AI Based Water Demand Prediction Algorithm in Cape Town

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ABSTRACT

Water crisis is a scary topic which is playing out in Africa, for this will lead to countries fighting each other over drops of water that is left in time. Demand for water is rapidly growing this is due to several factors playing a role in it. For instance, population growth is one that will cripple water catchments. This is due to water demand ever rising against water supply, worse off in countries that experience high tourism rate, also in countries that has high birth rate. Climate changes also do play roles in the demand and supply of water. This article will analyze prediction models and compare them. Thereby, constructing a model that will combine framework and algorithms to perform a prediction of water demand. Execution basis may involve one or several of these; forecast accuracy, training speed, and delay in time between the presentation of inputs and reception of outcomes for trained network. Network size should also be considered, the larger it is the increased time it will take to perform one weight update.

KEY WORDS

Water Demand Prediction; ANN; genetic algorithm

1 INTRODUCTION AND BACKGROUND

1.1 Introduction

Water is very important on earth to all living organisms like humans, plants, animals and even insects. Organisms need water as a substance to survive the harshness and temperature conditions in all areas. Water can do many things and is vital not only as a substance for drinking but contributes more to the body (health wise) and in other uses like projects for example hydropower among others. Water regulates body temperature, flushes out waste from body and aids in the functioning of the brain. Agriculture needs water without it the country's produce will drop. There are so many countries that rely on agriculture for instance South Africa. These countries are well known for its grapes produce which leads to wine produce, now without water they will crumble in many ways not just one. Water is also used to produce electricity in countries such as Mozambique, Zambia, Zimbabwe and Democratic Republic of Congo. As indicated from the beginning, water is essential in all aspects. However, water shortage can disturb the balance of nature. The absence or lack of water will lead to outbreak of diseases, crops dying, shortage of other energy, like electricity if the country has hydroelectric power plant(s), among others. Water shortage can be caused by climate changes, temperature changes, an increase in population growth and an unequal balance between demand and water supply (contributed by slow water life cycle). The shortage of water can be fought off by implementing catchments and other policies to govern the demand and supply of water. There are six reservoirs, that provide Cape Town with water. When Cape Town noticed their reservoirs have reached levels of concern, they introduced a program they called "Day Zero". This is where taps if not all are to be closed in parts or throughout Cape Town. This paper will focus on the development of an accurate prediction model that will assist in operational decision-making and as well predict water demand in Cape Town. Calculating and predicting water levels in dams and lakes is a vital thing to fight off this water crisis we are experiencing in Africa, it also plays an essential role in the navigation of water resources and planning catchment management[1]. This paper will focus on predicting future water demand. From research, water consumption is connected to weather conditions like temperature and precipitation. This paper will be based on coming up with an accurate prediction model that will assist in developing informed decisions. Reservoirs are much more effective and important when it comes to changing unbalanced flow of water over land. The reservoirs have several uses such as providing certain areas with hydroelectric energy and water, they also provide in times of droughts and assist in times of floods. Reservoirs are vital in making future water usage, there should be a chain of decision making when it comes to the release of water and as well as intake of water in reservoirs such as Theewaterskloof in Cape Town. Futures forecasting can also ensure the safety of reservoirs, also avoid overflow of waters in reservoirs. This paper will look at the prediction models that have been explored and propose a favorable prediction model.

1.2 Background

South Africa has faced 3 years of dryness and these are among the driest. South Africa is said to have very low rainfall as well as per capita water availability compared to other countries. As shown in Figure 1, South Africa has a very low average annual rainfall as well as water per capita per annum compared to India, Botswana and other countries. The problem is, it is uncertain when it's expected to fill up dams in Cape Town to a point of normality. It is unknown when the end of ''Day Zero'' program will be reached, in other words, it is uncertain of how long we will endure the period of water crisis.

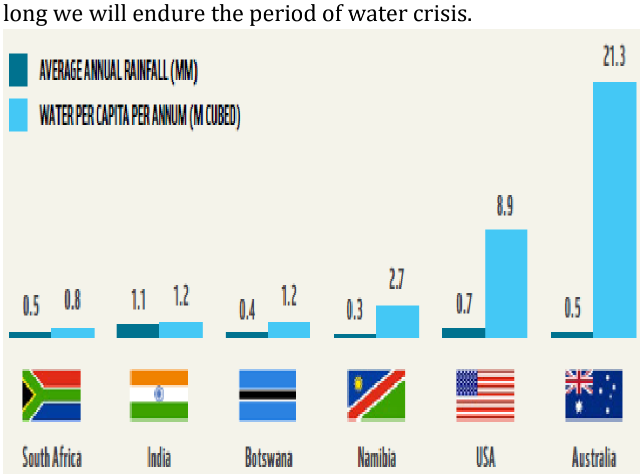

Figure 1 Water Availability in Selected Countries m^3 [2]

Figure 2 shows the three drivers that contribute to the increase in demand for water. Municipal demand, which is at 26% is greater than industrial demand at 11%, but not greater than agriculture which demands 63% of water. These are the 3 major contributors of water demand in South Africa. Demand is expected to grow around one percent annually to reach 18 billion cubic metres in the year 2030 from 15 billion cubic metres in 2016[2].

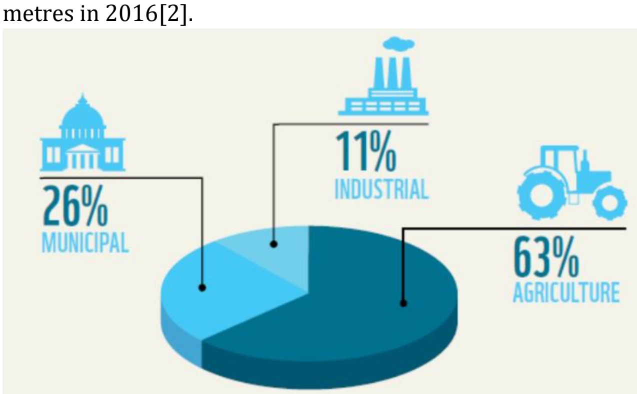

Figure 2 Drivers for increase in water demand [2]

Labor also increases the supply and demand rate of water. In the agriculture field, not only do crops require water but the livestock also demands water. In industries, water is used for manufacturing applications (processing of minerals and crops, component, and auto supplies, textile, chemical refinement just to name a few), mining and power applications (extraction, refining, and cooling)[2]. The Cape Town dams are clearly in critical state due to the water crisis, click here. It is seen that WemmerShoek has reached 36011 mile (mi) this March 2019, this dam has the lowest compared to other dams for it is below the red line(safe zone)[3]. In the same month Theewaterskloof is at 198472 MI just below Berg River, the highest so far 97480 mile (mi) of water, of which for now it is above the red line[3]. This is a vital moment where decisions are required, with an aid from water prediction models. In 2018 Cape Town had been preparing for "Day Zero" where the city was going to have the taps shut off in homesteads and companies, to accommodate for shortage of water throughout Cape Town due to perilously low reservoirs[4]. As much as water is a renewable resource, changing weather patterns and a slowed water cycle entails water cannot be replenished as fast as it is being consumed. Moreover, the rural areas are only able to access unclean water which has led to health issues such as cholera epidemics and several diseases.

1.3 Proposed Solution: Water Demand Prediction Model

A web application that implements a hybrid methodology to predict water demand in Cape Town for the water utility is proposed in this work. This hybrid methodology will combine Artificial Neural Networks with a framework that will aid in reducing the features required from that data used to train the model. By doing so, proper preparations in meeting water demand levels through well informed decisions will be made. The ANNs model chosen will be used to predict water demand for a particular year or span several into the future. This will assist City of Cape Town and government in preparing to store water or enforce regulations in order to meet future water demand. This will also help decide how fast the water demand needs to be met. This application will be a web application that will use an Artificial Neural Network (ANN) model and a genetic algorithm to predict water demand levels in the future years. This web application will use as much of the data from the City of Cape Town to train the model and then test it for accuracy. Afterwards, it will be used online to determine future water demand. This data may be taken from database or from the sensors, or possible aquifers to indicate how significant the levels are to the municipal. For the proposed ANN model, Convolutional Neural Network will be used. This web application will aid businesses and people in making their long term decisions, in whether to store more or less water to accommodate for water demand predicted.

2 Literature-Review

Water demand predictions is still an active area for research because of the continuous increase in consumption of water, worse of in urban areas. Moreover, it is vital for tactical decisions and efficient operation and management in short, medium and long terms. An analysis of both short- and long-term predictions is made, where short-term predictions are viewed as daily or monthly water consumption which is important in supporting daily operation decisions. Whereas, long-term predictions are established on several years, which is more suited for decision making over long term point of view[5]. Some papers have used economic factors like water price and household income as features in water demand predictions, others, regression models have been utilized in the prediction of water consumption levels[5]. Regression models used water features like temperature and rainfall. A multivariate regression model that encompasses temperature, precipitation and evapotranspiration was made as a proposal. The importance of weather attributes for water demand predictions was reviewed and models were tested with and without the involvement of weather attributes. The model with weather attributes outperformed the model which did not include weather attributes[5]. Other models extended features like temperature, customer count, median income, holidays, precipitation in forms of rainfall and snow, and previous day's water consumption[5]. The importance of each attribute in prediction of daily and monthly consumption was analyzed. Moreover, they used Feed-Forward Neural Network and Recurrent Neural Network. However, it was known that recurrent neural network, may have not been used for water demand predictions in previous work[5]. In addition, an analysis of the weights of each input attribute was made and reduced the input attribute set to maximum temperature, day of the year and precipitation, which led to a modified recurrent neural network (dMRNN) model as a proposal[5]. This model displayed improvements with a very low average error and coefficient of determination. Once online further improvements were made due to continued training and it showed resilience and has an ability to self-correct within 2 days of mispredictions in almost every scenario[5]. In another paper, Computational Neural Networks and fuzzy inference systems were implemented with success on times series prediction. A methodology involving the incorporation of CNNs, fuzzy logic and genetic algorithm to predict water demands at irrigation districts a day ahead was formulated[6]. The use of Historical time series data from Fuente Palmera irrigation district located in Andalucia, southern Spain was enforced in the methodology[6]. Models made use of univariate autoregressive CNNs trained by using Levenberg-marquardt algorithm (LM)[6]. The prediction accuracy was improved by correction made with a genetic algorithm. The use of univariate autoregressive CNN models trained by Extended-Delta-Bar-Delta algorithm (EDBD) and calibrated in previous study for same irrigation district for comparison purposes led to the application of a hybrid methodology[6]. This resulted in the hybrid model performing exceptionally well compared to univariate and multivariate autoregressive CNNs. Moreover, another methodology to provide short-term prediction of daily irrigation water demand when data provided is not whole was developed. This was done by connecting dynamic Artificial Neural Network (ANN) architecture, the Bayesian framework and the Genetic Algorithm (GA) together. The methodology was executed in Bemberzar MD Irrigation District (Southern Spain)[6]. The CNN applications of water resource management and preparation involved modelling of monthly, daily and hourly rainfall-runoff process, real-time and lake stage forecasting, rainfall forecasting, groundwater modelling, assessment of stream's hydrologic and ecological response to climatic change, drought analysis, among others[6]. It has been observed that using these models alone, they have rather good results. In addition, combining them will combine the strengths and advantages of each which will bring forth favorable and desirable results. Therefore, this has shown that promotion of the idea of combining the models and techniques together is legal. Furthermore, a hybrid methodology with combination of CNNs, fuzzy logic and genetic algorithms was used to predict consumer demands of irrigation area using-on-farm water use information[6]. For the estimation of corrections in predictions obtained from a univariate autoregressive neural network was a fuzzy inference system and a genetic algorithm which was used to locate optimal values of parameters of fuzzy system. The model proved powerful without using large data requirements becoming useful towards development of policies on irrigating water consumption, since information pertaining water demand is vital when scheduling pumping efforts, reduced running costs of water administration systems and response level to distinct irrigation water rates[6]. It has been viewed by other papers that weather inputs will not automatically ameliorate production of the prediction model. They viewed this as extra costs and plausible risks depending on the execution of weather input data of missing input for the model. Another paper for Hail region, Saudi Arabia, displayed annual municipal water consumption being modelled with 3 distinct techniques that involved artificial neural network (ANN), stochastic time-series (STS) and particle swarm optimization (PSO)[7]. Feed-forward ANN was viewed to be outperforming STS including PSO due to relatively small data records used and the power to model non-linear systems. It has been analyzed from 2000 to 2010, a wide variation of techniques rely on prediction variables like climate and socio-economic, and on prediction horizon like, short, medium and long term[7]. They emphasized on the strains bound by the nature and standard of the attainable data. From theory and practice findings it has been deduced that combining different tools and techniques is effective in predictions[7]. More research talk of evolution in sensors, and ICT advocate that there are chances for development of Big Data and new management tools-based predictions and Artificial Intelligence (AI)[7]. A development of daily water predictive model utilizing Fuzzy Logic technique and Artificial Neural Network which also applied Genetic Algorithms to optimize shape of fuzzy sets, the overlapping level of fuzzy sets and fuzzy rule definitions[7]. However, structure of the ANN was decided by trial and error. More research displayed growth for an Artificial

Neuro-Genetic Network that predicted irrigation demand in irrigation district with parameters that defined ANN structure and ANN generalization by circumventing overfitting through optimization by GA[7]. However, outcome indicate that predictive model resulted in errors when it may be handy to managers in scenarios of high and low water demand because of the generalized ANN. ANNs in other papers were used in the prediction raindrops, with temperature, pressure and humidity as parameters for the model. The outcome indicates that ANN is competent and suitable, in making raindrop predictions. From the comparison of 3 ANN methods which include GRNN, FFNN and RBNN, it has been viewed that GRNN consisting of 3 input variables that are; monthly water bill, population and monthly average temperature, becoming the best performing predicting water consumption in city of Izmir, Turkey[7].

3 User Requirements

3.1 User View of The Problem

The system must have access to the internet in order to make user predictions. The system will be clear and simple to use by the government, the City of Cape Town and agriculture industry. The data provided will be in a form ready for use in situations of short and long-term decision making. Hence it must be simple. Users must sign up to control flow of information. The look and feel of the web application will be consider for different people have different preferences.

4 REQUIREMENTS ANALYSIS DESIGN

4.1 Functional Requirements

Functional requirements for this web application are as follows;

- The web application will inform the users of water demand trends and changes in Cape Town.
- Drought monitoring and prediction tab for users who are within the agriculture industry.
- Display relative water information of all Cap Town Dams (water levels).
- Users must log in.
- Users can view notifications from the notification page in-regards to water crisis in Cape Town.
- Users can predict water demand several months/years ahead.

4.2 User Specification

User specification for this web application will be as follows;

- Home page which will show clear details of water crisis or situation in Cape Town.
- A section where notifications are displayed regarding the water crisis in Cape Town.

4.3 Data Requirements

Data requirements for the web application will be as follows;

- The data used here will be retrieved from the City of Cape Town.
- Whilst offline, some of the data in hand will be used for training the model, then its accuracy will be tested with the remaining data soon after. See diagrams below in Figure 4;

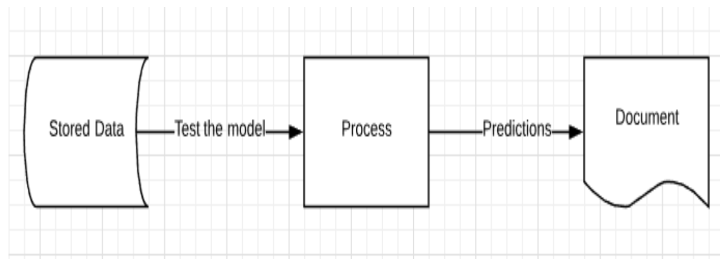

Figure 3 Typical prediction model

- More data will be retrieved to test its accuracy when its up and running online, as shown below in Figure 5;

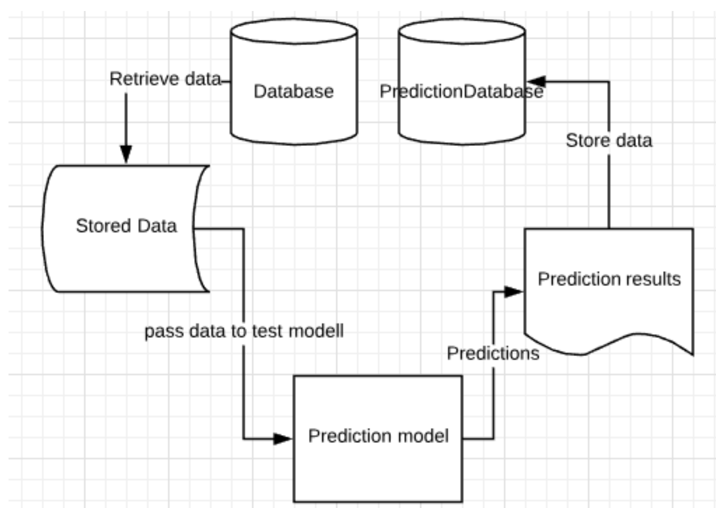

Figure 4 Typical Online Testing prediction model

- The system database must be connected to the internet to keep track of updated data.

- The database must be updated frequently to give accurate data.

- A connection to the City of Cape Town's data base should be established, to allow retrieval of complete data to ensure accurate results from the web application.

4.4 Usability Requirements

From the user's perspective, the requirements will be as follows;

1. The system must be accessible. Therefore,

2. The web page must be simple and clear when presenting data. Visible and standard icons, font sizes should be standardized.

3. The system must be consistency

4. Huge data is retrieved from the City of Cape Town. Therefore, simplicity is of importance.

5. Users can customize the web application in accordance to dates/months/years for predictions.

5 TECHNOLOGY SPECIFICATION

5.1 Programming Language

The computer programming languages required to move forward with this web applications or system are as follows;

- HTML5 – To incorporate structures and layout of the web data to the users in the frontend of the website application.

- Python – will be used to code and execute the Artificial Neural Network offline and online.

- MySQL – database for storing the data needed or used by the Artificial Neural Network for making accurate predictions. This data will also be used to store predictions and keep data updated regularly.

- CSS – To aid HTML5 incorporate structures and layout of the web data to the users in the frontend. As this will aid in describing the presentation of the web pages with respect color, font and layout. This will allow to accommodate small, medium and large screen users.

- JavaScript – Will provide a framework for our web application. It will aid in the interactive behavior of our web application with the users.

- PHP – for setting our database with our web application.

6 CONCLUSIONS

ANN models are used in different applications and it has been seen that CNN models perform quite well as compared to other ANN models. Research papers have shown that these models can be combined to construct a hybrid model that is an embodiment of the strengths and capabilities of each separate model in the hybrid. Training the model before testing is a logic way of preparing model testing, without this then the model will be useless. All the necessary attributes needed are within the data that will be retrieved from the municipal of Cape Town. CNN is a choice of model for it performs well from literature reviewed. Hence will be ideal to use in the methodology chosen. More attention is needed to the optimization of model to reduce error made in prediction accuracy. The processing speed of feedforward networks is greater than recurrent networks of equivalent.

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