuwait City (capital): 30%

3- Nearness to streets network: 20%

4- Nearness to the closest commercial district: 10%

5- Nearness to future city center: 10%*

*Applied only for future cities; otherwise, Nearness to Kuwait Capital parameter weight was 40%.

## 6. Model Algorithm

The model simulation runs according to the following steps:

1- Starting the simulations

In this step, the input data is loaded as feature classes in ArcMap to start at the year 2020. Also, the chosen end year is selected.

2- Check step

In this step, the model will check several objectives:

- Suitability weights to ensure their sum equals 100%.
- The numbers of newborn citizens, non-citizens, and new incoming immigrants of non-citizens to be used in further steps.
- The numbers of newly deceased and emigrants of citizens and non--citizens.

3- Open future cities step

Planning authorities open the future new cities based on their official projected open dates according to an if/else rule applied in every interval.

4- Moving to future cities step

Both citizens and non-citizens will be allocated to the newly established cities from old districts based on the suitability weights and under three assumptions:

a. District type percentages of citizens and non-citizens matching the values explained earlier for both new districts in new cities and old districts.
b. 40% of the maximum capacity of each new district in future cities is reached.
c. The type of the new district changes to old district for the next period.

5- Distributing step

All newborn citizens, non-citizens, and new incoming immigrants are distributed in old districts according to the suitability weights and after considering the preset district type percentages of citizens and non-citizens.

6- Internal migration step

In this step, 5% of the population in all districts is moved randomly from their current district to another to simulate internal migration. The suitability parameters and district type percentages of citizens and non-citizens rules still apply.

7- Declining step

In this step, a specific percentage of all population is removed from the district under the assumption that 70% of the population will leave Kuwait 5 years after an event of oil economy collapse. This event's timing depends on the scenario being simulated.

8- Correction step

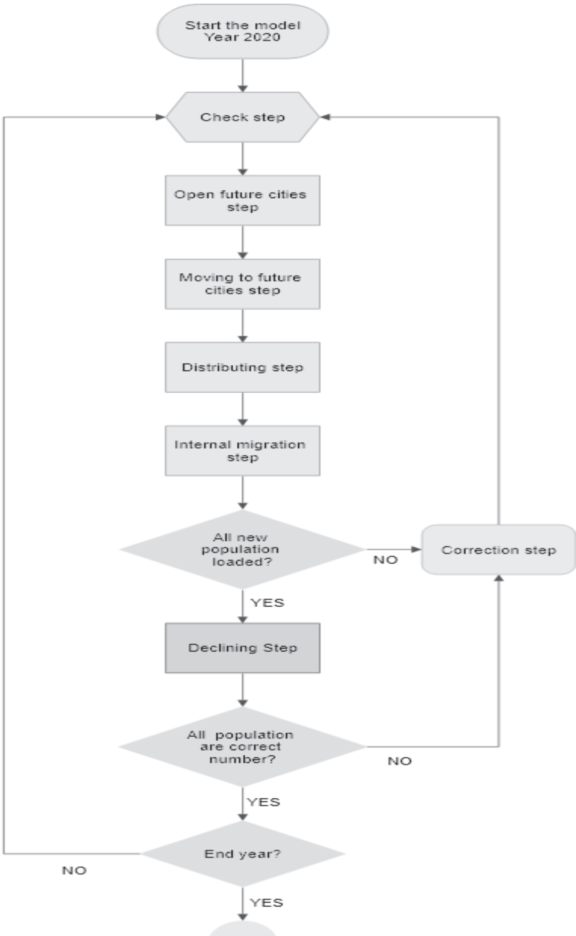
This step is activated twice (before and after the declining step) and involves several calculations to ensure that all the population is added correctly and the number of residents is not a decimal number.

9- Simulation end

The display map is updated, and the outcomes are saved.

Figure 4. shows the model flowchart.

**Figure 4.** *Model flowchart*




# Results

## 1- 1- Impacts of oil economy collapse on population size, growth rate and urban density

As shown in Table 4, the population change rate in any scenario will be approximately -13 to -14% per period. However, there is a huge different between the simulation outcomes and the growth rates projected under normal circumstances (no oil economy collapse). The scenarios with the biggest differences in growth rates versus the normal circumstances scenario are scenarios 6 and 1 respectively.

**Table 4.** *Population before and after the model*

| Scenario | Years | Reality & Projection | | | | | | Simulation outcomes | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Urban area ($km^2$) | Citizens | Non-citizens | Total | Growth rate* | Urban density (person/ $km^2$) | Citizens | Non-citi-zens | Total | Growth rate* | Urban density (person/ $km^2$) |
| Current situation | 2020 | 355.65 | 1,432,045 | 3,344,362 | 4,776,407 | 3.4% | 13,430.1 | - | - | - | - | |
| 1 | 2020-2025 | 496.55 | 1,526,257 | 3,441,472 | 4,967,729 | 0.8% | 10,004.5 | 457,877 | 1,032,441 | 1,490,318 | -13.8% | 3,001.3 |
| 2 | 2020-2030 | 652.9 | 1,623,321 | 3,680,158 | 5,303,479 | 1.4% | 8,122.9 | 486,996 | 1,104,047 | 1,591,043 | -13.6% | 2,436.9 |
| 3 | 2020-2035 | 807.3 | 1,734,708 | 3,921,948 | 5,656,656 | 1.3% | 7,006.9 | 520,412 | 1,176,584 | 1,696,996 | -13.6% | 2,102.1 |
| 4 | 2020-2040 | 1,019.6 | 1,844,550 | 4,092,750 | 5,937,300 | 1% | 5,823.2 | 553,365 | 1,227,825 | 1,781,190 | -13.7% | 1,746.9 |
| 5 | 2020-2045 | 1,070.9 | 1,945,788 | 4,197,654 | 6,143,442 | 0.7% | 5,736.7 | 583,736 | 1,259,296 | 1,843,032 | -13.8% | 1,721.0 |
| 6 | 2020-2050 | 1,158.6 | 2,036,043 | 4,206,167 | 6,242,210 | 0.3% | 5,387.7 | 610,813 | 1,261,850 | 1,872,663 | -13.9% | 1,616.3 |

*** Growth rate is based on 5 years.**

Urban density is expected to decrease even under the normal circumstances, due to the increasing space of future cities. According to the model scenarios, it will decrease more dramatically between 3,800 to 7,000 people/ $km^2$ as the additional impact of a declining population is accounted for.

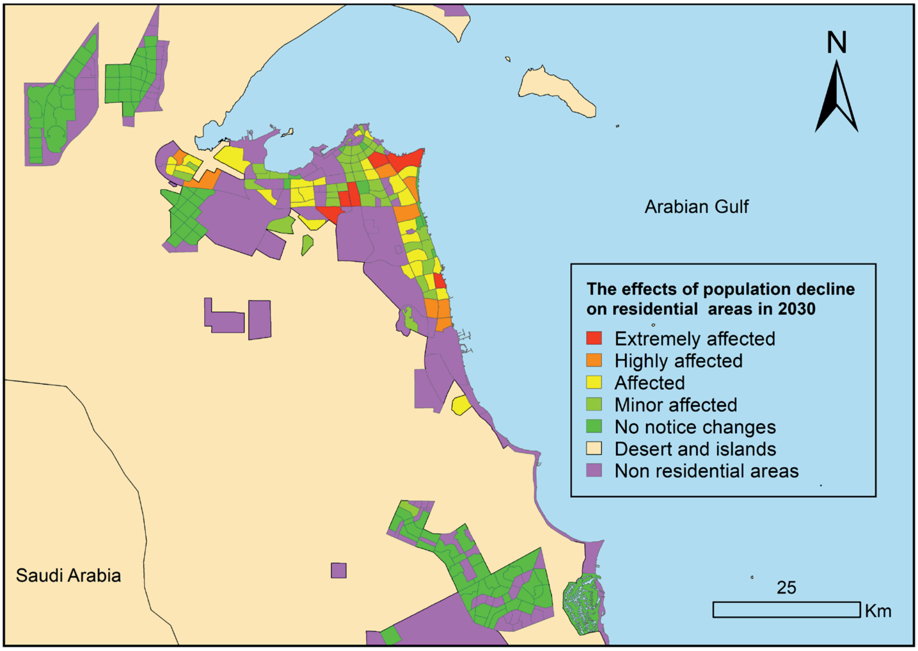
**2. Impacts of oil economy collapse on different districts**

The calculation used to evaluate the impacts of the collapse on different districts was based on subtracting the total population in each district after running the model (declining step) from the projected population in districts before that step. This calculation was applied for both residential and commercial areas.

*2.1. Impacts in scenarios 1, 2 and 3*

The first three scenarios demonstrated very similar outcomes in regard to population declines. As shown in Figure 5, the most affected areas were Salmiya and Hawally (in Hawally governorate), Khaitan, Farwaniyah and Jeleeb Alshuyoukh (in Al Farwaniyah governorate), Mahboula (in Al Ahmadi governorate). Other highly affected districts in scenarios 1-3 were Fahaheel, Mangaf and Subahiya (in Al Ahmadi governorate), Salwa and Jabriya (in Hawally governorate), Sabah Alsalem (in Mubarak Al-Kabeer Governorate), and Saad Alabdullah and Jahra (in Al Jahra governorate). The Al Asimah governorate was the least affected governorate. Overall, commercial areas experienced a higher decline than residential districts.

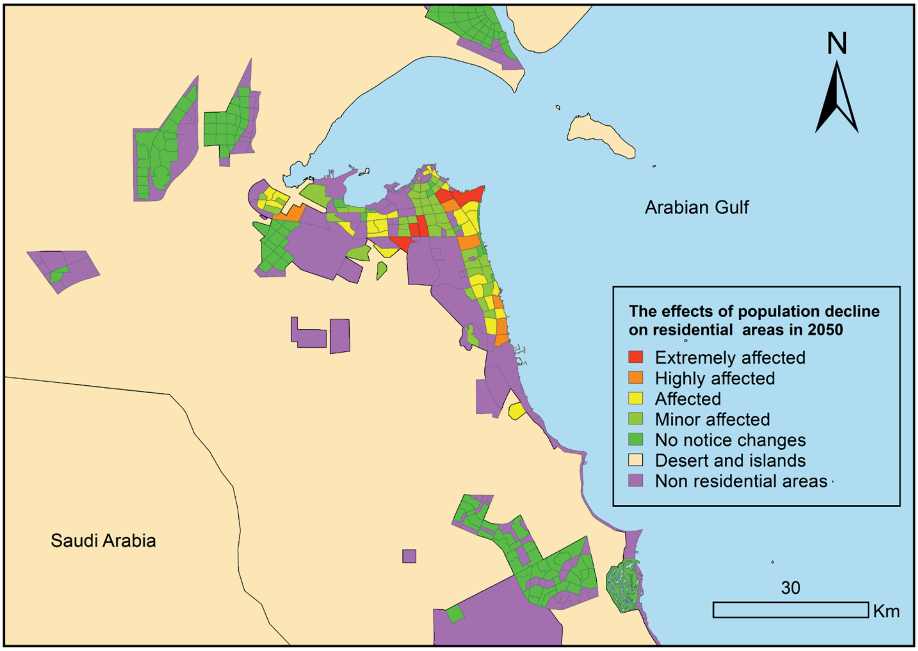
**Figure 5.** *Outcome map for Scenarios 1, 2 & 3*




*2.2. Impacts in scenarios 4, 5 and 6*

The last three scenarios also showed a relatively similar decline in population when compared to each other. Under these scenarios, the districts that experienced the highest declines were similar to scenarios 1-3, except Mahboula (in Al Ahmadi governorate) that was projected to see significantly higher declines than in the first three scenarios. Subahiya (in Al Ahmadi governorate), Salwa (in Hawally governorate) and Jahra (in Al Jahra governorate) were less affected than in the first three scenarios. All newly opened cities were not affected by the population declining compared to other districts, for these cities will be mostly occupied by citizens. The results can be seen in the map of Figure 6.

**Figure 6.** *Outcome map for Scenarios 4, 5 & 6*




## Discussion and conclusion

This paper investigated different scenarios of population decline because of a potential oil economy collapse in Kuwait between 2020 and 2050. The oil economy collapse in Kuwait could be like other case studies, such as the shrinking cities in Germany, and Detroit in the US. Higher penetration of renewable energy sources, supply of shale oil, geopolitical tensions, or black swan events (like the recent COVID-19 pandemic) are all factors that could adversely impact the oil economy. This research assumed that in the worst-case scenario of a major oil crisis, 70% of the population will leave Kuwait, as its economy is tied to the oil industry. This is a similar percentage to the population declines seen in Kuwait during the Iraqi invasion in 1990-1991. GIS (ArcMap) and ABM were used to simulate the population declines under different scenarios. The outcomes included the future population distribution, growth rates and urban density in Kuwait from 2020 to 2050 investigated over six different rolling periods of 5 years.

Although data was not available for certain demographic parameters, certain assumptions based on the authors' knowledge and expertise were taken into consideration to ensure the highest degree of realism in the model simulations. It was found that the population distribution will be affected mostly in commercial areas, as these areas are home to the majority of non-citizens (who form the majority of the total population in Kuwait), and they are expected to be the first ones to flee the country in case of a major crisis. As expected, in such an event, the predicted growth rates were sharply lower with major emigration outflows. Urban density was also projected to heavily decline due to a lower population and cities spanning over larger areas.

Planning authorities in Kuwait should consider these predictions in their contingency plans and make appropriate adjustments in the rate they plan to open new cities. Another suggestion that can be extracted from the results is that the government must re-evaluate its incentives to balance the population distribution between citizens and non-citizens in commercial areas (currently in the ratio of 10% to 90%). As major commercial areas are predicted to be abandoned from non-citizens in large numbers, many small businesses and buildings will be closed and may remain vacant for long. Kuwait's government should consider re-urbanization plans (like repurposing some vacant spaces to public facilities) and relocating population from older suburbs to the most severely affected districts in case of a crisis instead of opening new cities. Without any such contingency plans, it is expected that many commercial districts and/or new cities will be ghost cities in the event of a major oil crisis.

Future research work directions include investigating residents' circumstances and characteristics that could influence their decision to stay or leave Kuwait in case of a major oil crisis. This could be achieved by directly surveying people in Kuwait. The suitability weights used in the model may also be modified according to the responses from the survey to achieve more realistic outcomes. Furthermore, investigating the government's future plans via interviews with the decision makers in Kuwait could improve the reliability of the modelling assumptions. Moreover, modeling future migration in Kuwait and immigration from Kuwait of citizens and non-citizens could be projected in the future in different scenarios based on the gradual decrease of oil prices.

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