Water availability model based on system dynamic: Sadar sub-watershed case study

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Abstract. Sadar Sub-watershed is one of 32 Brantas sub-watersheds located in the southern part of Mojokerto district and parts of the city of Mojokerto. Based on government regulation (PP) No 26 of 2008, Mojokerto is one of the national strategic areas from the point of view of economic interests. The National Strategic Area (KSN) with an economic interest point of view has an important role for national development, because these areas have the potential for a fast-growing economy and a leading sector capable of driving the national economy. This economic growth must be supported by the availability of various supporting facilities, one of which is the provision of clean water. The current condition of the existence of clean water is decreasing due to various reasons. The purpose of this research is to predict the availability of water in the future as a basis for water resources planning. The stages of the research are as follows: (1). Secondary data collection in the study. The data is used to calculate current water availability and predict future water availability. Primary data is in the form of interviews with groundwater users and experts. (2) Data Analysis. (3) Build the model of water availability in the study area. (4) Simulation of water availability in the study area under various scenario (5). Model validation. The results of this study indicate that there is an effect of land-use change on water availability in the sub-basin. Water conservation scenarios can maintain water availability in the future.

1. Introduction

Watershed is an area of hydrological unity and an area of ecosystem unity where there will be dynamic interactions between the elements of living things, the biophysical environment, and chemical elements. The ecosystem consists of abiotic, biotic and cultural components. water is an abiotic component with the clearest movement following the hydrological cycle and its area (river basin) [1]. Based on this, natural resource management currently refers to the watershed area. Water resources management is one of the natural resource management activities aimed at meeting human needs today and in the future. Sadar Sub-watershed is one of 32 Brantas sub-watersheds located in the southern part of Mojokerto district and parts of the city of Mojokerto.

Based on government regulation (PP) No 26 of 2008, Mojokerto is one of the national strategic areas from the point of view of economic interests. The National Strategic Area with an economic interest point of view has an important role for national development because these areas have the potential for a fast-growing economy and a leading sector capable of driving the national economy. This economic growth must be supported by the availability of various supporting facilities, one of which is the
provision of clean water. As we all know, water is a critical factor for the growth and development of a region. The results of research conducted by Cheng Qi (2011) show that economic development affects income, real estate status, and levels of health care that affect domestic water needs [2]. The existence of water resources is currently under pressure due to increasing demand for water due to population growth, rapid urbanization, climate change, and economic growth [3].

The same thing was stated by Qin (2018) that most of the metropolitan cities in the world experience water shortages caused by population, land use, urbanization and industrial development [4]. Most of the springs that are the source of water for the regional drinking water company in Mojokerto Regency are located in the Sadar sub-watershed, where their current condition has decreased by 60% from the initial conditions. The influence of climate change in the Mojokerto Regency is marked by a decrease in rainfall by 11%, an increase in temperature of 2°C and a decrease in dependable discharge from surface runoff and a decrease in rainwater which will seep into groundwater [5].

System dynamic has been widely used for water resources management purposes. Environmental problems have complex systems and require input from various sources and types of knowledge to make appropriate decisions as well as problem in water resources management. The feedback mechanism in a system dynamic allows stakeholders to explore problems in a system from an environmental, economic, and social perspective [6]. The purpose of this research is to predict the availability of water in the future as a basis of water resources planning Naive Bayes (NB) is a Bayes-oriented learning method that is very useful for learning involving high-dimensional data [1]–[3], such as text classification [1], [4]–[6], Searching [7]–[10] and web mining [11]. In general, the Bayesian classification method has a conditional dependency between random variables.

2. Literature Review

2.1. Water availability

Water availability is the volume of water contained in the hydrological cycle in a region, which is a combination of rainwater, surface water and groundwater. Rainwater that falls to the earth's surface will experience an evapotranspiration process, some will enter the ground, and the rest will flow on the earth's surface as surface flow to a lower location [7]. The accumulated surface flows will form a river flow, which can then be spatially defined as a watershed. Water availability in a watershed is the result of the overall calculation of water availability starting from meteorological, surface water, and groundwater. Calculation of water availability is important to determine the potential of water resources in an area [8]. The availability of water in a watershed can indicate that an area is in critical water condition or not, this is indicated by the water availability index. The water availability index is expressed in terms of the area's primary water availability divided by the population [9].

2.2. System dynamic

In the late 1950s, Jay Forster and his research team from MIT developed a system dynamic for analyzing business cycles in the industry. In 1969, Jay Forester wrote a book of Urban Dynamic in which system dynamics are used to model urban social and economic problems. As previously stated, that system dynamics have been widely used in the modelling of water resources management. Elsawa et al. (2017) analyzes system dynamics in five different case studies, namely the Berlin urban development case study, Gnangara groundwater, Texas groundwater, MedAction, and ACT water management. The purpose of their research is to demystify the system dynamics modelling process and investigate the important problems faced when developing and evaluating system dynamics in applications. The results of the research indicate that system dynamics provides strong advantages over other modelling approaches in their feedback representation systems [6]. Qin et al. (2018) recommend that the water demand prediction model they have developed can be applied to other megacities which in general have similarities in calculating water demand based on sector, scenario design, and analysis procedures [4].

In contrast to Qin, Holmes (2014) used a system dynamics model to explore the dilemma of water supply and demand in small cities in South Africa. he models simulation result showed that the
municipality unable to constrain the connection rate, so that conservation action is needed in the form of reducing water loss in the distribution network and water conservation at the household level [11]. A system dynamics model for supporting water management in semi-arid regions of Brazil was developed by Araujo et al. (2019). The system dynamics simulation results show that water supply is sensitive to tariffs, reuse of wastewater, and transfer of water between basins. This study also concludes that pricing methods that encourage rational use of water based on scarcity can increase income and investment in water management strategies [3]. Research conducted by Purnama (2013) shows that the dynamic model uses The Powersim 2.5c program can be used to simulate hydrological models, particularly groundwater conservation models [10].

3. Research Method
3.1. Description of the case study
The Sadar sub-watershed is located in Mojokerto Regency with latitude 112°24'35" - 112°37'35" E, 7°27'5"30" - 7°43'7"30" S, and an area of 358 ha. Administratively, the Sadar sub-watershed area includes 8 sub-districts in Mojokerto regency and one sub-district in Mojokerto city. Water use in the Sadar sub-watershed comes from groundwater, surface water, and spring water. Based on the decree of The Minister of Public Works number 268 / KPTS / 2010 concerning the Management of Water Resources in the Brantas river area, the potential for surface water for the Sadar sub-watershed is 270 million m$^3$ / year with a flow rate of 8.57 m$^3$ / s. Sadar Sub-watershed is included in the area of the Brantas groundwater basin, with a groundwater potential of 222.01 million m$^3$. There are five springs that are the source of the Regional Drinking Water Company in Mojokerto Regency, namely: 1. Jubel springs with a discharge of 18.4 l / s; 2. Wonolopo spring with a discharge of 30 l / s; 3. Coban Pelangi spring with a discharge 10 l/s; 4. Mojo springs with a discharge 10 l/s; 5. Ubalan springs with a discharge 10 l/s [5]. The map of the study area is presented in Figure 1 below.

3.2. Data collection and Methodology
3.2.1. Primary and secondary data collection methods are as follows:
   a. Primary data obtained from the results of direct observations in the form of interviews with community groundwater users and experts. Respondents were determined using the expert method the survey was divided into two ways: respondents from the community other than experts at the research location were conducted using a purposive random sampling method proportionally.
   b. Secondary data used in this study are data on water resource potential, land use data, population data, rainfall data, climate data, groundwater data obtained from related agencies, and previous research

Figure 1. Map of research area
3.2.2. Analysis Method

3.2.2.1. Water availability analysis.

Availability of groundwater is calculated from the availability of surface water, groundwater, and spring water. Some of the assumptions used in this study are presented in the following table.

**Table 1.** The initial data and assumptions used in the water availability model in the Sadar sub-watershed.

| Description                        | Substantial | Unit | Source of data                                      |
|------------------------------------|-------------|------|----------------------------------------------------|
| 1. Catchment area                  | 35,800      | ha   | The decree of The Minister of Public Works number 268/KPTS/2010 |
| 2. Residential area (RA)           | 7,738,85    | ha   | Mojokerto District Planning Agency                 |
| 3. Agriculture area (AA)           | 22,484      | ha   | Central Statistics Agency of Mojokerto Regency 2019 |
| 4. Plantation area (PA)            | 242         | ha   |                                                    |
| 5. Forest area (FA)                | 5,135,83    | ha   |                                                    |
| 6. Mixed garden (AMG)              | 3,591,07    | ha   |                                                    |
| 7. Existing runoff coefficient:    |             |      |                                                    |
| - residential area (RAROC)         | 0,3         | -    | U.S Forest Service, 1980                           |
| - agriculture area (AAROC)         | 0,7         | -    |                                                    |
| - plantation area (PAROC)          | 0,3         | -    |                                                    |
| - forest area (FAROC)              | 0,05        | -    |                                                    |
| - mixed garden (MGOC)              | 0,2         | -    |                                                    |
| 8. annual average rainfall         | 2325,2      | mm/yaer | IUWASH report,2014                           |
| 9. evapotranspiration (Ep)         | 102,589     | mm/yaer | Widiyono,2015; Sisca,2015                        |
| 10. Existing runoff                | 1040000000  | m³/yaer |                                                    |
| 11. Availability of groundwater volume (EGWA) | 222,010,000 | m³ | The decree of The Minister of Public Works number 268/KPTS/2010 |
| 12. Availability of surface water (SW) | 270 x 10^6 | m³/year |                                                    |

The equations used in analyzing groundwater availability are as follows:

\[ C = \frac{\sum C_i A_i}{\sum A_i} \]  \hspace{1cm} (1)

\[ Q = 0,0028 \times C \times I \times A \]  \hspace{1cm} (2)

\[ Rr = P - Ro - Ep \]  \hspace{1cm} (3)

\[ V_{gw} = (V_o + Rr) \times 2,5 \% \]  \hspace{1cm} (4)

Remarks:

- \( C \) = total runoff coefficient
- \( C_i \) = the area expansion coefficient of runoff
- \( A_i \) = wide area (ha)
- \( Q \) = discharge of runoff (m³/year)
- \( I \) = rain intensity
- \( Rr \) = groundwater recharge (m³/year)
- \( P \) = precipitation (mm/year)
- \( Ro \) = runoff (mm/year)
Ep = evapotranspiration (mm/year)  
Vgw = volume of groundwater  
Ve = volume of existing groundwater

3.2.2.2. System dynamic analysis
The systems approach stages are as follow:

- Needs analysis
  Needs analysis is the initial stage in assessing a system. At this stage, the needs of each stakeholder are identified. Needs analysis is carried out based on literature review and interviews with stakeholders involved in the use of water.

- Problem formulation
  Based on the need’s analysis, it is seen that the needs are inline or contradictory which can lead to conflict in the achievement of the objectives of this study.

- Identification systems
  This stage is carried out to recognize the relationship between statements needs and problem statements that must be resolved in order to meet those needs. At this stage, one of the approaches taken is to compile a causal loop diagram then interpret it in the concept of an input-output diagram (black box). This aims to identify the relationship between "statement of need with the statement of problem"

- System modelling
  Model is a representation of the system. The model built is not will be exactly the same as the actual system. The modelling process is a creative, non-linear process, but must comply with scientific disciplines and logical and iterative thinking. The procedure in modelling is restating the problems to be resolved in accordance with the objectives of the system, formulating the model, testing, and analyzing the model. The variables involved in the system are combined in the shape of the flow chart and the variables are divided into several sub-models. This dynamic model will be built using the Powersim Studio 10 Academic software.

- Model validation
  Validation of model validity is an attempt to conclude whether the aforementioned system model is a legitimate representation convincing. In this research, two kinds of validation tests were used, namely structure validation and performance validation.

4. Result and Discussion
Water use in the study area is divided into two categories, namely domestic and non-domestic. For domestic requirements, some people use groundwater, and others use water from regional drinking water companies. In the 2019 the number of customers of the Mojokerto regency drinking water company is 22,757 people, only about 0.2% of the total population of Mojokerto regency which amounted to 1,159,593 people in the same year. Non-domestic needs include water needs for agriculture, livestock, industry, tourism, hotels, restaurants, schools, and commercial facilities.

4.1. Requirement analysis
From the results of discussions with stakeholders and literature studies, requirement analysis is obtained as in table 2 below.

| Number | Stakeholders  | requirement                      |
|--------|---------------|----------------------------------|
| 1      | Water users   | - Fulfilment of water requirement in various sectors |
|        |               | - Good quality of water          |
2 Government agencies

- Increase the coverage of the system service area
  Provision of Drinking Water (SPAM) and non-network
  SPAM piping in urban and rural areas.
- Maintain a balance of water availability with
  optimization use of raw water for irrigation, drinking
  water, and maintenance watershed.
- Controlling pollution related to protection groundwater
  quality.
- Policy on groundwater conservation and water saving.

4.2. Formulation problem

Based on the analysis of the current needs and conditions of water resources in Mojokerto Regency, the
formulation of the problems are as follows:

a. The number of populations increases that continues to increase every year.

b. Clean water infrastructure and facilities that are not yet in balance with increasing population growth.

c. Not all villages/wards have received clean water services from local drinking water companies.

d. There has been no effort to reuse wastewater for industry and irrigation.

4.3. System identification

System identification is described in terms of causal loop diagram as figure 2 below.

![Causal loop diagram of water availability at Sadar sub-watershed](image)

**Figure 2.** Causal loop diagram of water availability at Sadar sub-watershed

4.4. Model simulation

The rate of recharge affects the availability of groundwater. The main source of groundwater recharge comes from rainwater. The potential for rain in Mojokerto Regency is 2325.2 mm / year with an area of 358 km², so the potential for rain in Mojokerto Regency is 832,421,600 m³ / year. The rainwater that falls in the research area does not completely penetrate the ground as a supplement to groundwater. Some of the rainfall will be lost to the atmosphere as evapotranspiration, some will become runoff and flow directly into the sea. Based on several research results, it is known that evapotranspiration in the tropics is around 4-5 mm / day.

The amount of water runoff depends on the value of the land cover coefficient (C). The value of C is very dynamic depending on changes in land use in an area. Based on these parameters, a water availability model will be built in the research area. From the simulation results, it can be seen that the total infiltration volume in one year has decreased, from the original about 20% in 10 years. Reduced
volume infiltration which is an input for groundwater reserves is a concern will cause drinking water supply problems in Mojokerto. The availability of water in the study area is still sufficient to meet the needs of the community but it is necessary to pay attention to the distribution of the distribution of the water availability.

4.5. Validity test
After the model is made, the validity test will be carried out in order to find out whether the model made is close to the actual system (real). From the structural test, it can be seen that the model structure is the same as the actual structure. From the simulation results, it can be seen that the variable water demand increases with population growth. This is in accordance with the actual existing system.
The results of the validity test using AME obtained a value of 4.3% <10% so that the model can be said to be valid. Meanwhile, the validity test using the Absolute Variance Error (AVE) value obtained a value of 8.6% <10%, the model can be said to be valid.

5. Conclusion
Conclusion of the research are:

a. The groundwater balance in Sadar sub-watershed area still shows a surplus.
b. The water available in the Sadar sub-watershed is able to meet the water requirement of the community.
c. The occurrence of land use changes to some extent affects water availability.
Suggestion: it is necessary to create scenarios for water conservation with various kinds of conservation efforts.

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