Population Projection Using a Dynamic System Approach: the Case of Population in Banda Aceh

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Abstract. Population growth is the change in the amount and composition of the population from year to year. It requires a method to project not only number of the population, but also the composition of the population in a region. In this study we apply dynamic system approach to simulate and project the number and composition of the population of Banda Aceh based on factors that influence population growth, that is, births, deaths, and migration. This simulation and projection is done by Vensim PLE 6.0.1c. Projecting population growth of Banda Aceh to year 2100 shows a positive trend with an average population growth of 0.88% every year with a ‘demographic bonus’ estimated to be around 2025-2035.

Keywords: population, projection, simulation, dynamic system, vensim

INTRODUCTION

Residents have an important role in regional development because it can influence policy development, education, culture, and resources. The population also has a contemporary and sustainable characteristic that are constantly changing every year. This population change caused by the fertility, mortality, and migration \cite{3}. Therefore, we need a method to estimate the population and the composition of the population as an effort to meet the data needs of the population. One of the roles of demography science to estimate the number of population growth in the future is a projection method. Projection is an indication of future demographic changes that calculates births, deaths, and migration. There are several methods of projection that are often used, one of which is a component method. The component method allows as obtain the projections of population by cohort (based on the age group). The results of the calculation method of these components can be analyzed using simulation method with various scenarios.

Based on the description above, this research will be conducted to model and simulate the population growth factor in Banda Aceh. The simulations will be performed by using the dynamical method systems in accordance with the characteristics of the system being simulated. This study about population growth projection and population structure in Banda Aceh is based on population cohort that influenced demographic factors by the component method. The projection then simulated with a number of scenarios on components: births, deaths, and migration.

METHOD

The data used in this study is a secondary data including data of population, date of birth, and mortality data that all are grouped based on age group, the data of life expectancy (AHH), and data of migration. The source of in this research is from the Central Statistics Agency (BPS) of Aceh and the Department of Population and Civil Registration Banda Aceh 2008-2012.

Conceptual Model. The conceptual model is represented by causal diagram describing causal relationships among variables. In this process each variables is connected with the an arrow line. The step of conceptual modeling in this study begins with classifying variable levels on the productive age group (age 15-64 years) and non-productive age group (age 0-14 years and 65 years and over). Furthermore, associated with each variable rate, auxiliary and constants variable. Here is a conceptual model of the number and structure of population based cohort of four levels.
Based on Figure 1 seen that the total population is affected by the components of population consist of births, deaths, and migration.

**Birth.** Birth is one of the factors increasing the number of residents. Birth can also affect the number of deaths in that cohort and the number who survive to get into the next cohort. The birth also affects the dependency ratio of the population. The number of births is determined by the level of fertility (TFR) in a certain region, the higher the total fertility rate, the more likelihood the number of births. Here is a chart TFR Banda Aceh in 2008-2012 as shown in the following graph:

![Figure 2](image)

**FIGURE 2.** The total fertility rate of Banda Aceh Year 2008-2012

Based on Figure 2 seen that the TFR Banda Aceh continues to increase every year. In 2011 occurred a significant increase on the TFR to 2.85. This means that every woman in the Banda Aceh bore three children during the fertile period. The increase is due much to the birth of this year, but declined again in 2012. Decline of this TFR could have been caused by one of the government programs is family planning programs. From the graph, average of TFR of Banda Aceh from 2008-2012 of 2.01, which means there are 2 births per population of women of childbearing age in each year from 2008 to 2012.

**Deaths.** Death is one of the factors causing a reduction in the amount of and changes in population structure. The number of deaths is determined by the high mortality rate. The death rate is obtained from the table of death and life expectancy. Mortality rate is calculated based on the chance of dying in each population cohort. Number of deaths each cohort is influenced by the number of inhabitants and the mortality rate in the cohort in question.
Furthermore, the number of deaths in each cohort into factors that affect the total number of deaths. While the life expectancy can be seen in the following graph:

![Life expectancy graph]

**FIGURE 3.** Life expectancy of Banda Aceh Year 2008-2012

Based on Figure 3 seen that the life expectancy Banda Aceh from 2008-2012 tended to have a positive trend with an average 70.85. This means that babies born in the year 2008-2012 will be able to live up to 70 to 71 years.

**Migration.** Migration of the population is one other factor that determines population growth that can reduce or increase the number of residents. Migration caused by the push factor of the area of origin and pull factors in destination areas.

**Computation Model.** The formulation of the model is done after a structured conceptual model composed. The formulation of this model is done by inserting mathematical formulas and relationships between variables so that the model created can be simulated.

**Verification and Validation Model.** Stages to ascertain whether of that model create in accordance with the modeler perception called verification. Verification is done by software Vensim, namely by looking at the model check and check unit. If checking the unit on software models and appears OK, the models and the overall unit of variable compliance.

**Validation Model.** Validation is the testing of the model whether the model is correct and made in accordance with the real system. Validation of the model is done by comparing the average value and variance amplitude difference between the actual data and simulation data. According to [10] there are two ways of testing the validation that is mean comparison and amplitude variance comparison.

a. **Error rate (mean comparison)**

\[ E_1 = \frac{|\bar{S} - \bar{A}|}{\bar{A}} \]

where:
- \( \bar{S} \) = the average of simulation
- \( \bar{A} \) = the average of data

Model is considered valid if \( E_1 \leq 5\% \)

b. **Amplitude variations comparison**

\[ E_1 = \frac{|\bar{S}_a - \bar{S}_d|}{\bar{S}_d} \]
where:
\( \bar{S}_e \) = standard deviation of model
\( \bar{S}_d \) = standard deviation of data
Model is considered valid if \( E_2 \leq 30\% \)

Validation of the model is obtained as in the following table:

<table>
<thead>
<tr>
<th>Cohort</th>
<th>( E_1 ) (%)</th>
<th>( E_2 ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cohort 1 (age 0-14)</td>
<td>0.047</td>
<td>0.557</td>
</tr>
<tr>
<td>Cohort 2 (age 15-44)</td>
<td>0.007</td>
<td>0.273</td>
</tr>
<tr>
<td>Cohort 3 (age 45-64)</td>
<td>0.004</td>
<td>0.830</td>
</tr>
<tr>
<td>Cohort 4 (age 65+)</td>
<td>0.040</td>
<td>0.577</td>
</tr>
<tr>
<td>Total of Population</td>
<td>0.009</td>
<td>0.687</td>
</tr>
<tr>
<td>Births</td>
<td>0.285</td>
<td>0.773</td>
</tr>
<tr>
<td>Deaths</td>
<td>0.647</td>
<td>0.983</td>
</tr>
</tbody>
</table>

Based on the table above, it appears that the validity of using means comparison test (E1) shows the results considered valid, because the value of \( E_1 < 5\% \). It's just for the birth data and death data is not valid because the actual data is not recorded completely. To test the validity of using Amplitude Variations Comparison (E2) the data looks not valid, because the result of the validation > 30\%, yet for the second cohort of the data is seen valid because the result of the validation <30\%. In this study the testing of validity of using Amplitude Variations Comparison visible is invalid, and then tested the paired-t test for the actual data with simulated data. This test is done to see whether there is any difference in the actual data with simulated data. Confidence interval used in this test was 95\% with the following hypotheses:

- \( H_0: \mu = \mu_0 \) there is no difference between the actual data with simulated data
- \( H_1: \mu \neq \mu_0 \) there is difference between the actual data with simulated data

Data will reject \( H_0 \) if the value of \( \alpha < P\)-value. Testing paired-t test was performed using SPSS software version 22.

Results of testing paired t test are shown in Table 2.

<table>
<thead>
<tr>
<th>Cohort</th>
<th>( \alpha )</th>
<th>P-value</th>
<th>Selisih data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cohort 1 (age 0-14)</td>
<td>0.807</td>
<td>-2206</td>
<td></td>
</tr>
<tr>
<td>Cohort 2 (age 15-44)</td>
<td>0.794</td>
<td>869</td>
<td></td>
</tr>
<tr>
<td>Cohort 3 (age 45-64)</td>
<td>0.909</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>Cohort 4 (age 65+)</td>
<td>0.05</td>
<td>740</td>
<td></td>
</tr>
<tr>
<td>Total of Population</td>
<td>0.887</td>
<td>-1777</td>
<td></td>
</tr>
<tr>
<td>Births</td>
<td>0.140</td>
<td>955</td>
<td></td>
</tr>
<tr>
<td>Deaths</td>
<td>0.172</td>
<td>18929</td>
<td></td>
</tr>
</tbody>
</table>

Based on Table 2 it appears that the value of the P-value of each model > 0.05, which means not enough evidence to reject \( H_0 \). We can conclude there is no difference between the actual data with simulated data, so that the model is quite feasible to use.
SKENARIO OF MODEL AND DISCUSSION

The scenario is done by changing the parameter values of the model and the structure of the model to estimate the other results are in accordance with the wishes. There are two types of scenarios in the simulation of dynamical systems, namely the structure scenario and the parameters scenario. Structure scenario is used to change the structure of the model by adding or reducing the number of variables. While the parameters scenario are used to change the value of a variable parameters that affect the model. In this study, researchers developed a scenario parameters only for projecting the population of the Banda Aceh. Parameter values are changed is the value of the variable total fertility rate and life expectancy by considering the condition optimistic.

In the optimistic scenario, the number of births and deaths appear comparable population that continues to increase every year, estimated birth and death of Banda Aceh will be stable in the year 2054. Along with the birth and death of the population, the population of the Banda Aceh has also continued to increase in every year, an average increase of Banda Aceh population at 0.0088 or 0.88%. It is estimated that the city of Banda Aceh will have a demographic dividend in 2027 with a dependency ratio of 0.18714. Means that every 100 working age population (considered productive) has dependents as much as 18 to 19 people who are not productive. Banda Aceh dependency ratio is expected to hold steady in 2045 is equal to 0.2. Here is a graphic simulation model scenario:

![Birth Graph](image)

**FIGURE 4.** The graph projection of the total birth population of Banda Aceh Year 2008-2100

Based on Figure 4 number of born in Banda Aceh population both in scenario 1, scenario 2, as well as the optimistic scenario (model) looks comparable to that continues to increase every year. Total fertility is expected to be stable in the year 2054. In scenario 1 the number of births estimated population of Banda Aceh about 7,000 births in 2100, in scenario 2 range 4,000 births, while the optimistic scenario (models) of approximately 5,000 births.

![Deaths Graph](image)
FIGURE 5. The graph projection of the total death population of Banda Aceh Year 2008-2100

Based on Figure 4, the number of deaths in Banda Aceh residents both in scenario 1, scenario 2, as well as the optimistic scenario (model) looks comparable to that continues to increase every year. The number of deaths is expected to be stable population in the year 2054. In scenario 1, the number of deaths estimated population of Banda Aceh before 2100 about 22,000 deaths, in scenario 2 around 19,000 deaths, while the optimistic scenario (models) of approximately 20,500 deaths.

FIGURE 6. The graph projection of the total population of the Banda Aceh Year 2008-2100

Based on Figure 5, the total populations in Banda Aceh residents both in scenario 1, scenario 2, as well as the optimistic scenario (model) looks comparable to that continues to increase every year. The total population is expected to be stable in the year 2054. In scenario 1, the estimated total population of the Banda Aceh before 2100 around 450,000 people with an average population increase of 1%, in scenario 2 of about 380,000 inhabitants with an average population increase of 0.84%, while the optimistic scenario (model) around 400,000 residents with an average population increase of 0.88%.

FIGURE 7. The graph dependency ratio projected population of Banda Aceh Year 2008-2100

Based on Figure 6, seen that the dependency ratio of Banda Aceh continued to decline from 2008 to 2030, then rose to the landless stable until the year 2045. In scenario 1 is estimated lowest dependency ratio in 2025 was 0.216, scenario 2 in 2029 amounted to 0.164, while the scenario optimistic (models) in 2027 amounted to 0.187. This means, in scenario 1 for every 4.6 people bear the productive age population aged 1 person unproductive. In
scenario 2, for every 6 people bear the productive age population aged 1 person unproductive. In the optimistic scenario (model), for every 5.3 working age people aged bear 1 unproductive. Banda Aceh Dependency ratio will stabilize in 2045 is equal to 0.2, in other words, by the year 2045 every 5 people of childbearing age would have dependency 1 person productive age population. This could be due to the population growth of Banda Aceh, the better, the higher the per capita income so the ability to save residents of Banda Aceh higher.

CONCLUSION

1. Total of the births, deaths, and a total population of Banda Aceh continues to increase every year with different levels. The increase is highest between now and the year 2030 continued to show a positive trend growth but the rate continues to decline towards a steady growth after 2050.
2. Projected population of the city of Banda Aceh has a positive trend with an average population increase of 0.88% every year.
3. Under the optimistic scenario, the estimated population of Banda Aceh will have a demographic dividend in 2027 with the lowest dependency ratio in 0187 or 18.7. This means, every 5.3 people of productive age care on population aged unproductive.
4. Migration of Banda Aceh residents assumed the same for each year up to 2100.

REFERENCE