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Projection for new city future scenarios – A case study for Kuwait

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Abstract

The creation of new cities is a planning approach adopted in several regions around the world, in order to accommodate urban growth. New cities are typically constructed according to well-thought out, centralised plans in areas without any prior development. However, whether the development of these new cities is able to address existing urban issues more effectively than traditional methods such as intensification, is currently an unanswered research question. Several Arabian Gulf countries, such as Kuwait are considering the construction of new cities to address urban issues, specifically the traffic congestion and housing shortages. In Kuwait, the master plan for these construction projects was developed solely by state authorities without any public participation or urban modelling that may have provided a more well-rounded view of the potential impacts and effectiveness.

This paper aims to address these research opportunities of investigating the effectiveness of new cities in addressing traffic congestion and housing shortage, as well as the potential to integrate public opinions in urban development in the form of a model. Towards that end, the study proposes an Agent Based Model (ABM) that will allow simulating the population distribution and urban growth impacts of new cities in Kuwait by 2050. The methodology involves collecting primary data via interviewing the key government stakeholders of urban development and surveying the residents in order to collect the model inputs. In Kuwait's society, citizens and non-citizens form two distinct resident groups with

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often very diverse needs and lifestyles; hence the survey responses will differentiate between them. The data from the interviews and surveys from both resident groups will be incorporated as agent behaviours in the ABM. The simulations examine a multitude of scenarios for the new cities, involving construction delays and infrastructure project delays. The results indicate that the impacts of constructing new cities will be favourable across all different scenarios in terms of alleviating the traffic congestion and housing shortage compared to a business as usual approach of existing urban centre expansion. Furthermore, the survey responses confirm that the resident perspectives closely align with the government's priorities in the master plan for the new cities, further improving the chances for the successful project implementation. The methodology and findings may be applied in cities in the Gulf area or elsewhere with similar urban issues.

Keyword: Geography

1. Introduction

Urban growth is a result of the global population rising and the ever-increasing appeal of cities to house the majority of people (United Nations, 2015). Cities offer a significant range of opportunities and life quality improvements to their residents; however, living in a city is not without any challenges. Among the most common issues city-dwellers have to face globally are traffic congestion (Glaeser and Kahn, 2004; Duranton and Turner, 2012), low housing affordability (Chen et al., 2011; Isma'il et al., 2015), social imbalance (Farber and Li, 2013; Zhao, 2013; Pereira et al., 2014) and environmental degradation (Irwin and Bockstael, 2004; Seto et al., 2010, 2012; Sypharda et al., 2011; Arouri et al., 2012). The physical shape of a city, or urban form, and the ways it expands directly affect the severity of these issues (Broitman and Koomen, 2015). As such, there is a growing research interest in the field of urban systems on how modern cities grow and expand; for instance, the mobility patterns of city dwellers and the commute times are strongly correlated to the spatial patterns of existing and new residential developments (Camagni et al., 2002).

While the ways cities grow differ according to their geographic location, history, political and economic conditions (Kaiser et al., 1995), they tend to follow similar patterns. Urban growth may manifest as outward radial expansion of the urban form (Biddle et al., 2006; Newton, 2010) or upwards as urban intensification of existing districts (Melia et al., 2011). Intensification is associated with increasing the population density in existing city districts, for instance through the construction of high rise buildings (Broitman and Koomen, 2015). This results in a more compact urban form, which is often considered more desirable than outward expansion (Bronstein, 2009; Caragliu et al., 2011; Echenique et al., 2012). Some of the stated benefits of

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intensification are: easier access to the workplace and public services, lower car dependency, avoiding costs for extending transport infrastructure, reduced degradation of the local environment and lower levels of residential segregation (Dieleman and Wegener, 2004; Crooks, 2010; Newton, 2010). An alternative to within-city urban expansion or intensification is through the creation of new satellite cities at the periphery of existing centres (Wang et al., 2011). The main advantage of new cities is that they may be better planned and balanced according to the needs of a growing population. For instance, transport constraints in older cities with road connections and infrastructure that cause severe traffic congestion may be addressed with planned new cities. Fig. 1 illustrates different types of urban growth and the resulting types of cities.

New satellite cities are developed for a number of reasons: i) establishing a new capital such as Putrajaya in Malaysia and a proposed capital in Egypt (Moser, 2010; Monks, 2016), ii) creating new residential districts to accommodate urban growth, and iii) developing special purpose districts for financial, tourism or entertainment activities like in Qatar and Dubai (Tok et al., 2015).

New cities may be linked to existing ones via public transportation systems, such as train or light rail (Campos and Rus, 2009). Train connections have several advantages such as reliability, fast average commute speed and less pollution compared to motor vehicles; and are considered vital for the successful integration of new cities (Dun, 2014). However, constructing new cities also has risks; such as the high initial capital cost and their viability for attracting enough new residents (Moreno and Blanco, 2014). Furthermore, new city projects are sensitive to delays, commonly associated with large construction projects, such as from budget limitations, shortage of labour, poor scheduling or unfavourable weather. These delays may prove to be detrimental to the success of a new city and its planned benefits (Al-Tabtabai, 2002;

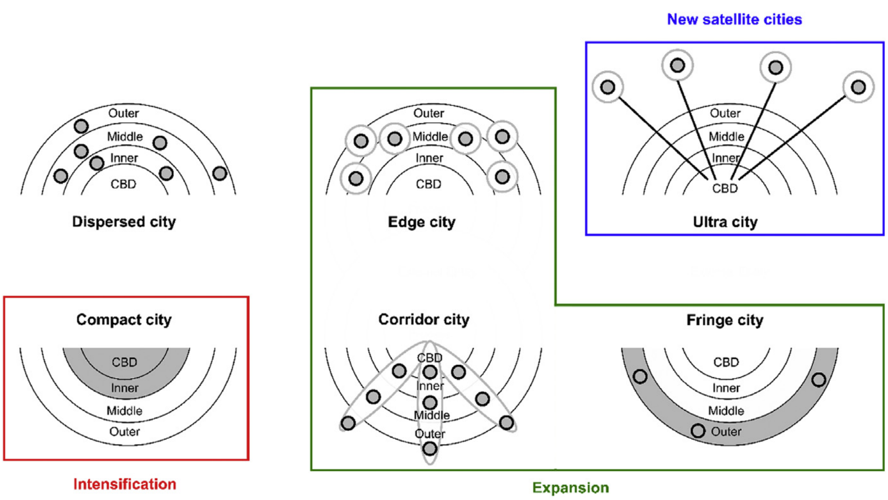

Fig. 1. City types based on urban growth types (adapted from Petersen, 2002).

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Assaf and Al-Hejji, 2006; Singh, 2010; Soliman, 2010) Therefore, it is imperative to carry out extensive modelling about the feasibility of new cities and potential issues in order to minimise the risks.

Urban simulation has been used in many instances for both new and existing city development to empirically analyse future impacts (Waddell, 2002; Sivakumar, 2007; Batty, 2009; Liu, 2009) and to predict future spatial trends of urban and population growth under various scenarios (Batty, 2005; Crooks and Castle, 2012). In order to simulate urban growth, urban models typically need various types of disaggregated data related to land use, population, infrastructure and transportation (Batty, 2012). Additionally, data on population mobility and settlement patterns is needed to model the dynamic aspects of urban growth (Camagni et al., 2002). Consideration of urban dynamics is important in order to model the way cities evolve as a result of the collective interactions of individuals and the urban environment (Benenson and Torrens, 2004). The ability to collect data related to urban dynamics and use them in models, gives rise to the concept of “smart cities”. In smart cities information about transportation patterns, population and resource flows can be gathered from buildings, individuals and corporations and used as feedback in urban models to further improve the efficiency of existing urban systems and simulate the effects of different expansion scenarios (Rodríguez-Núñez and Periáñez-Cañadillas, 2016).

In the literature, most case studies of urban modelling are for cities in Europe, the US or East Asia. However, cities in the Arabian Gulf countries experience rapid urban growth too, and issues related to traffic congestion (Rizzo, 2014; Aldalbahi and Walker, 2015), housing shortages (Alshalfan, 2013) and segregation by nationality between Arab citizens and foreign workers (Khalaf, 2006; Gardner et al., 2014) are becoming more dirsuptive. Traditionally urban planning is guided by conceptual approaches in Arabian Gulf countries, and lack data analysis and modelling to predict outcomes (Abu-Ayyash, 1980; Rizzo, 2014; Alghais and Pullar, 2017a). In addition, there is a lack of consultation with residents, and hence little to no information about the concerns of residents and their preferences of how new development is planned. Urban development has followed a business as usual approach resulting in greater urban expansion, which has not addressed existing urban issues and lead to further deterioration of urban liveability. For instance, previous research for Kuwait (Alghais and Pullar, 2017a) has shown that if the current trends of growth persist then traffic congestion and housing availability issues will be aggravated; and that modelling provides a means to make planning adjustments to avoid these issues. The key issues identified are: limited number of public transportation options (currently only bus), high car dependency, and government housing policies that limit the choices for new housing (UNDP, 2009; Alshalfan, 2013; Al-Nakib, 2014; Dakkak, 2016).

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This paper presents a new urban simulation model that is used to investigate whether establishing new cities may solve the current urban issues in Arabian Gulf countries. This is a contemporary question as many Arabian Gulf countries plan to establish new cities in the near future (Gulf News, 2010; Rizzo, 2014; Summers, 2016). Kuwait is used as a case study as the government plans to establish 12 new urban centres that will be independent from the sole existing urban area of Kuwait City (Keay, 2012). Fig. 2 shows a map of Kuwait and the new proposed cities locations according to the new master plan. The paper will simulate the development of the new cities in the master plan to model balanced growth and assess impacts.

The proposed model uses disaggregate urban data, a survey of residents and interviews with key stakeholders as inputs to simulate new cities and minimize negative growth impacts. The primary research questions formulated in this paper are:

a. What are the key issues of urban growth that affect future planning and concern the local government and residents in Kuwait?
b. Will establishing new cities be more effective in solving these key issues compared to expanding existing urban areas?
c. What are the main concerns related to the new cities projects according to the planning decision makers in Kuwait?
d. How can residents that are willing to move to the new cities be allocated?

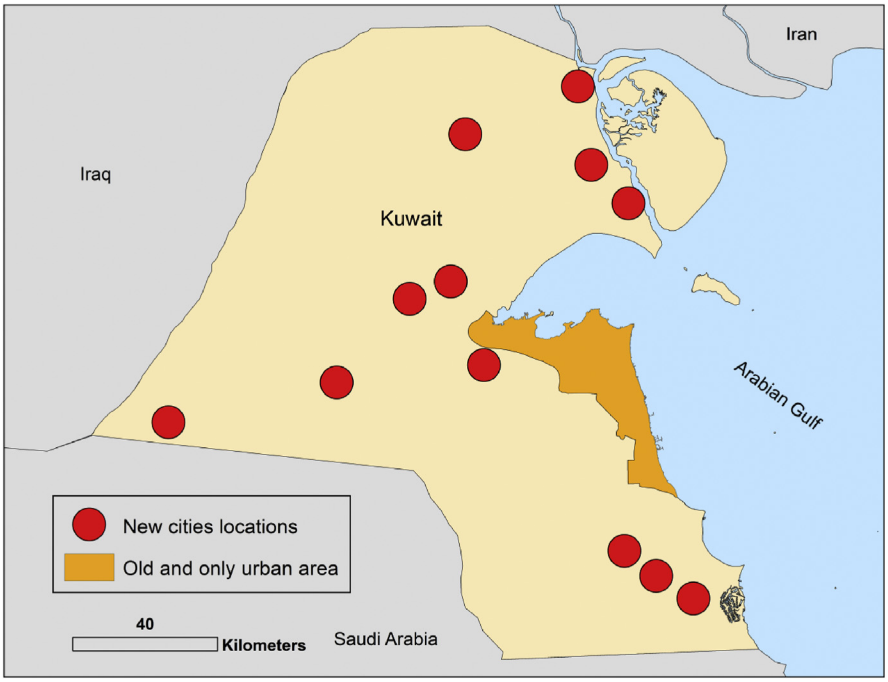

Fig. 2. Kuwait map and new cities locations.

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It is worth mentioning that the work presented in this study is an extension of a published conference paper (Alghais and Pullar, 2017b).

2. Materials and methods

2.1. Interviews with key decision makers

In Kuwait there is only limited public information on the key political and economic forces that shape urban growth, therefore we undertook interviews with government officials and private sector representatives to understand the perspectives of urban decision makers. Surveys given to targeted participants and their responses helped in understanding the role of the state and private sector in developing urban plans. The questionnaires were developed with closed-ended questions in English and Arabic. Additionally, the interviews assisted with identifying the main perceived negative impacts of urban growth according to the government, and any concerns for the new cities projects. Finally, the process enabled the collection of state data that were not available in government official websites.

The participants (13 in total) were important decision makers representing the key planning ministries and organisations in Kuwait; these included the Kuwait National Assembly (Parliament), Kuwait Municipality Council, Ministry of planning, Kuwait Central Statistical Bureau, Traffic department- Interior Ministry, Council of Ministries General Secretariat, Oil Ministry, Public Authority for Housing Welfare and Ministry of Public Works.

In addition, representatives from the private sector (4 in total) were also interviewed, specifically General Managers or Companies Executive Officers (CEOs) from construction and consultation companies, real estate developers and traffic consultancies.

The findings from the interviews are summarised in Table 1.

The interviews showed that traffic congestion and housing shortages are the main officially recognized urban issues, and these are intended to be solved with the latest master plan. However, there is neither quantitative assessment nor modelling to verify this. There was also the possibility of project delays for establishing the train network and new city construction, and concern on what consequences this may have. These concerns were shared with those interviewed in the private sector, but it was confirmed that they had a minimal role in developing the new master plan and influencing its execution.

For these reasons, we decided to develop an urban simulation model that could run multiple scenarios to model urban growth as urban intensification in Kuwait city along with developing new cities at locations identified in the master plan without

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Table 1. Summary of interview key findings.

Question	Summarized Response
What is the planning approach in Kuwait and what is the role of the authorities in the planning process?	The main planning approach is based on the master plan and the role of the authorities is distributed according to disciplines. Final decisions are made by the Council of Ministries.
What are the main concerns about the development of new cities?	There is lack of cooperation and coordination between the planning authorities. The government fully controls the funding for the new cities. There are concerns about potential delays in train and new cities construction.
Is the plan modelled or evaluated by any tool?	There are no simulations or modelling tools used to evaluate the new plan.
What is the role of private investors in the projects?	Private sector's role is limited to consultations and projects execution.
What is the role of residents in the projects?	The resident perspectives are not taken into account and there is no future plan for community participation.
What are most important urban issues?	Housing shortage and traffic congestion.
What is the importance of new cities in solving the issues?	New cities are expected to solve the housing shortage and traffic congestion issues.
What is the plan for public transportation?	There is no plan for upgrading or expanding the existing bus system. A new train system will be established to link the existing urban area with the new cities. The planning authorities are doubtful on the government's willingness on establishing the train network.
Will nationality segregation be addressed in the new plan?	There are no plans to address segregation in the new cities.

expanding the existing urban area. The simulation needed to be able to assess impacts on traffic congestion and housing shortages as new cities are opened and better train transport is made available; and additionally to assess the effect of delays from projected completion dates in the master plan. More details on the modelling and scenarios can be found in later Section 2.3.

The simulation model is driven over time with official estimates of population forecasts and movement of people in line with historical settlement patterns, but it was also important to obtain data from people on their concerns and preferences on places to live. The next section describes a survey of people living in Kuwait, both Kuwait citizens and the larger non-Kuwaiti work force without national citizenship. This information is used along with the historical settlement patterns to allocate people to the new cities as new population growth and existing population movement.

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2.2. Survey with people

As the new cities were planned mainly for residents, the authors decided it was necessary to survey them. In the surveys, citizen and non-citizen residents were treated as separate groups. The citizen group was the primary group for simulating the housing shortage impact, as the problem is mainly related to them. On the other hand, the traffic congestion is a problem that affects both citizens and non-citizens.

The survey extracted resident opinions and preferences for settling in new districts based on suitability weights collected directly from both groups. Residents below 18 years old and non-citizen servants were excluded from the survey, because they are not the decision makers and in most cases they can only follow their parents or employers. The survey was written for Arabic and English speakers. The whole process was online and delivered through social media such as Twitter, Instagram and WhatsApp, as these application networks are used extensively in Kuwait (Tawfik et al., 2015). More than 2000 invitations were sent with an expected response ratio of 20% (Smith, 2013) to statistically achieve a design confidence level of 95% (+/− 5% margin of error) and standard deviation of 0.5.

The survey stayed open for 2 months. During that time, 879 responses were collected from Kuwaitis, which provide a 3% of margin of error, whereas 406 responses were collected from non-Kuwaitis, which provide a 5% of margin of error (Bartlett et al., 2001). Table 2 shows a summary of the survey respondents.

The main findings from the survey are summarized in Table 3.

The survey confirmed that the main negative impacts resulting from urban growth and affecting residents are traffic congestion and housing shortage. This finding is aligned to the government planning authorities' response.

It was noted that the majority of residents were interested in being involved in the planning process. However, the government does not intend to involve them in its near future plans. The main reason behind this is the high degree of centralization in decision making processes in Kuwait (Madbouly, 2009). However, a more detailed analysis of the reasons of low public involvement in Kuwait is beyond the scope of this study.

Moreover, it was possible to extract information about the citizen and non-citizen groups to be used as inputs in the model. The main behaviours for citizens and non-citizens can be seen in Table 4.

From Table 4 it is can be seen that there are plenty of residents willing to move to the new cities and use the train system in the future. Details about the suitability parameters that will be used to model the resident allocation in the new cities can be found in Section 2.5.

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Table 2. Survey respondents' data sheet.

Classification	**Nationality**	
	Citizens (Kuwaitis)	**Non-citizens (Non-Kuwaitis)**
Number	879	406
Gender	Male: 52% Female: 48%	Male: 71% Female: 29%
Age	<18–34: 53% 35–49: 29% 50–>60: 18%	<18–34: 60% 35–49: 29% 50–>60: 11%
Employment status	Student: 16% Employed: 64% Unemployed: 3% Retired: 13% Other: 4%	Student: 27% Employed: 59% Unemployed: 4.5% Retired: 0.5% Servants: 5% Other: 4%
Monthly income[a]	<500 K.D: 11% 500–999 K.D: 18% 1000–1500 K.D: 33% >1500 K.D: 38%	<500 K.D: 46% 500–999 K.D: 37% 1000–1500 K.D: 12% >1500 K.D: 5%
Marital status	Never married: 30% Married: 63% Divorced: 6% Widower: 1%	Never married: 38.5% Married: 55.5% Divorced: 4% Widower: 2%
Educational background	Less than bachelor degree: 25% Bachelor: 61% Post graduate degree: 14%	Less than bachelor degree: 36% Bachelor: 53% Post graduate degree: 11%
Residential status	Own house: 28% Rented house: 7% Own apartment: 2% Rented apartment: 18% Living in parents' house: 45%	Own house: 10% Rented house: 19% Own apartment: 3% Rented apartment: 67% Living in Kuwaitis house as servant: 1%

[a] 1K.D = 3.3 USD.

It should be noted that this project's interviews and surveys were approved as complying with the Australian National Statement on Ethical Conduct in Human Research and University of Queensland Regulations in 16/2/2016. Furthermore, based on the responses collected from both the government and residents it was clear that there is a necessity to simulate the new cities approach and assess it in terms of its potential to solve the main urban issues. In addition, the model can help with understanding to what extent the negative impacts may be reduced with the new train network and examining how delays in construction projects may influence the future key negative impacts.

2.3. The urban model

As discussed earlier, there are several urban simulation tools developed to simulate and predict future urban growth, such as Land Use and Transportation Models (LUTM), Cellular Automata (CA) and Agent Based Models (ABM) (Sivakumar, 2007;

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Table 3. Summary of survey key findings.

Question	Summarized Response
What are the two most important urban issues in Kuwait (in descending order of importance)?	For citizens: 1- Housing shortage 2- Traffic congestion For non-citizens: 1- Traffic congestion 2- Housing shortage
What is the time in years you had to wait to obtain a dwelling from the government? (Kuwaiti group)	The average time was 10 years.
Can residents buy a new house by themselves without using PAHW?	93% of Kuwaitis disagree and claim that house prices are unreasonably high.
Is there a housing shortage problem in Kuwait?	75% agree that there is a housing problem.
Is the waiting time for PAHW applications reasonable?	87% disagree, and claim that the waiting time is not reasonable.
Should public opinion be considered for new development and planning decisions?	85% of residents (citizens and non-citizens) believe their opinion should be considered.
What is your current preferred commuting mode? (own vehicle, bus, taxi, walking, cycling or motor cycling)	99% of citizens' said that they preferred to use their own vehicle. 89% of non-citizens said that they preferred to use their own vehicle.
What is the average time delays due to traffic congestion when commuting?	18 minutes.
Is traffic congestion perceived as serious problem in Kuwait?	94% of total residents agree.
Is there congestion even outside working hours, for example at night?	86% of total residents agree.

Batty, 2009). Each of these models has its advantages and disadvantages in terms of simulation flexibility and complexity (Goetzke, 2014; Crooks, 2015). In this study, it was necessary that the model would be able to simulate new cities and residents movements, as well as assess future negative impacts (traffic congestion and housing shortage) in the case study area. Based on the interview responses and resident surveys, it was obvious that the model in this study should be able to simulate top-down driven urban growth as dictated by the master plan. In addition, it should allow residents to be allocated according to bottom-up rules that can be derived from their preferences for settlement and movement to the new cities. Additionally it should be able to simulate the group interactions between each other and with the land use.

Thus, Agent Based Models (ABM) was selected. ABM has been widely advocated in urban planning research (Benenson, 2004; Beuck et al., 2007; Gaube and Remesch, 2013; Murray-Rust et al., 2013; Jordan et al., 2014). The agents represent different groups that function autonomously and can make independent decisions, as

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Table 4. Resident behaviours according to the survey responses.

Behaviours	Residents groups	
	Kuwaitis	Non-Kuwaitis
Preferred district type	88% prefer to live in residential districts.	52% prefer to live in mixed districts.
Movement to the new cities	38% of residents plan to move, 24% do not plan to move whereas 38% of them are neutral or don't know.	
Time spent on current dwelling	60% of residents have been in their current residence location for more than 5 years.	
Future train user %	70% of residents would like to use the train system in their future trips after it established in the future.	
Nationality segregation	44% of residents prefer to live in more segregated districts, whereas 28% of them prefer to live in less segregated districts.	
Suitability parameters rankings	1- Land value 2- Closeness to the old urban areas 3- Closeness to new cities CBDs 4- Closeness to street networks 5- Closeness to train stations 6- Closeness to airports	

well as interact with other agents and their environment (Crooks and Heppenstall, 2011; Aliaga, 2012). In ABM, agents may be groups such as residents, developers or urban planners (Crooks, 2015), and the environment is the land on which changes occur. Urban development is a process administered through the decisions of planners (Knox and McCarthy, 2012), who may be simulated easily as an agent group in ABM. Furthermore, interactions with the changing urban environment are carried out by different groups according to their needs and priorities.

There are certain rules that affect agent behaviour and their relationships with other agents and their environment. These rules are typically based on 'if-else' statements that are activated when a specified condition has been met. Agent actions can be standardised and "learned" by the simulation framework, making the agents autonomous. Scheduling agents' behaviours takes place synchronously or asynchronously over a period of time that could be from seconds to decades (Crooks, 2015). The environment within agents live, commute and interact can be analysed at various spatial scales, as well as over different time frames. In this model, the environment is the land use districts.

The benefits of ABM include its ability to model local interactions within dynamic urban systems from a bottom-up perspective and its flexibility in terms of geospatial model development (Crooks and Heppenstall, 2011). Therefore, the agents affecting urban planning in the simulations of this work may be seen in Table 5.

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Table 5. Agent groups used in the simulations.

Agent group	Actions	Behaviours/Rules
Government planning authorities	Responsible for urban planning and the development of new districts and transportation infrastructure. Opening new dwellings for the citizens group.	Based on new master plans policies and data collected from interviews.
Citizens (Kuwaitis)	Moving from older to new districts. Applying for housing from the government group.	Prefer to settle in residential districts (surveys).
Non-citizens (Non-Kuwaitis)	Moving from older to new districts.	Prefer to settle in mixed use districts (surveys).

The ABM described in this work was combined within ArcGIS by using Agent Analyst extension ArcGIS (Johnston, 2012) that has been a staple in similar research studies (Robinson et al., 2013; Dahal and Chow, 2014; Haslauer et al., 2015). The simulations will run in seven 5-yearly time steps between 2015 and 2050, Fig. 3 shows the model design flowchart.

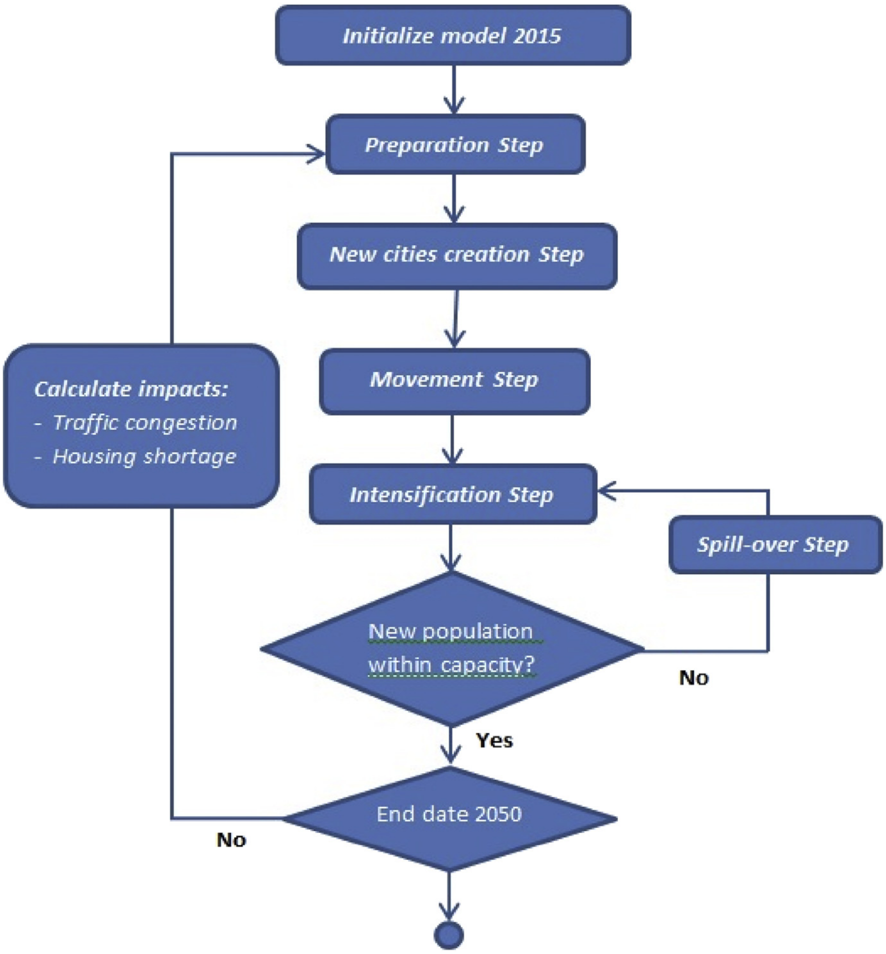

Fig. 3. Simulation algorithm flowchart.

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The model assumes that population and land use distribution are going to evolve as planned by the Kuwait Municipality from a top-down perspective and according to resident responses in the survey (bottom-up perspective) (Helbig et al., 2015). The model will simulate the population movement from old urban areas to the new cities, as well as future traffic congestion and housing shortage issues.

Different scenarios for the development of new cities were simulated in the methodology of this work with the following variations:

- Delays in construction of a major new city.
- Delays in construction of four minor new cities.
- Effectiveness of train network in reducing traffic congestion.

Therefore, six scenarios were simulated in total and the different outcomes were recorded. Table 6 shows the setup of the scenarios.

2.4. Data preparation and disaggregation

The data collected from the government planning authorities and used in the ABM includes:

i) GIS data, such as existing road networks and district land use borders
ii) Demographic data about population and nationality distributions obtained from the Kuwait Central Statistical Bureau (KCSB) and the Public Authority for Civil Information (PACI),
iii) Housing related data, such as the number of applicants and the supply of dwellings from the government based on figures supplied from the Public Authority of Housing Welfare (PAHW),
iv) Future demographic data with aggregate projections for the period 2015−2050 from the Kuwait Institute for Scientific Research (KISR), and
v) The new master plan obtained from the Kuwait municipality.

Table 6. Details of simulation scenarios.

Scenario number	Inputs				
	Construction delays			Train network	
	No	Major city	Minor cities	Yes	No
1	☑			☑	
2	☑				☑
3		☑		☑	
4		☑			☑
5			☑	☑	
6			☑		☑

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According to Batty (2012) simulating future urban development requires disaggregating statistical and spatial data. The first step towards disaggregation was adding the data collected from surveys and interviews to the attribute tables of each district or as parameters and values of the model. Each new city was segmented into districts based on the master plan or according to the new street network. The new districts were classified to residential, mixed use, business centres and other. The districts were also classified to new proposed or old districts in a format that can be read by the model. The outcome of this segmentation step can be seen in Fig. 4.

Following that, the new dwellings and overall capacity for the new cities into the new segmented districts was simulated. In this step, it was assumed that the total number of the dwellings and the capacity were evenly distributed between the districts in the new cities. New city locations, train stations and transportation networks were then superimposed on the resulting map. Figs. 5 and 6 show the outcome maps from this step.

2.5. Suitability weights for new cities

A land suitability model was used to allocate the residents in the new cities and determine the order of establishing new cities and infilling their districts. To achieve a realistic allocation, the model uses a number of preferential criteria based upon

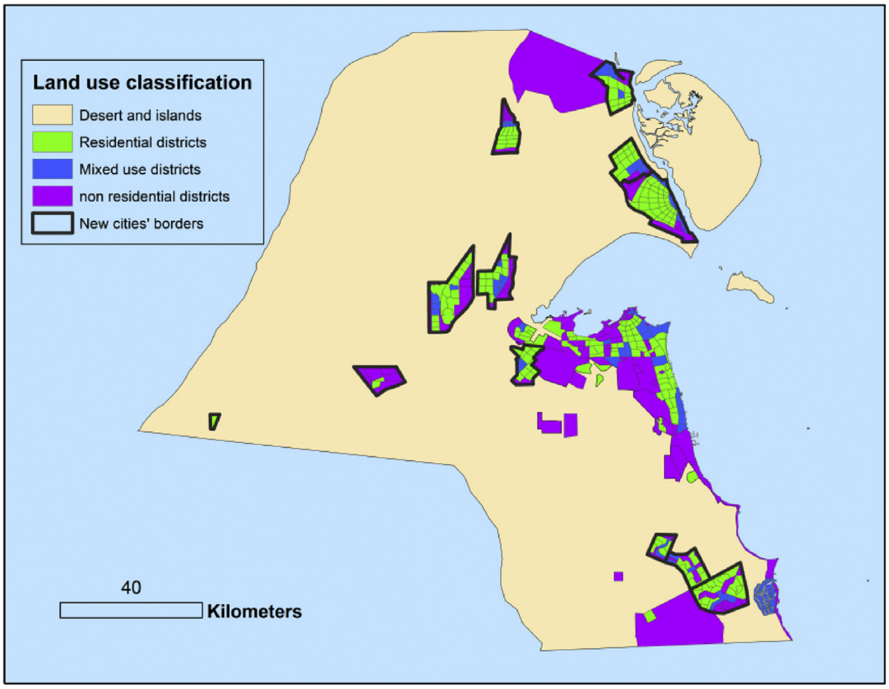

Fig. 4. New land use classification.

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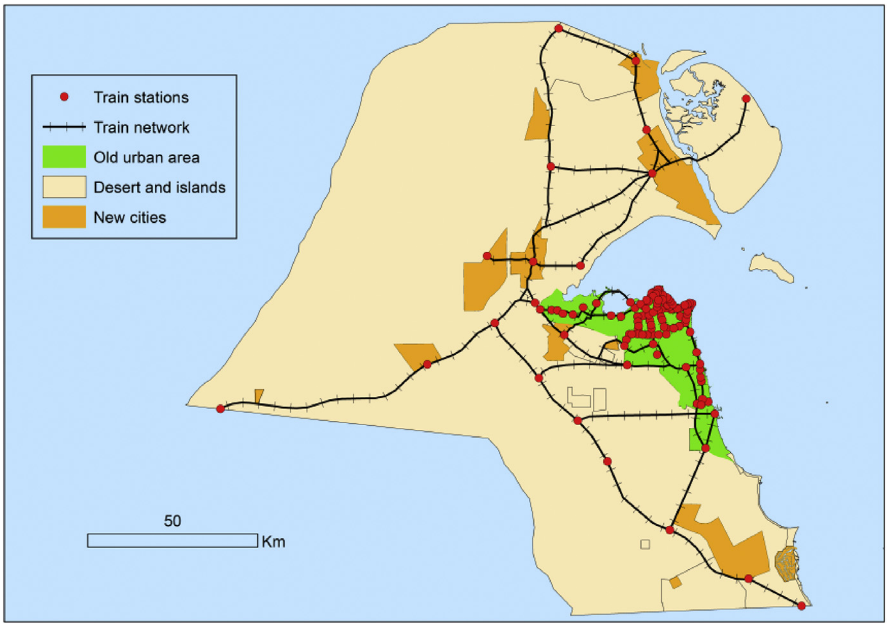

Fig. 5. New train network and stations.

proximity to: CBD for new cities, old urban area, train stations, airports and street networks. In addition to closeness parameters, land value was also considered. The aforementioned parameters were ranked by the residents in order of importance as seen in Table 4 and then used to determine the weights of each criterion.

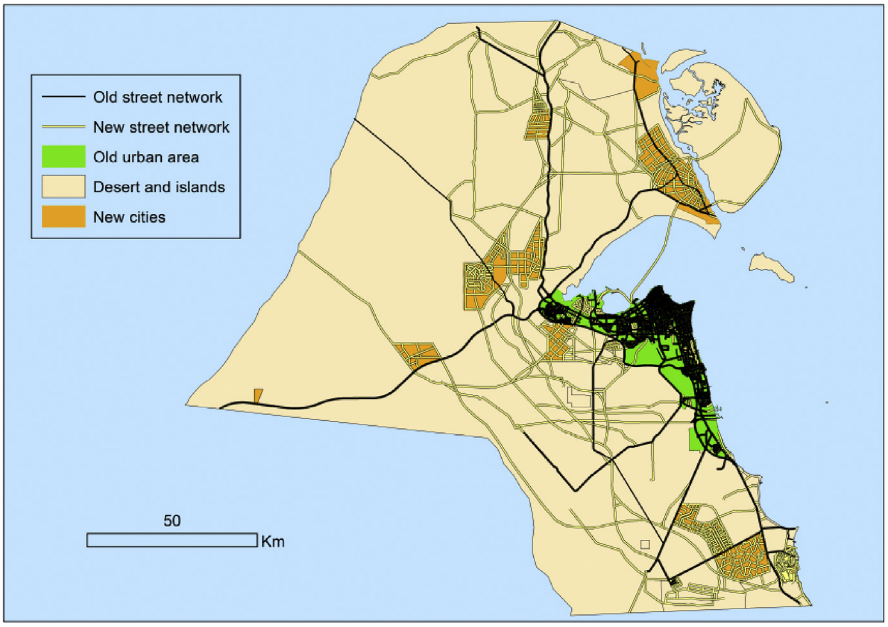

Fig. 6. New road network.

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Table 7. Suitability parameter rankings and weights according to the resident agents.

Parameters	Rank	Weight %
Land value	1	38
Closeness to the old urban areas	2	25
Closeness to new cities CBDs	3	16
Closeness to street networks	4	10
Closeness to train stations	5	6.5
Closeness to airports	6	4.5

Transforming the residents' responses from the surveys into weights was done via Analytic Hierarchy Process (AHP) (Nyerges and Jankowski, 2010). The final weights can be seen in Table 7.

The values of these weights were calculated for each new district separately. For the closeness parameters, the *Near* tool was used. The values were normalised to values between 0-100 relative to the maximum closeness (100 suitability value). For the cost parameter a statistical report (KFH, 2015) was used to identify the land value for each existing district. The highest land value was assigned with a suitability value of 0. The land value in new cities is calibrated to be higher if it is near to existing urban areas. In addition, the land value was assumed to increase linearly by 5% per time step.

2.6. Traffic congestion index

As there is no historical traffic congestion data in Kuwait, we used traffic data shown on Google maps (traffic tool) along with land use data to develop a simple regression model for predicting traffic congestion for future development. The Traffic Congestion Index (TCI) was calculated according to the following steps:

1. Model explanatory variables indicative of traffic congestion (Abdullahi and Pradhan, 2015; Chen, 2016, Choi and Lee, 2016) were mapped from available data at a district scale for: i) population density, ii) street density, iii) closeness to existing urban areas, and iv) closeness to train stations and networks (applied in future predictions only).
2. The dependant model variable for traffic congestion (TCI) was observed from current data in Google Maps traffic tool and summarised to a district scale; a congestion indicator (Marfia et al., 2013; Solé-Ribalta et al., 2016) on a point scale from 1 to 100 was developed as follows:
   - No or low congestion level (0−24%) = 25
   - Medium congestion level (25−74%) = 75
   - High congestion level (75−100%) = 100

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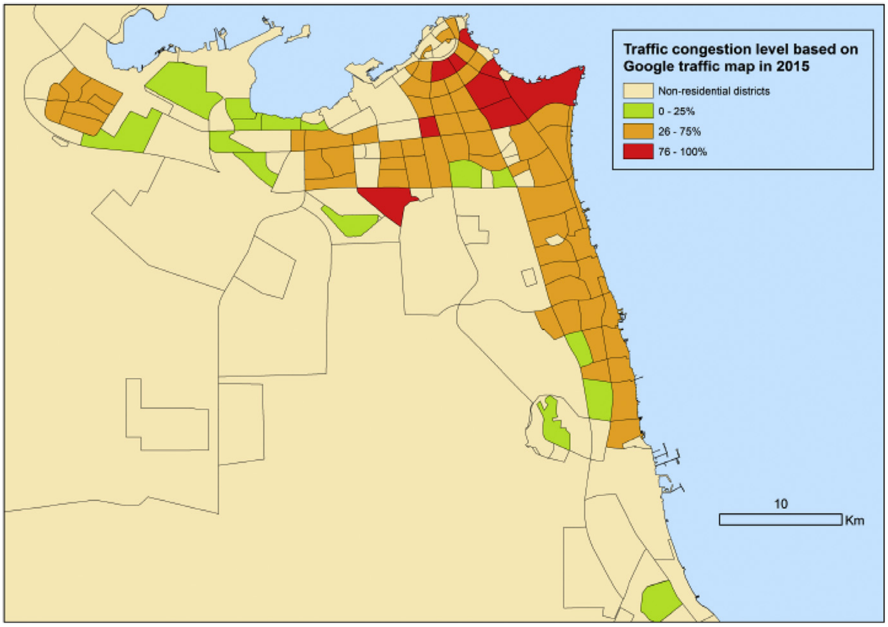

Fig. 7. Traffic congestion level per district in 2016.

The level of congestion was recorded for major streets along in each district at 3 different times (Sunday 8am, Sunday 2pm and Thursday 8pm). The maximum level was taken as the district congestion level. It should be noted that Sunday mornings and afternoons were selected as Sunday is a normal working and school day and typically congestion during these times is very high. Thursday evening was also selected as it is the first weekend night and residents spend time driving to leisure and shopping venues. The traffic data were recorded weekly for 8 continuous months between January and August 2016. The outcome map of this step can be seen in Fig. 7 and it was applied in the model as 2015 input data. A linear regression model was developed; the results are summarised in Table 8.

The TCI for new districts were calculated at each time step based on the regression coefficients applied to projected explanatory variables, according to the following equation:

$$\text{TCI} = (\text{proximity} \times 0.612814) + (\text{population density} \times 0.447435) + (\text{street density} \times 0.361718) \quad (1)$$

Table 8. Summary output from linear regression with zero set at origin.

	Coefficients	Standard Error	t Stat	P-value
Proximity to existing urban area	0.612814	0.039217	15.62606	2.34E-28
Population density	0.447435	0.144343	3.099793	0.002528
Street density	0.361718	0.132327	2.733509	0.007436

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2.7. Parameters and assumptions for simulation algorithm

The parameters used in the government scenario model steps (explained below) are summarised in Table 9.

For modelling the scenarios, the following adjustments were made:

- Train % TCI: This is the percentage deducted from the TCI of a district close to a train station based on the interview data. This percentage was initially assumed to be 5% as the decision makers regarded this is the expected ratio of car commute trips replaced by of train trips. However, the survey results showed that 70% of residents consider taking the train. This ratio provides a very optimistic prediction, but it is probably not an accurate one, as desire to use the train does not necessarily mean it will be used in all trips. Therefore, the Train % TCI in the simulation was double the government's proposed percentage (10%).
- Movement: Although 38% of residents expressed willingness to move, this will likely occur over some time. Hence in the simulation scenarios, the group of

Table 9. Simulation parameters.

Parameter name	Description	Application
Kuwaitis & non-Kuwaitis distribution %	Population distribution according to nationality based on historical trends.	Movement, intensification and Spill-over steps.
Average capacity of existing districts (Persons/ha)	Average capacity for adding people to district based on the historical data average.	Movement and Intensification steps.
Maximum capacity of new cities' districts (Persons/ha)	The maximum population that a new district can have based on the master plan disaggregated data.	Movement and Intensification steps.
Population ratio of new districts in the opening time step	The maximum population percentage of the maximum capacity that a new district can have during the opening time step (in the first 5 years).	Movement step.
Movement %	The percentage of people who will move to the new cities based on the survey data.	Movement step.
Traffic congestion index (TCI)	The average TCI for all districts in each time step.	Impacts calculation step.
Train % TCI	The percentage that will be deducted from the TCI of a district close to a train station based on the survey data.	Impacts calculation step.
Suitability parameters' weights (dimensionless from 0–10)	The suitability weights of parameters based on the survey data as seen in Table 7.	New cities creation, intensification and spill-over steps.
Pending housing applications	The number of pending housing applications in each time step based on data collected from the interviews.	Impacts calculation step.

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residents willing to move was evenly spread over the simulation time steps to (5.5% per year).

2.8. Simulation steps

The simulation steps for all scenarios were as follows:

2.8.1. Initialization

Initialization involves creating the environment (spatial land use districts) in GIS, initialising the default parameters values, loading data for the disaggregate population projections and initialising the model schedule to start in the year 2015.

2.8.2. Preparation and calculation step

This step contains several actions; the first action is calculating the average capacities of existing districts and setting the infill availability count for existing and new districts, which determines whether they may accept new residents. Furthermore, the suitability of districts for opening is calculated.

2.8.3. New cities creation step

In this step, the first action opens the districts in the new cities based on the master plan open dates and start populating them with new Kuwaitis & non-Kuwaitis from the disaggregated 5 yearly population projections using increments of 5000 people. The allocation is based on the district suitability.

2.8.4. Movement step

People move to new districts based on suitability as assumed from the AHP. To calculate the number of moving residents, firstly the number of available Kuwaitis and non-Kuwaitis for movement are calculated based on the following equations:

$$\text{Available Kuwaitis for movemet} = \text{Movement Percentage} \times \text{Total Kuwaitis in old districts} \quad (2)$$

$$\text{Available non} - \text{Kuwaitis for movement} = \text{Movement Percentage} \times \text{Total non} - \text{Kuwaitis in old districts} \quad (3)$$

Then, Kuwaitis and non-Kuwaitis are moved to the new cities' districts (residential, mixed-use and CBDs) according to the Population ratio of new districts in the opening time step (20% of the Maximum capacity of new districts) based on the following equations:

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$$\text{Actual Kuwaitis for movement} = \text{Population ratio of new districts in the opening time step} \times \text{Available Kuwaitis for movement} \quad (4)$$

$$\text{Actual non} - \text{Kuwaitis for movement} = \text{Population ratio of new districts in the opening time step} \times \text{Available non} - \text{Kuwaitis for movement} \quad (5)$$

Following that, a movement calibration action runs to ensure that the distribution percentages of Kuwaitis and non-Kuwaitis in residential and mixed-use districts are similar to the pre-set distribution percentages. Typically, the nationality distribution in residential districts is 55% and 45% for Kuwaitis and non-Kuwaitis respectively and in mixed districts it is 9% and 91% for Kuwaitis and non-Kuwaitis respectively. The number of residents is recalculated in the case that the number of actual moved residents exceeds the average capacity of the new districts in the opening time step. Based on historical data, the capacity for Kuwaitis in residential and mixed districts is 40 persons/ha and 20 persons/ha respectively. For non-Kuwaitis in residential and mixed districts the capacity is 30 persons/ha and 2,000 persons/ha respectively. Finally, the actual moved residents are removed from old districts.

2.8.5. *Intensification step*

This step performs infill to assign population to any (old or new) district with available capacity. Population is added from the disaggregated 5 yearly population projection in increments of 5000 people and allocates them in districts based on their suitability weights. If population growth exceeds the capacity of all districts the model accounts for the difference in the next spill-over step, otherwise it continues on to the next period for growth.

2.8.6. *Spill-over step*

The Spill-over step is a mechanism in the simulation algorithm that initiates when it is not possible to add new dwellings so the only solution would be to increase the density in the old developed districts. This step checks whether there are Kuwaitis or Non-Kuwaitis still in the waiting lists in the end of each time step. If there are, a loop will start to call the previous infilling step and add more residents to the old districts until the waiting list empties. This is achieved by increasing the average capacity of the old districts by 0.0001 person/hectare. If delays in constructions of new cities occur, this step will run until all waiting population is allocated to existing districts.

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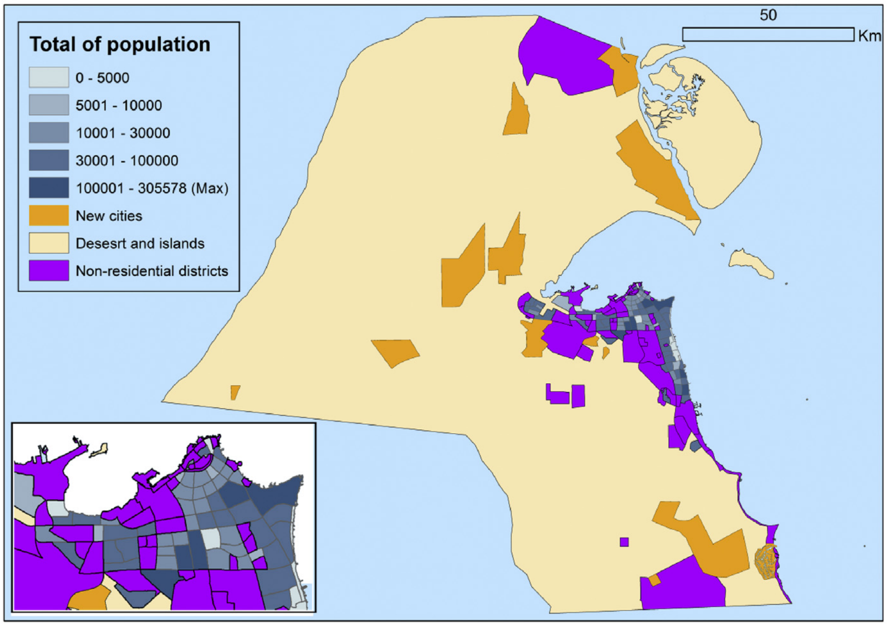

Fig. 8. Population distribution in 2015.

2.8.7. *Impacts calculation step*

This step produces the predictions for the key urban issues: housing shortage and traffic congestion. Output maps and figures are produced to show details about the population, districts and the future impacts in each time step. Fig. 3 shows a flow-chart of the model architecture.

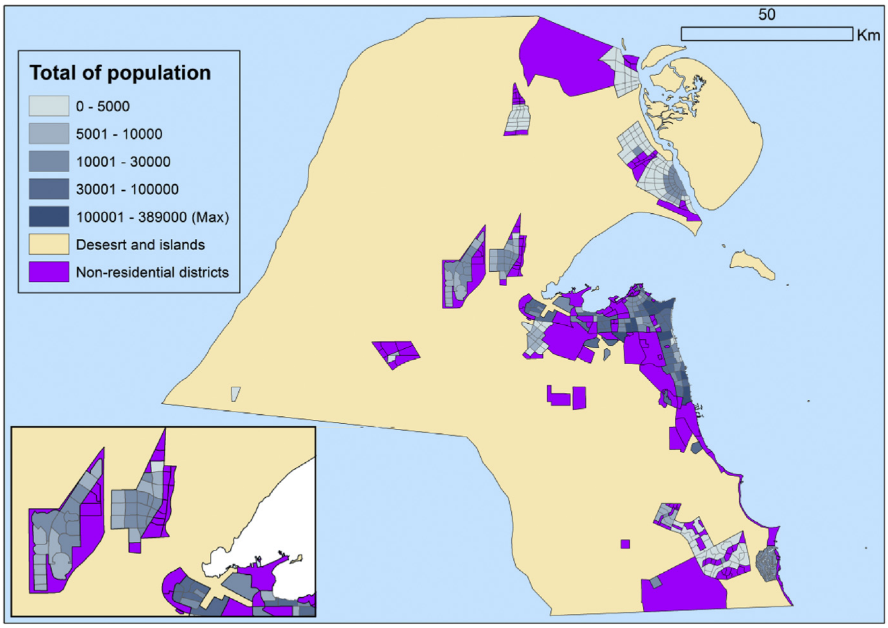

Fig. 9. Population distribution in 2050 in scenarios 1−2.

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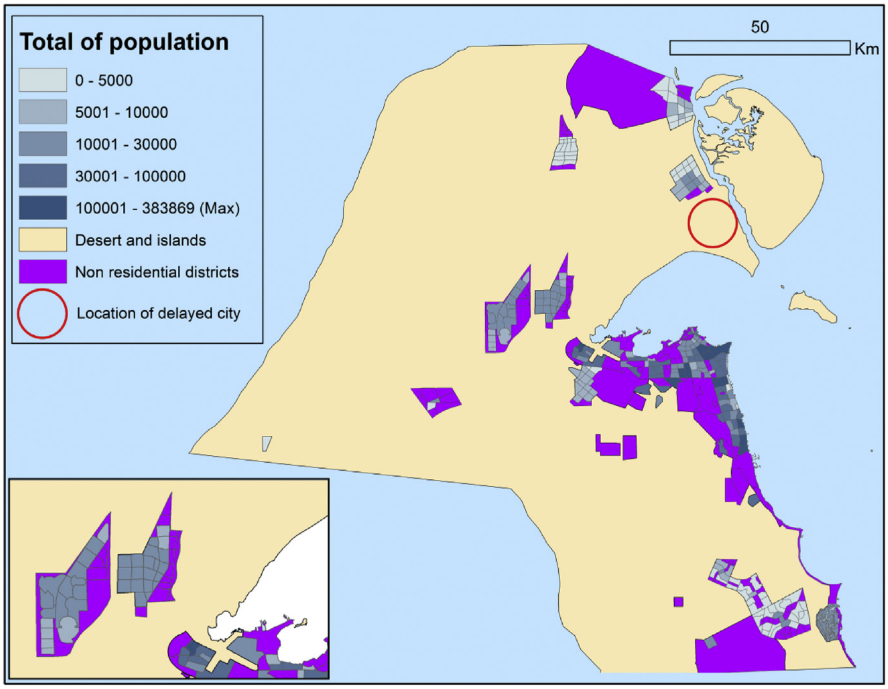

Fig. 10. Population distribution in 2050 in scenarios 3–4.

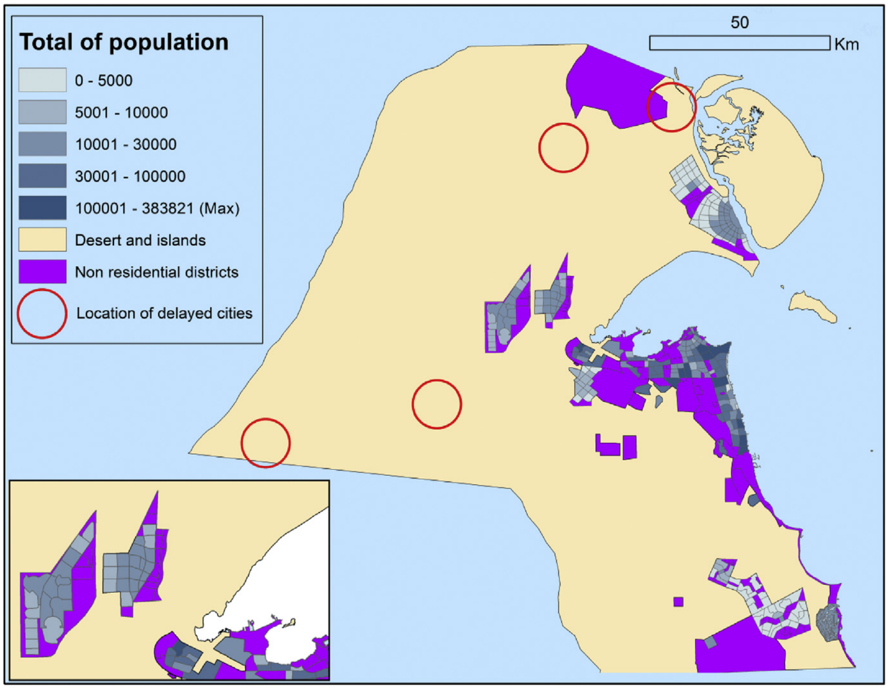

Fig. 11. Population distribution in 2050 in scenarios 5–6.

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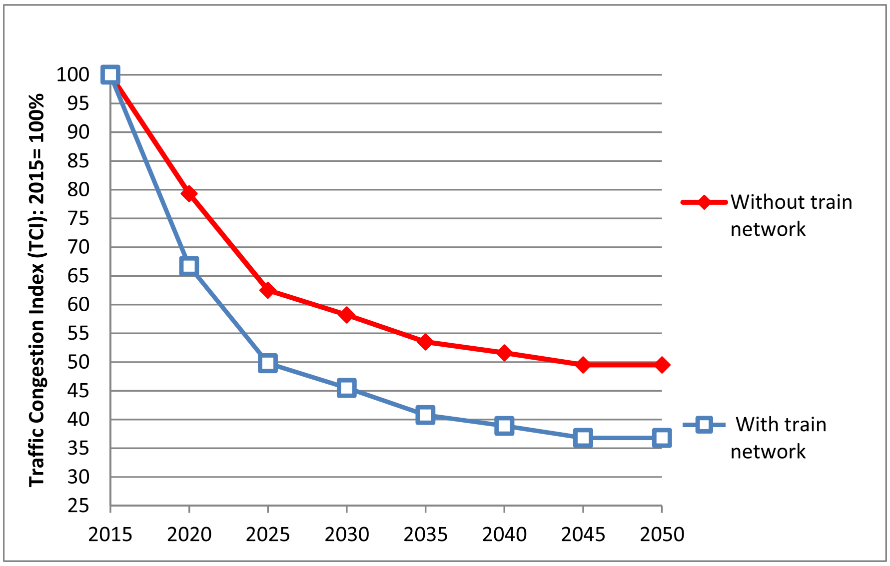

Fig. 12. Comparison of TCI in scenarios (1 and 2) without construction delays.

A more thorough explanation of using ABM for analysing urban growth in Kuwait was explained in earlier work by Alghais and Pullar (2017a). The difference in the current model is that it includes a movement step (step 4) for allocating population to new cities and other minor modifications for alternative transportation options with train network.

3. Results

3.1. Traffic congestion

The population density in scenarios 1 and 2 the population density will be 5.3 persons/ha and in scenarios 3−6 it will be approximately 6 persons/ha. This shows that

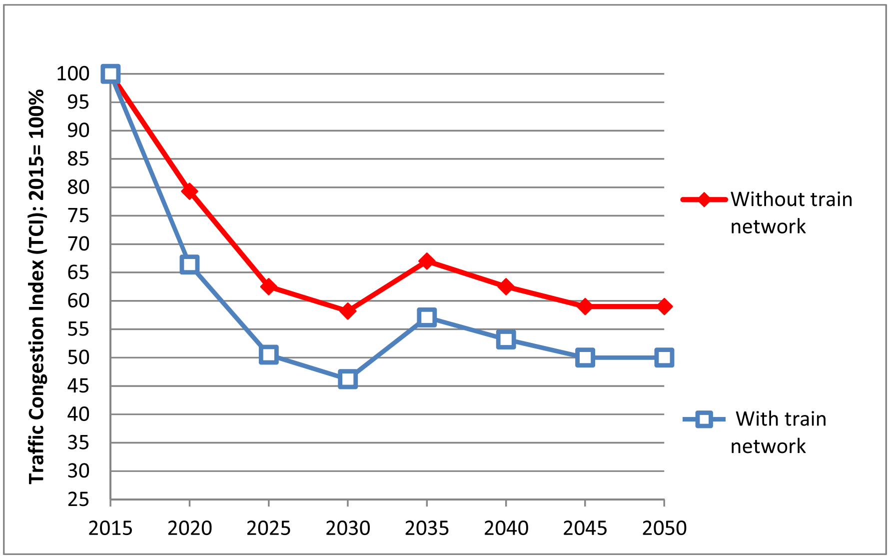

Fig. 13. Comparison of TCI in scenarios (3 and 4) with construction delays in the major city.

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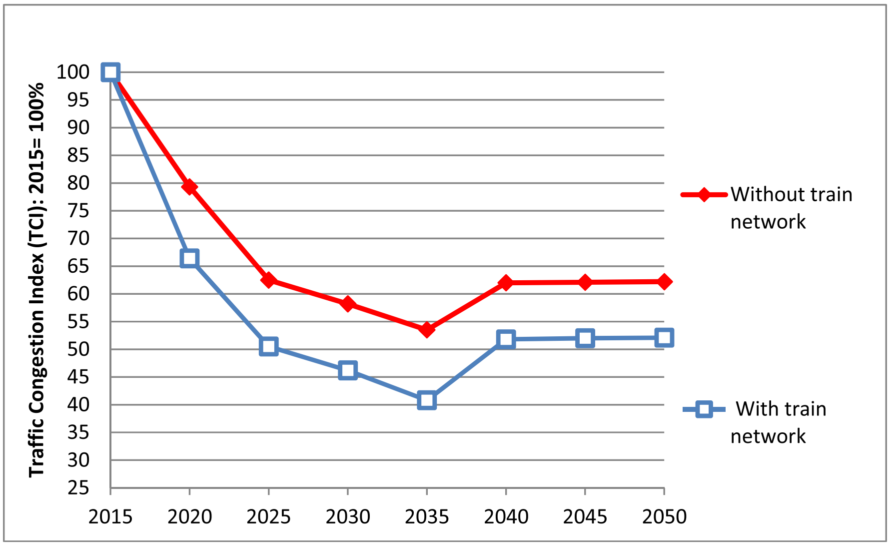

Fig. 14. Comparison of TCI in scenarios (5 and 6) with construction delays in the minor cities.

even with delays the population density will decrease compared to the population density in 2015 (13.5 persons/ha), which in turn is expected to mitigate traffic congestion as density is a variable that indicatives traffic congestion (see Section 2.6). Figs. 8, 9, 10, and 11 show the population distribution maps.

Indeed, by comparing the current situation with the scenario results the simulations showed a significant reduction in traffic congestion in 2050 for scenarios 1 and 2. Specifically, the predictions show that in 2050, the TCI may be as low as 35–50%. If delays in construction occur, the TCI will be still lower than 2015. Figs. 12, 13, and 14 compare the congestion predictions for of the simulation scenarios.

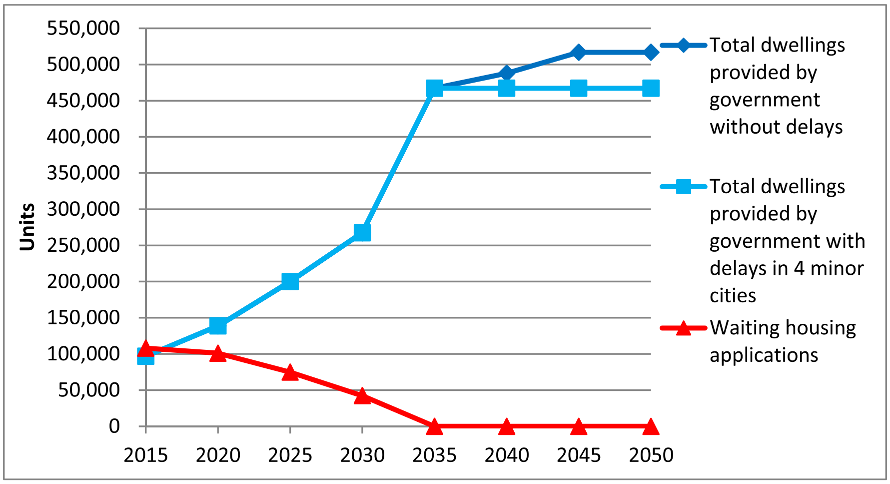

Fig. 15. Housing demand and supply in case of no delays and with delays in 4 minor cities.

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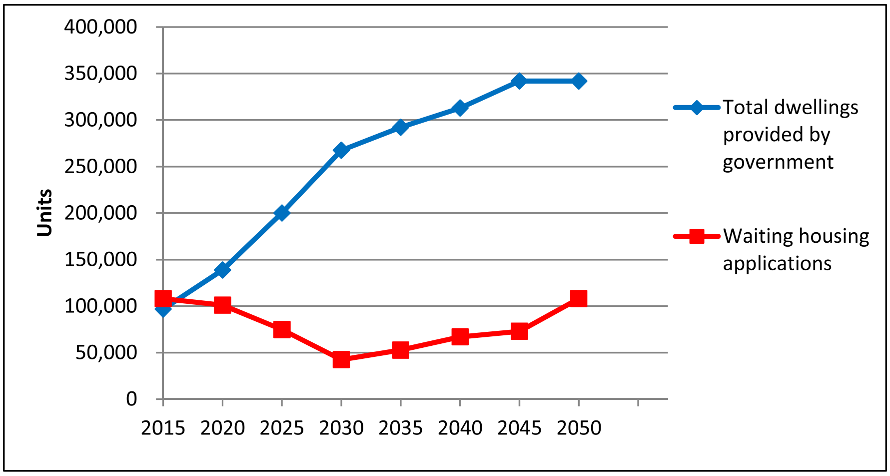

Fig. 16. Housing demand and supply with delays in the major city construction.

3.2. Housing shortage

The impact of developing new cities on housing shortage according to the simulations depends mainly on any delays. Fig. 15 shows the impacts of delays in the construction of minor cities on the supply of dwellings and housing applications.

The results showed that without delays the housing shortage problem will be solved by 2035. However, if delays in the construction of the major city occur, the housing shortage problem will persist. In fact, the predictions show that in 2050, the pending applications for housing may reach up to 108,000 as shown in Fig. 16.

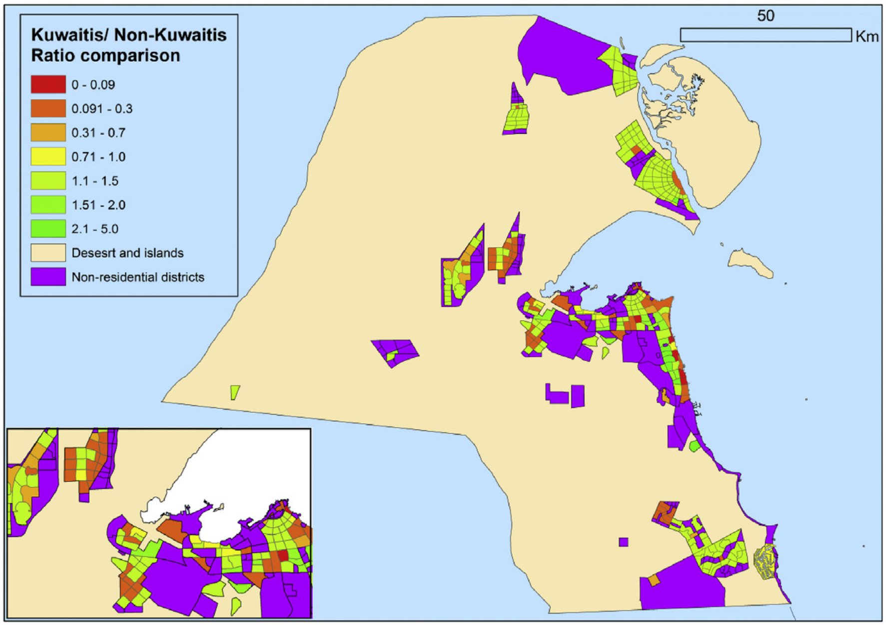

Fig. 17. Population distribution average (citizens and non-citizens ratio) in 2050 in scenarios 1−6.

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Finally and regarding the nationality segregation, the results showed that according to the simulations in 2050 the new cities will be less nationality segregated than the current urban areas. The respective maps based on the average of the six scenarios can be seen in Fig. 17.

4. Discussion and conclusion

The main purpose of this study was to assess if developing new cities addresses growth issues and specifically the urban issues of traffic congestion and housing shortage in Kuwait. The simulations and predictions of the situation by 2050 were carried out with ABM in a GIS environment. The results of this study showed that using urban modelling to assess future plans of developing new cities is essential to help predict urban and population growth trends. The ABM used in this paper has proven particularly effective in assessing the potential impacts of urban growth (congestion, housing shortage and transport efficiency). Furthermore, the ABM was able to model the drivers of population changes as postulated in the new master plan, forecast the population growth in the case study area and match it with a spatial pattern of urban settlement that was defined by the resident survey responses.

The first research question attempted to identify the key issues of urban growth in Kuwait. The interviews carried out with the local government representatives and the survey responses from residents indicated that traffic congestion and housing shortage are the most important issues, and solving these is the main goal of the new master plan. The interviews with the planning authorities also revealed that the government does not use any urban modelling or simulation technology in their planning process, which raises the concerns about traffic congestion and housing shortages significantly.

The second research question asked whether establishing new cities is an effective development strategy in addressing urban growth and the aforementioned issues. The results showed convincing support for establishing new cities as urban growth form in Kuwait. Specifically, assuming that the construction of new cities is completed without delays and according to the initial master plan, the results indicate a reduction of 60% in traffic congestion compared to 2015 levels and no housing shortage before 2050. These predictions require establishing a modern train transportation system on time according to the master plan. The feasibility of this urban development type (new cities) depends heavily on the availability of funding for the intensive capital investment stage. Hence, the methods and findings may be generalized for other Arabian Gulf countries, such as Dubai and Qatar, which have adequate government funding support.

In regard to the third research question, the interviews and survey responses showed that the main concern related to the success of the new proposed cities

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was a delay in construction. Those interviewed expressed their worries about whether the completion of new cities and the proposed train network will be done in a timely fashion as planned, given the long history of delays in past construction projects in Kuwait. The simulations have shown that delays will indeed have detrimental effects on traffic congestion and housing availability. Delays in development of one major new city were associated with the worst outcomes in regards to traffic congestion and housing shortage. However, even with construction delays, the traffic congestion and housing shortage issues will be better compared to the business as usual scenario of infilling and expansion of the existing urban areas (Alghais and Pullar, 2017a).

Finally, the online surveys, used for the first time in Kuwait, allowed residents to have a say in the urban planning process. The survey responses allowed the collection of data directly from the residents and the integration of this information in the model as behaviours and rules for the citizen and non-citizen agents. Hence, it was possible to allocate the residents that expressed willingness to move to new cities in a reliable pattern based on primary data.

The survey responses and simulation results showed that a sufficient number of residents is willing to move to the new cities and the housing shortage will be very likely solved in line with the expectations of the master plan. The results also showed that there are more residents willing to use the new train network than the government initially assumed, which means that the traffic congestion should be lower in the future. This emphasizes the importance of the completion of the new train system without any delays. Certain issues stemming from the results analysis in this work that may be investigated further in future work include a more detailed modelling of the nationality segregation and each resident group's preferred district type and location. Additionally, further integration of survey responses in urban planning may be considered to assist the government and satisfy the public's desire for participation in more direct ways. Regardless, the evaluation the new master plan and it impacts was carried out for the first time in Kuwait and the results of this work may provide the government with significant recommendations.

Declarations

Author contribution statement

Nayef Alghais: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

David Pullar: Conceived and designed the experiments; Wrote the paper.

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Additional information

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