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Sustainable Development of Domestic Water for Jeddah City Using Object Oriented Programming

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Abstract. The paper discusses the present and future (1405-1440) water demand and water resources for the domestic use in Jeddah city. It presents an integrated model for setting guidelines for the water policy in the next century. The paper also illustrates the powerful tool of Object Oriented Programming (OOP) as a fast modeling technique. Projection of both water demand driven by population as well as water resources are illustrated. Three scenarios are presented representing optimistic, most likely and pessimistic cases. Under each scenario, the level of water shortage problem is addressed and it was shown that without water conservation Jeddah city will face significant water shortage. A development plan is suggested to satisfy the domestic water demand up to year 1440.

Introduction

The National Development Plans for the Kingdom of Saudi Arabia entail the provision for water of adequate quality to meet public health standards and quantity to provide for the total requirements of the population. Previous surveys (Abu-Rizaiza *et al.,* 1988) have shown that the Jeddah-Makkah-Taif area to be the most water deficit area in the Western Region. Jeddah city is one of the seven large cities in the Kingdom. It has the largest airport and seaport in the Kingdom as it is the major and pivot point en route to the Holy Mosque in Makkah. The population of Jeddah has increased from 916000 capita in 1980 to 1475990 capita in 1990 (Allehaibi, 1996). In the same period the water supply from Jeddah desalination plant increased from 56.688 million m^3 per year to 133.056 million m^3 per year. Despite the significant increase in the capacity of the desalination plant , the demand increased substantially due to the large development in both the agriculture and industry sectors (Abu-Rizaiza *et al.,* 1994).

The objectives of this paper are to present the current and future (1405-1440) water resources and demands for the domestic water supply. The current water resource is Jeddah desalination plant which will be used to forecast the future water supply as the present rate of development will be retained. The current water demand is decomposed into the population and the demand rate. Based on the current population, three population projection are investigated, namely, optimistic, most likely and pessimistic cases. The current demand rate will be retained and then it will be used as one measure for water conservation in order to bring the supply and demand in balance. Finally, a plan will be suggested for sustainable development of desalination water to satisfy the future domestic water demand.

Water supply

Domestic water supply to Jeddah city is mainly from Jeddah desalination plant. Table 1 shows the amounts of desalinated water produced by this plant from 1405 A.H. up to 1416 A.H. (Ministry of Planning, 1995). The rest of the data up to 1418 A.H. was obtained from Quarterly reports produced by Holy Makkah Region Water Projects (Ministry of Agriculture and Water, 1417, 1418). The table shows a steady rate of increase of water production.

TABLE 1. Desalinated water production in 000' m^3 from Jeddah plant.

Year	Production	Year	Production
1405	111568	1412	134861
1406	109347	1413	134818
1407	107760	1414	143474
1408	109383	1415	154335
1409	116837	1416	150049
1410	133056	1417	149731
1411	131011	1418	150603

Projected water production is predicted based on extrapolation of the present production data using polynomial function of the second degree as it gives the best fit. Fig. 1 illustrates the present and future projection of the desalinated water.

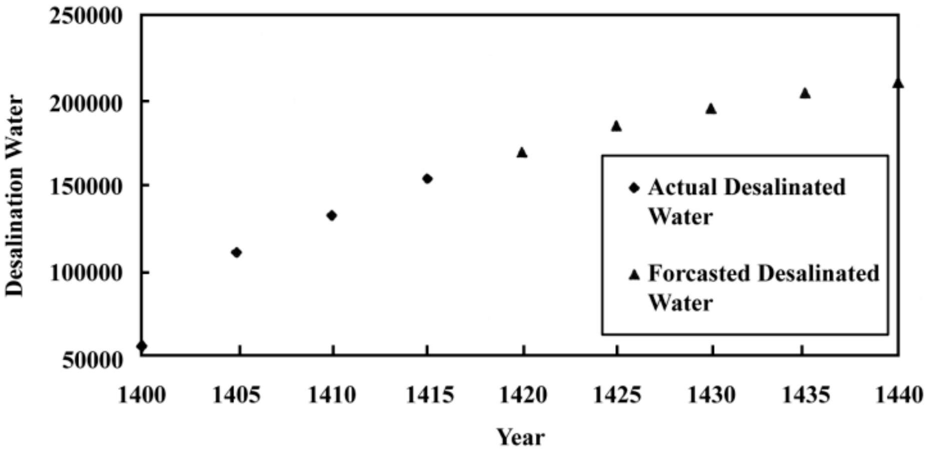

FIG. 1. Actual and forecasted desalinated water in 000' cm.

Water Demands

Water demands are classified into two categories, municipal and industrial. However, as the industrial demands in Jeddah represents less than 10% of the total demands, it will be incorporated within the municipal water demands (Abu-Rizaiza *et al.,* 1994). Municipal water demands can be decomposed into population and rate of water consumption. Population of Jeddah city obtained from data collected from its different municipalities for the years 1980, 1985 and 1990 (Allehaibi, 1996) were found 916000, 1076662 and 1475990 capita respectively. It is to be noticed that these figures include the non-saudi citizens. Future estimates of population can be obtained using various methods (Steel and McGhee, 1985). However, due to the lack of lengthy data to conduct a proper population forecast, three simple methods has been used, one that gives high rate of growth, one that gives low rate of growth and an average between the two results to represent a most likely case. The first method that gives a high rate of growth is the Geometrical Progression Method. Under this method, it is assumed that the population growth rate is proportional to the population, *i.e.*

$$\frac{dy}{dt} = K_g Y \tag{1}$$

where dy/dt is the change in population, K_g is the geometric rate of increase and Y is the population. Integrating Eq. 1 and setting the limits yields;

$$k_g = \frac{\ln\ y_2 - \ln\ y_1}{t_2 - t_1} \tag{2}$$

Thus the population estimate is given by

$$\ln Y = \ln Y_2 + K_g (t - t_2) \tag{3}$$

The second low growth rate method is the Arithmetic Method which assumes that the rate of population change has been and will remain constant, *i.e*

$$\frac{dy}{dt} = K_u \tag{4}$$

where K_u is the uniform growth rate. By integrating Eq. 4 and setting the limits, then the population estimate can be written as,

$$Y = Y_2 + K_u (t - t_2) \tag{5}$$

Finally, the population estimates by the two previous methods along with the average values are given in Table 3 and are shown in Fig. 2.

TABLE 3. Present and future population (Capita) of Jeddah city.

Year	Geometric	Average	Arithmetic
1400	916000	916000	916000
1405	1076662	1076662	1076662
1410	1475990	1475990	1475990
1415	2033427	1949372	1875318
1420	2773904	2524275	2274646
1425	3802730	3238352	2673924
1430	5213142	4143222	3073302
1435	7146667	5309649	3472630
1440	9797327	6834642	3871958

Water consumption rate is not known as a figure for Jeddah city, however, it can roughly be estimated based on the population and the actual domestic water consumed (Ministry of Planning, 1995). Table 4 shows the estimated water consumption rate. It can be seen that the rate increased substantially in 1405 then it decreased in 1410. A rate of 180 lit/cap/day will be assumed based on engineering judgement.

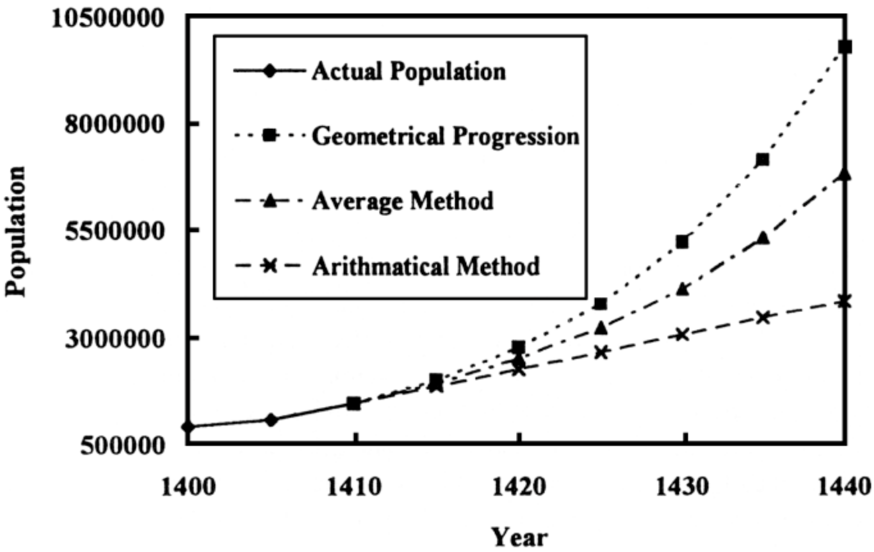

FIG. 2. Actual and forecasted population of Jeddah city.

Table 4. Estimated water consumption rate in lit/cap/day.

Year	Population (capita)	Water consumed (m^3)	Consumption rate (lit/capita/day)
1400	916000	56694130	170
1405	1076662	115792000	295
1410	1475990	134309000	250

Model Framework

Object oriented approach is now considered as the state of the art in water resources planning and management since it facilitates the water decision making in the complex systems (Simonovic *et al.,* 1996). Accordingly, the Object Oriented Programming (OOP) approach is selected to model the domestic water system in Jeddah city. The model is built by simulating the two basic sectors of the domestic use, *i.e.* population which drives the water use and available water resource. In the population sector, future population up to year 1440 is calculated as described earlier for three different cases. Population is then used to drive the water use considering the water consumption rate. While in the water resource sector, estimation of the future water availability is an input based on the consideration described earlier. An indicator is calculated as the ratio between the available water and the water demands which shows the state of the water security in the city.

Object Oriented Modeling Process

Perhaps the most significant shortcoming of classic programming languages modeling is related to who uses the programs and the way in which they can be used. Because of their complexity, these programs cannot encourage non-programmers to participate in the modeling process. Moreover, communication with nontechnical decision makers is impossible. To enhance decision making today, computer tools must aid the nontechnically trained decision maker and/or water resources planner to understand the potential benefits and damages created by a water resources project (Palmer *et al.,* 1993). The models must be easily and quickly constructed, easy to understand and present results clearly to a wide audience. Ideally, future water resources planning and management computer tools will sufficiently be powerful and flexible to allow a variety of non programmers, who are important in the planning process but not trained to be effectively involved.

Several commercially available tools have been developed to simplify the construction and application of water resources simulation models. These software tools include STELLA, Vensim and Ithink among others. These simulation tools provide a graphical, object oriented environment that allows the user to model complex systems without requiring extensive training in computer programming. An understanding of important system components and their interaction is the primary prerequisite for model development. STELLA programming tool (version 5) is selected for implementation of this study (High Performance System, 1997).

Model Application

Three cases are introduced to test the model and its efficiency in the field of integrated water resources management. The three cases are optimistic, most likely and pessimistic. In the water resources side, the production of desalinated water over the previous 14 years was used to derive the future estimate of the production up to year 1440. As it will be seen later that the model can be used to set a development plan for desalination water production to cover the expected demands. On the water use side, three scenarios for population forecast are presented. The rate of water consumption is set first at 180 lit/cap/day, then it is reduced to 150 lit/cap/day as a conservation measure to see its effect on the water state.

Results, Discussion and Analysis

The model results are presented as a comparison between the available water resource and the domestic water use. Figures 3 through 8 illustrate the model output resulting from the three different cases optimistic, most likely and pessimistic.

i) Optimistic Case

As shown in Fig. 3, the available water will satisfy the water demand up to year 1428. After that year, water shortage is expected. Therefore, conservation measure must be implemented to alleviate the problem. If the rate of consumption is reduced to 150 lit/cap/day, the water shortage could be delayed to the end of the simulation period, year 1440 as shown in Fig. 4.

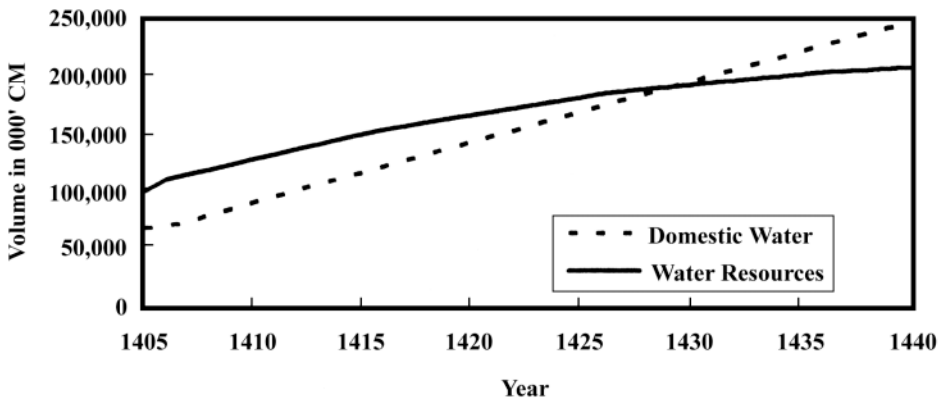

FIG. 3. Optimistic case (180 l/cap/day).

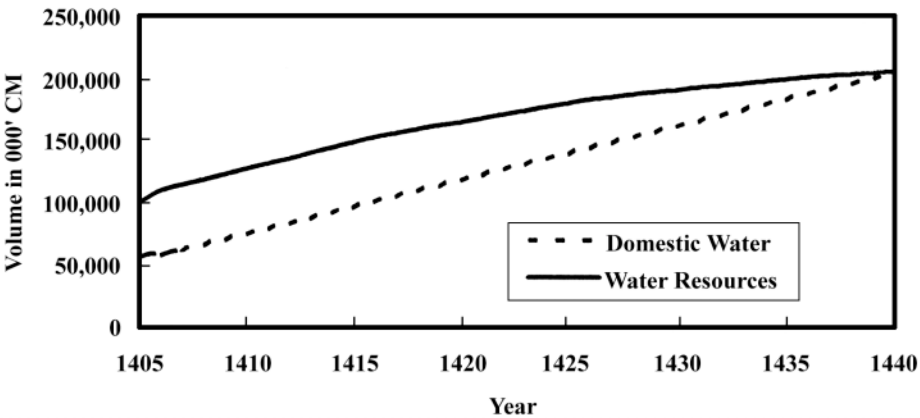

FIG. 4. Optimistic case (150 l/cap/day).

ii) Most Likely Case

Figure 5 shows that the water shortage problem will be as early as year 1421. By reducing the rate of consumption to 150 lit/cap/day, water shortage is delayed to year 1426 as shown in Fig. 6.

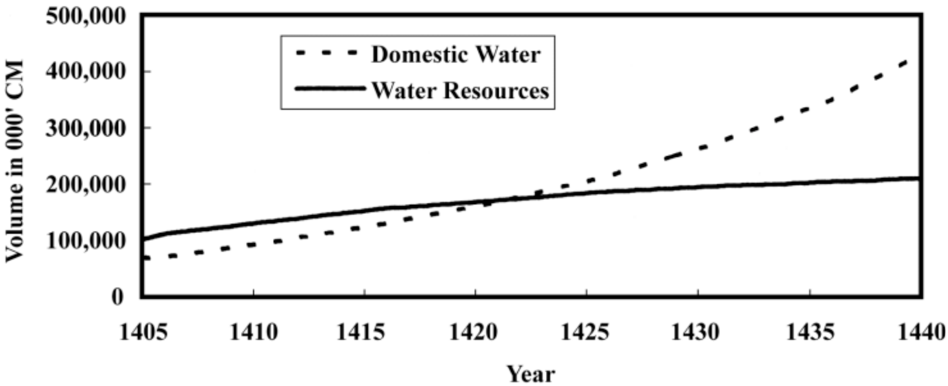

FIG. 5. Most likely case (180 l/cap/day).

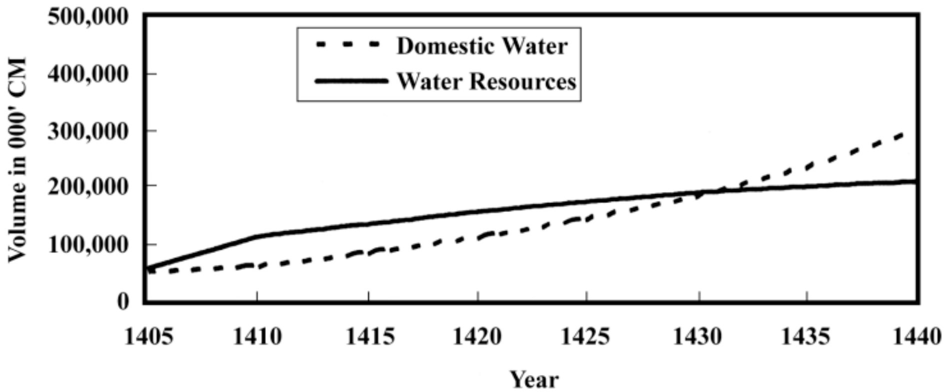

FIG. 6. Most likely case (150 l/cap/day).

iii) Pessimistic Case

Figure 7 illustrates that the water shortage should have been occurred by now which is not the case. This condition can be delayed to year 1422 if the rate of consumption is reduced to 150 lit/cap/day as shown in Fig. 8.

The results point out that water shortage is pound to occur by the near future even under the optimistic case. Therefore, now is the time for earlier planning as the present rate of development of desalination water production is not coping with the rate of increase of population. In fact it is fortunate that a national campaign is launched to conserve water and it is hoped that this will lead to the reduction of the rate of water consumption.

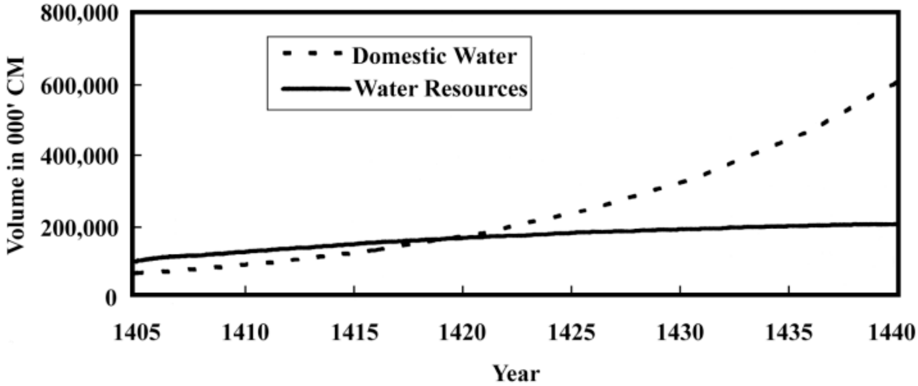

FIG. 7. Pessimistic case (180 l/cap/day).

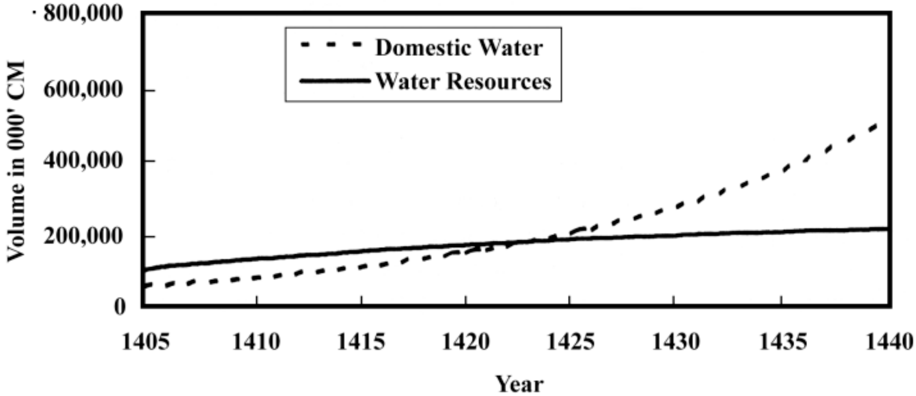

FIG. 8. Pessimistic case (150 l/cap/day).

Water Resources Plan up to Year 1440

Figure 9 illustrates the suggested water plan up to year 1440. This plan is based on the most likely rate of population growth. It can be seen that an increase of 50 million m^3 of desalinated water, more than the current development rate, is needed to satisfy the domestic water requirement. This increase over the current development plan is to be executed in a five yearly steps at years 1423, 1427, 1432 and 1437. It is to be mentioned that this suggested plan is based on the assumption that the current conservation plan is successfully carried out and the rate of water consumption is reduced to the level of 150 lit/cap/day. Otherwise, the rate of increase of the production would be much higher.

Conclusion

In this paper, it is demonstrated that the current development plan for desalination water for Jeddah city will not cope with the population increase in the

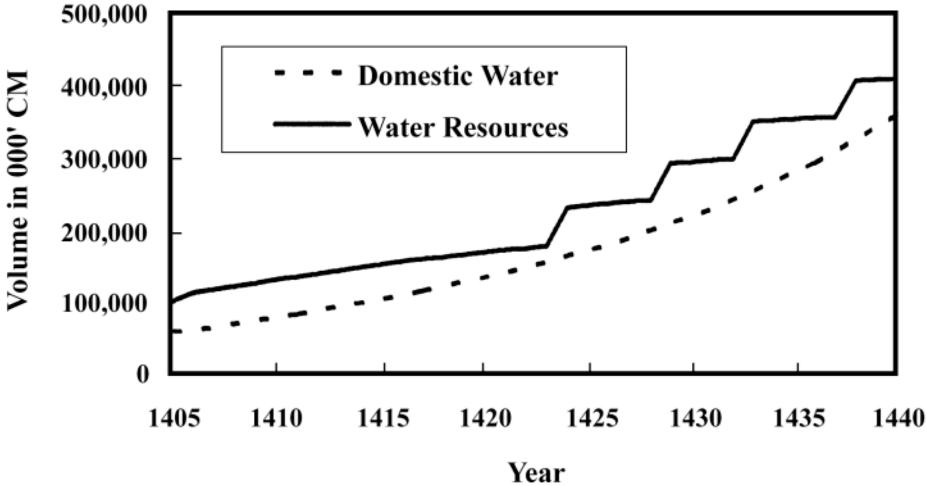

FIG. 9. Suggested development plan.

near future. Three cases, optimistic, most likely and pessimistic for Jeddah population increase are explored. Even under the optimistic case it was shown that the current plan can not cover the domestic requirement if the current rate of water consumption is remained unchanged. However, if this rate is reduced to 150 lit/cap/day, the current plan will satisfy the demand up to year 1440. In the most likely case, with the current consumption rate (180 lit/cap/day), a water shortage is expected within two years. If the current conservation plan is successfully carried out, the current development plan will satisfy the demand up to year 1426. Therefore, it is suggested that an increase in the desalination production, over the current rate of development, of 50 million m^3 is needed to satisfy the demands up to year 1440. This figure is based on the successful execution of the conservation measures being undertaken in the meantime.

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التنمية المستمرة لمياه الشرب بمدينة جدة باستخدام البرمجة الموجهة على الحاسب الآلي

أحمد سامي الزاهر

قسم علوم وإدارة موارد المياه ، كلية الأرصاد و البيئة و زراعة المناطق الجافة

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المستخلص . يعرض هذا البحث الوضع الحالي و المستقبلي (١٤٠٥ - ١٤٤٠) لكمية مصادر مياه الشرب و استهلاكها في مدينة جدة . وهو يقدم نموذج متكامل لوضع الخطوط العريضة لسياسة المياه في القرن القادم . كذلك يعرض البحث قدرة أداة البرمجة الموجهة التي استخدمت كأداة نمذجة سريعة و فعالة تمكن متخذ القرار من المشاركة في عملية النمذجة بدون الحاجة إلى كونه متخصص في البرمجة باستخدام الحاسب الآلي . ويظهر البحث عملية التوقع لاحتياجات مياه الشرب بناءً على الزيادة السكانية المتوقعة وكذلك عملية التوقع لإنتاجية محطة التحلية بجدة بناءً على إنتاجيتها خلال الفترة السابقة . ويعرض البحث ثلاثة حالات (متفائلة والأكثر توقعا والمتشائمة بالنسبة للزيادة السكانية) . وفي كل حالة أظهر البحث مشكلة النقص في كميات مياه الشرب المتوقعة مستقبلا وأظهر الحاجة الماسة إلى ترشيد استخدام المياه والتي بدونها ستواجه مدينة جدة نقصا حادا في مياه الشرب . ويعرض البحث في النهاية خطة مناسبة لزيادة إنتاجية محطة التحلية لتتواءم مع الاحتياجات المستقبلية المتوقعة .