# Using Remote Sensing Satellite Data and Artificial Neural Network for prediction of Potato yield in Bangladesh

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## ABSTRACT

Potato is one of the staple foods and cash crops in Bangladesh. It is widely cultivated in all of the districts and ranks second after rice in production. Bangladesh is the fourth largest potato producer in Asia and is among the world's top 15 potato producing countries. The weather condition for potato cultivation is favorable during the sowing, growing and harvesting period. It is a winter crop and is cultivated during the period of November to March. Bangladesh is mainly an agricultural based country with respect to agriculture's contribution to GDP, employment and consumption. Potato is a prominent crop in consideration of production, its internal demand and economic value. Bangladesh has a big economic activities related to potato cultivation and marketing, especially the economic relations among farmers, traders, stockers and cold storage owners. Potato yield prediction before harvest is an important issue for the Government and the stakeholders in managing and controlling the potato market. Advanced very high resolution radiometer (AVHRR) based satellite data product vegetation health indices VCI (vegetation condition index) and TCI (temperature condition index) are used as predictors for early prediction. Artificial neural network (ANN) is used to develop a prediction model. The simulated result from this model is encouraging and the error of prediction is less than 10%.

**Keywords:** Remote Sensing, Artificial Neural Network, Prediction model, Back Propagation, Potato Yield.

## 1. INTRODUCTION

Bangladesh is one of the most densely populated (967/sq.km, census 2011) and climate change vulnerable country in the world. It is mainly an agricultural country because agriculture is the imperative culture of people's livelihood and national economy. Agriculture has an apparent contribution to the Gross Domestic Product (GDP) and employment. 47% of the total labor force engaged with agriculture and the contribution of agriculture to GDP is 16% [1]. In Bangladesh agriculture has played a key role in reducing poverty from 48.9% in 2000 to 31.5% by 2010 with over 87% of rural people part of their income comes from agricultural activities [2]. Potato is an important crop in consideration of production and its high demand in both domestic and international market. The soil and climate condition in Bangladesh are very favorable during the lifecycles for potato cultivation. Potato is one of the staple foods mainly consumed as vegetable and is the second largest food crop grown in Bangladesh. Potato is suitable as a security crop in times of rice shortage due to its high carbohydrate content contributing to improved food security.

In Bangladesh net cultivable land would decrease from 8.42 million hectares in 2000 to 7.89 million hectares in 2025 and population would increase from 127.22 million in 2000 to 168.90 million in 2025. This scenario shows that annually Bangladesh has to produce additional 0.274 million tons of food to maintain pace with the needs of population growth [3]. Since potato is a short duration crop, its increased use can reduce the pressure on rice and wheat. Potato is considering a potential crop, the total cultivated area of potato in the year 2013-2014 was 4,62,032 hectares and total production was 89,50,024 metric tons [1].

With its high carbohydrate content potato is considered a leading food ingredient and is one of the most popular and widely used vegetable in the world. It is the fourth largest food crop in the world following the Maize, wheat and rice respectively. Potato is consumed by more than one billion people all over the world and is grown in more than 100 countries in the world with a production of around 364 million tons in the year 2012. China is now the biggest potato producer and almost one-third of all potatoes is harvested in china and India. China is the largest producer of potatoes with more than 85.9 million metric tons annual production. While Bangladesh is the 8$^{th}$ largest among the world's potato producers and 3$^{rd}$ in Asia, its annual production was 8.2 million metric tons in the year 2012 [4]. At present, potato is high quality vegetable cum food crop in respect of world food scenario.

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Remote sensing is the science concerned with acquiring information about an object without physically interfering with that object. Any remote sensing system requires a source of energy, a target and a sensor for recording the interactions of electromagnetic radiation with that object. On striking an object, energy may be reflected, absorbed or transmitted. Typically, the reflected energy is measured using a specially designed sensor system. Measurement of the amount of energy reflected allows some inferences to be made about the nature of the target [5]. Remote sensing makes it possible to collect data on dangerous or inaccessible areas [6]. Moreover, satellite data are available and will keep continue providing earth observation. In particular, the weather station network in Bangladesh is not dense enough for efficient monitoring [7]. A crop monitoring system that provided timely and accurate information on crop status and yield well before the harvesting period and without requiring a dense ground-based observation network would be of great value. This paper investigates the potential of using remote sensing technology for estimation Aus rice yield in Bangladesh. AVHRR-based vegetation health indices were found to be very useful for early drought and flood detection and monitoring their impacts on crop and pasture production around the world [8]. Application of AVHRR-based vegetation health indices for characterization of the impact of weather conditions on potato yield has also been investigated to use as predictors for predicting before harvest.

Artificial Neural Network (ANN) is an information processing paradigm that is inspired by human's central nervous system, such as the brain process information. Actually, ANNs are simply mathematical techniques design to accomplish a variety of tasks with the nonlinear relationships among their input variables which mimic basic biological neural systems. Neural Network is an intellectual approach that can be used to provide a good prediction model. In recent years, researchers have been attracted to the ANN for their model development due to high computational speed, ability to handle complex non-linear functions, robust and great efficiency [9]. In this research Neural Network approach has been used to develop a model to predict potato yield in Bangladesh. Potato yield mainly depends on climate components such as temperature, humidity, precipitation etc. This paper shows the application of remote sensing data for predicting potato yield in Bangladesh using official statistics of yield data with real time acquired satellite data from AVHRR sensor and ANN prediction tool are used to predict potato yield in advance. The inputs for this research are TCI & VCI and target is statistical potato yield in Bangladesh. The performance of this model is mainly depends on accuracy and the error of prediction.

## 2. POTATO CULTIVATION IN BANGLADESH

In Bangladesh potato is cultivated in all the districts and is limited to a winter crop based on its climatic conditions. It is the third largest food crop grown in Bangladesh and mainly consumed as vegetable. Potato grows best in a cool and moist climate. Well- fertilized, sunny land with sufficient moisture in soil is appropriate for potato plantation. Planting is undertaken in October through November, for harvesting in February through March [10]. Potatoes are not roots but specialized underground storage stems called 'tubers'. Maximum tuber formation occurs at soil temperatures between 60° and 70° F. The tube fails to form when soil temperature reaches 80° F [11]. Potatoes are planted manually with a row spacing usually from 45 to 60cm, with optimal depth of planting depending on local soil type and moisture (around 5 cm deep)[10]. There are two main varieties of potatoes that cultivated in Bangladesh are local and high yielding. Because of poor yield performance, farmers are interested to cultivate high yield varieties i.e., Sheel Bilatee, Lal Sheel, Lal Pakri and Du Hajari. According to Bangladesh Bureau of Statistics (BBS), during the last couple of decade potato cultivation area and production are increased almost every year. In 1980 production was 1065680 tons and in 2013 production was 8603000 tons.

## 3. CHARACTERISTICS OF BANGLADESH

Bangladesh is a developing country in South Asia located between 20°34′ to 26°38′ north latitude and 88°01′ to 92°42′ east longitude. The country has an area of 147,570 square kilometers with a population of 160 million and extends 820 kilometers north to south and 600 kilometers east to west. Bangladesh is bordered on the west, north, and east by a 4,095-kilometer land frontier with India and, in the southeast, by a short land and water frontier (193 km) with Burma (Myanmar). The high population density, low economic growth, lack of institutional infrastructure, an intensive dependence on agriculture and agricultural products, geographical settings, and various other factors, all contribute to make the country weak in its economic development and quality of life. The climate of Bangladesh can be characterized as tropical monsoon with three main seasons i.e., a hot and humid summer from March to May, a hot and humid monsoon season from June through October and a cooler and drier winter from November through February. Mean temperatures typically range from about 64° F in February to 82° F in July. Most region of Bangladesh receives at least

200 centimeters of rain fall annually, about 80 percent occurring during the monsoon season. Bangladesh is now widely recognized to be one of the most vulnerable countries to climate change. Natural hazards that come from flood, rising sea level and tropical cyclone are expected to increase as climate change and seriously affect agriculture, water and food security, human health and shelter [12].

## 4. DATA SET

### 4.1 Potato yield

Potato production data were collected from ‘The Yearbook of Agricultural Statistics of Bangladesh’. The Yearbook of Agricultural Statistics is a regular publication of Bangladesh Bureau of Statistics and published exclusively with agriculture related data. BBS estimates the production and the area sown from sampling surveys. Agricultural statistics consists of structural and annual statistics. The structural statistics are generated collecting data through full count/sample census normally at a regular interval of ten years as per FAO guidelines. The annual agricultural statistics are generated collecting data through annual/seasonal sample survey [13]. Yield (kilogram/acre) was calculated by dividing total Aus rice production (in kilogram, kg) by the sown area (acres). Potato yield data from 1980-2014 were used for this study.

### 4.2 Satellite data

Remote sensing satellite data were used for this study. Advanced Very High Resolution Radiometer (AVHRR) based polar orbiting environmental satellite sensor data operated by National Oceanic and Atmospheric Administration (NOAA) were used in this study. AVHRR is a satellite mounted instrument that measures radiances from the earth’s surface in several visible and infrared bands. The AVHRR-measured solar energy reflected/emitted from the land surface (in 8–bit counts) were collected from the National Oceanic and Atmospheric Administration (NOAA) Global Vegetation Index (GVI) dataset from 1980 through 2014. GVI is one of the most widely used satellite data products. Spatial data resolution was 4 square km, sampled to 16 square km, and the original temporal resolution of 1 day was sampled to 7-day composite [8]. The AVHRR sensor counts in visible (VIS, 0.58–0.68μm, Ch1), near infrared (NIR, 0.72–1.00μm, Ch2) and infrared (IR, 10.3–11.3μm, Ch4) spectral regions were used to generate GVI. Post-launch–calibrated VIS and NIR counts were converted to reflectance [14] and used to calculate the Normalized Difference Vegetation Index (NDVI),

$$NDVI=(NIR-VIS)/(NIR+VIS) \tag{1}$$

### 4.3 Vegetation health indices

Global Vegetation Index (GVI) data set was developed by sampling 4 square km Global Area Coverage (GAC) data to 16 square km spatial resolution and daily observations to seven-day composite [8,15]. The principle for constructing VH indices stems from the properties of green vegetation to reflect VIS and NIR and emit IR solar radiation. If vegetation is healthy it reflects little radiation in the VIS (due to high chlorophyll absorption of solar radiation), much in the NIR (due to scattering of light by leaf internal tissues and water content) and emits less thermal radiation in the IR spectral bands (the transpiring canopy is cooler). As a result, for healthy vegetation, NDVI is large and BT is small. Conversely, for unhealthy vegetation, NDVI is small and BT large [16]. The VH indices were calculated from NDVI and BT. Here, only important steps are mentioned, which include (a) complete elimination of high frequency noise from NDVI and BT annual time series, (b) approximation of annual cycle, (c) calculation of multi-year climatology and (d) estimation of medium-to-low frequency fluctuations during the seasonal cycle (departure from climatology) associated with weather variations. The Vegetation Condition Index (VCI) characterizing moisture and Temperature Condition Index (TCI) characterizing thermal conditions were calculated as:

$$VCI=100(NDVI-NDVImin)/(NDVImax-NDVImin) \tag{2}$$

$$TCI = 100(BTmax - BT)/(BTmax-BTmin) \tag{3}$$

Where NDVI, NDVImax, and NDVImin (BT, BTmax, and BTmin) are smoothed weekly NDVI (BT), their multiyear absolute maximum and minimum respectively. VCI and TCI algorithm have been developed from NDVI which separates weather component and ecosystem component by Max-Min criteria [17, 8]. VCI could assume values between

0 and 100, corresponding to variations from stressed to favorable and TCI could assume values between 100 and 0, corresponding to variations from stressed to favorable vegetation conditions. Finally, VHI is defined as a combination between the two previous indices:

$$VHI = a * VCI + (1 - a) * TCI \quad (a=.5) \tag{4}$$

The vegetation health indices were designed with the idea of extracting the weather component from NDVI and BT value[18]. The long-term changes in vegetation driven by climate, soil, vegetation type, topography etc. and short-term weather fluctuation such as moisture and thermal condition are represented by NDVI and BT.

# 5. TOOLS AND METHODS

Artificial neural network was used for this study to develop a prediction model. Nonlinear auto regressive with exogenous (external) input, or NARX time series neural network was used for early prediction and model development.

## 5.1 Artificial neural network

An Artificial Neural Network (ANN) is an interconnected group of 'nodes' known as 'neurons', 'neurodes', 'processing elements', or 'units' to form a network which mimics a biological neural network. ANNs are fundamentally a 'black box' approach. In this kind of technology the black box has the ability to learn the input output correlation by training the input to produce the expected output [19]. Prediction is an important application that best fit for NN model. ANN model is based on prediction by smartly analyzing the trend from an already existing voluminous historical set of data. The mathematical or statistical models are found to be very accurate in calculation but not in prediction, because they cannot adapt to be irregularly varying patterns of data which can neither be written in form of a function or deduced from a formula. In ANN model the artificial neurons, which can learn from experience i.e. by back-propagation of errors in next guess and so on is a better interpreter of real life situations [20].

## 5.2 Neural network basic operation

Neural networks (NN) are composed of simple elements operating in parallel. NNs are trained to perform a particular function by adjusting the values of the connections (weights) between elements. NNs are adjusted, or trained, so that a particular input leads to a specific target output. Figure 1 illustrates such a situation. The network is adjusted, based on a comparison of the output and the target, until the network output matches the target [21].

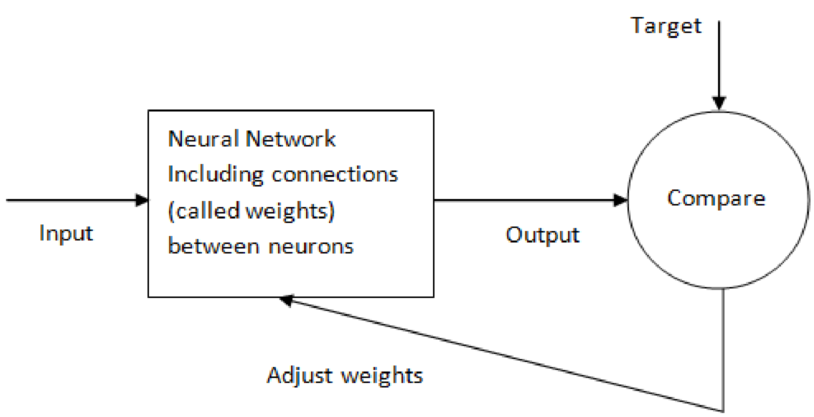


Figure 1: Artificial Neural Network Basic Diagram.

## 5.3 Artificial Neuron

The basic building block of an Artificial Neural Network is called an artificial neuron, that is, a simple mathematical model (function). Such a model has three simple sets of rules i.e., multiplication, summation and activation. A neuron is an electrically excitable cell that process and transmit information. Each neuron of neural network can either accept a vector or scalar input ($p$) and gives a scalar output ($a$). A single input neuron is shown in figure 2.

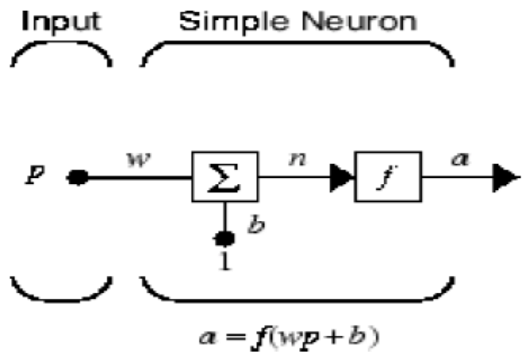


Figure 2: Block diagram of a Single input neuron.

The scalar input $p$ is multiplied by the scalar weight $w$ to form $wp$ that is sent to the summer. The other input, 1, is multiplied by a bias $b$ and then passed to the summer. The summer output $n$, often referred to as the net input, goes into a transfer function $f$, which produces scalar neuron output $a$ [22]. The actual output depends on the particular transfer function. The bias is much like a weight, except that it has a constant input of '1'. Note that, $w$ and $b$ are both adjustable scalar parameters of the neuron. Typically, the transfer function is chosen by the designer based on the desired output (predicted) value then the parameters $w$ and $b$ will be adjusted by some learning rule so that the neuron input/output relationship meets some specific goal. A multiple inputs neuron is shown in figure 3.

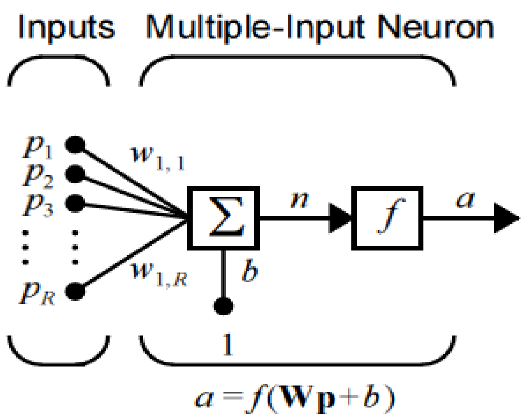


Figure 3: Block diagram of a Multiple inputs neuron.

A neuron that has more than one input is called multiple inputs neuron; the above figure has $R$ inputs. The individual inputs $p_1$, $p_2$, $p_3$… $p_R$ are each weighted by corresponding elements
$w_{1,1}$, $w_{1,2}$, $w_{1,3}$,…, $w_{1,R}$ of the weight matrix **W.** The neuron has a bias $b$, which is summed with the weighted inputs to form the net input $n$ for the transfer function.

$$n = w_{1,1}\, p_1 + w_{1,2}\, p_2 + w_{1,3}\, p_3 \ldots,\ w_{1,R}\, p_R + b$$

In the matrix form

$$n = \mathbf{Wp} + b$$

Neuron output

$$a = f\,(\mathbf{Wp} + b)$$

A particular convention is assigning the indices of the elements of weight matrix. The first index indices the particular neuron destination for that weight. The second index indices the source of the signal fed to the neuron. Thus, the indices in $w_{1,2}$ says that this weight represents the connection to the first neuron from the second source [23].

**5.4 Transfer function**

A transfer function also known as activation function that maps a neuron's (or layer's) net output '*n*' (weighted inputs and bias) to its actual output '*a*'. The actual output of a neuron depends on the particular transfer function that is chosen. The transfer function may be a linear or a nonlinear function of *n.* A particular transfer function is chosen to satisfy some specification of a problem that the neuron is attempting to solve [22]. The log-sigmoid and linear transfer function are used for this model, shown in figure 4

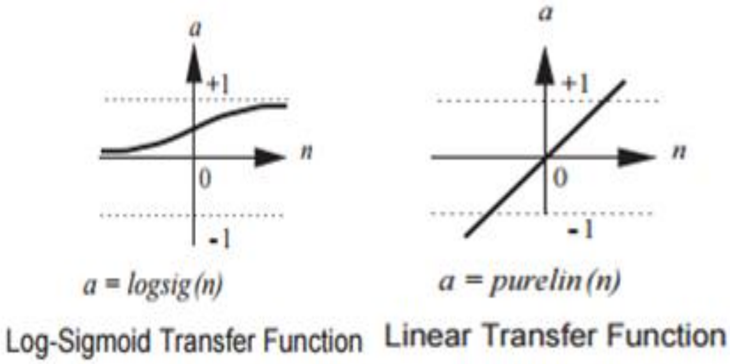


Figure 4: Log-sigmoid and linear transfer function

Log-sigmoid transfer function takes the input (Which may have any value between plus and minus infinity) and squashes the output into the range of 0 to 1, according to the expression:

$$a = 1/(1+e^{-n})$$

The log-sigmoid transfer function is commonly used in multilayer networks that are trained using the back propagation algorithm, in part because this function is differentiable.

A Linear transfer function is a function that produces its input as its output.

The output of a linear transfer function is equal to its input

$$a = n$$

**5.5 A layer neurons**

A layer is a group of neurons having connections to the same inputs and sending outputs to the same destinations. A single-layer network with *R* input elements and *S* neurons is shown in figure 5

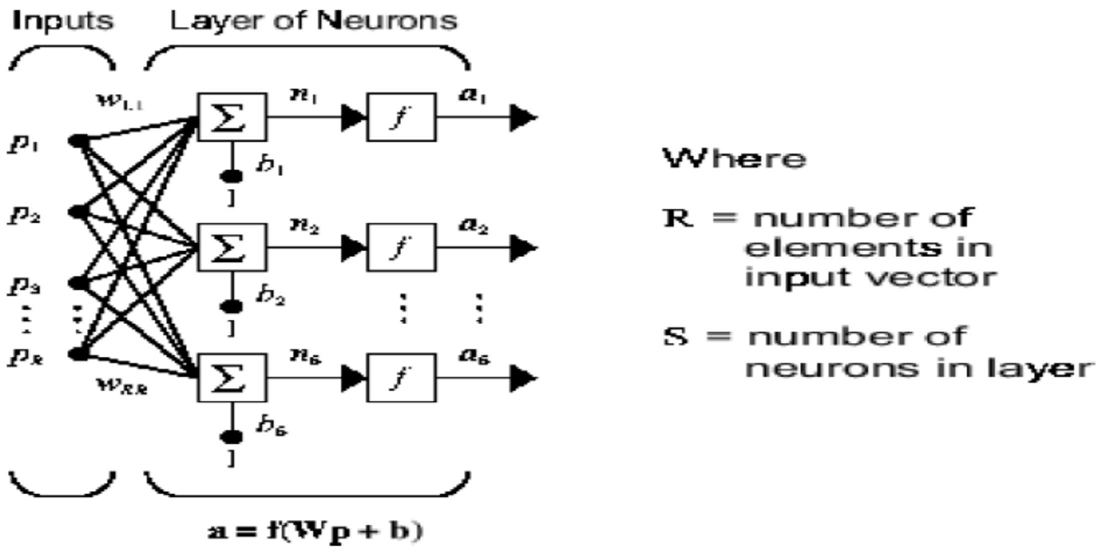


Figure 5: One Layer of Neurons with multiple inputs and neurons

The layer includes the weight matrix **W**, the summers, the bias vector **b,** the transfer function boxes and the output vector **a.** Each element of the input vector **p** is connected to each neuron through the weight matrix **W.** Each neuron has a bias $b_i$, a summer, a transfer function $f$ and an output $a_i$. The input vector elements enter the network through the weight matrix W.

$$\mathbf{W} = \begin{bmatrix} w_{1,1} & w_{1,2} & \cdots & w_{1,R} \\ w_{2,1} & w_{2,2} & \cdots & w_{2,R} \\ & & & \\ w_{S,1} & w_{S,2} & \cdots & w_{S,R} \end{bmatrix}$$

The row indices of the elements of matrix **W** indicate the destination neuron associated with that weight, while the column indices indicate the source of the input for the weight. Thus, the indices in $w_{3,2}$ say that this weight represents the connection to the third neuron from the second source [23].

## 6. PROPOSED NETWORK

Multilayer feed forward Back-propagation ANN is used to develop potato yield prediction model for Bangladesh shown in figure 6. The network has R input elements, S neurons in the hidden layer and one neuron in the output layer because there is only one target value associated with each input vector. Feed-forward network has default tan-sigmoid transfer function in the hidden layer and linear transfer function in the output layer. Each layer of a multilayer neural network has a weight matrix **W**, a bias vector **b**, and an output vector **a**.

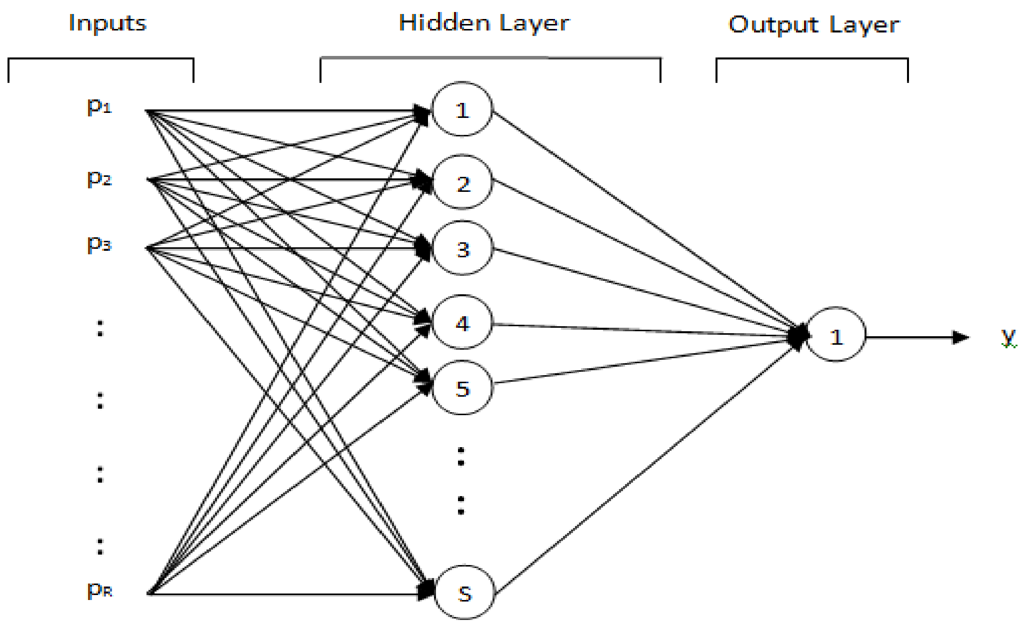


Figure 6: Feed-forward back propagation ANN with layers and connections.

Each element of the R inputs (vector **p**) is connected to each neuron through the weight matrix **W.** Network inputs **p** has R variables and each variable has 24 elements. Remote sensing satellite data of vegetation health indices (VCI & TCI) for week 49-52 from 1988-2011 for 24 years are taken as input variables. The input data (Potato_Input) is a 1×24 cell array of 8×1 matrices, representing dynamic data: 24 time steps of 8 elements. Potato yield from 1988-2011 for 24 years are used as a target data. The target data (Potato_Target) is a 1×24 cell array of 1×1 matrices, representing dynamic data: 24 time steps of 1 element. The length of inputs and target data must be the same. Y is the network output or the simulated result from the network. S is the number of neurons in the hidden layer. Table 1 show the inputs and target data.

Table 1: Potato yield prediction with vegetation health indices and potato yield statistical data

| Year | VHI(Vegetation Health Indices) Data | | | | | | | | Target data |
|---|---|---|---|---|---|---|---|---|---|
| | TCI49 | TCI50 | TCI51 | TCI52 | VCI49 | VCI50 | VCI51 | VCI52 | Potato Yield Ton/Hectare |
| 1988 | 55 | 51 | 47 | 44 | 48 | 52 | 54 | 54 | 10.3381 |
| 1989 | 13 | 9 | 9 | 7 | 61 | 65 | 65 | 67 | 9.7859 |
| 1990 | 9 | 7 | 7 | 8 | 73 | 72 | 70 | 65 | 9.1410 |
| 1991 | 11 | 12 | 16 | 18 | 69 | 67 | 63 | 61 | 9.9867 |
| 1992 | 63 | 64 | 62 | 60 | 24 | 26 | 29 | 32 | 10.7931 |
| 1993 | 63 | 58 | 52 | 49 | 37 | 38 | 38 | 35 | 10.6786 |
| 1994 | 82 | 79 | 76 | 70 | 9 | 10 | 11 | 12 | 10.9570 |
| 1995 | 48 | 45 | 42 | 40 | 52 | 54 | 52 | 50 | 11.1665 |
| 1996 | 43 | 39 | 34 | 30 | 70 | 69 | 67 | 66 | 11.2740 |
| 1997 | 41 | 41 | 36 | 31 | 65 | 61 | 60 | 60 | 11.2551 |
| 1998 | 81 | 79 | 71 | 67 | 43 | 50 | 55 | 55 | 11.3972 |
| 1999 | 49 | 39 | 33 | 28 | 65 | 72 | 75 | 77 | 11.2809 |
| 2000 | 73 | 66 | 64 | 60 | 34 | 34 | 32 | 32 | 12.0585 |
| 2001 | 93 | 91 | 83 | 70 | 1 | 1 | 2 | 5 | 12.9162 |
| 2002 | 24 | 22 | 20 | 16 | 68 | 71 | 72 | 73 | 12.6010 |
| 2003 | 35 | 34 | 31 | 31 | 69 | 66 | 63 | 58 | 13.8021 |
| 2004 | 40 | 36 | 31 | 28 | 60 | 64 | 66 | 65 | 14.4312 |
| 2005 | 40 | 38 | 34 | 35 | 56 | 57 | 58 | 56 | 14.8805 |
| 2006 | 39 | 31 | 25 | 22 | 71 | 73 | 70 | 63 | 14.3847 |
| 2007 | 37 | 33 | 34 | 33 | 59 | 58 | 53 | 50 | 14.9768 |
| 2008 | 51 | 38 | 28 | 37 | 71 | 83 | 86 | 66 | 16.5373 |
| 2009 | 38 | 30 | 49 | 46 | 72 | 64 | 45 | 41 | 13.3367 |
| 2010 | 43 | 40 | 37 | 38 | 49 | 51 | 51 | 54 | 18.2298 |
| 2011 | 41 | 37 | 32 | 30 | 75 | 77 | 75 | 73 | 18.0930 |

The selection of neurons for hidden layer is one of the challenges to design an ANN. The no. of neurons in the hidden layer has an impact on learning capability, complexity, generalization and accuracy of the problem. Therefore, the selection of the minimum number of neurons for hidden layer is just enough to ensure the complexity of the problem, but too many may cause over fitting of the training set and losing the generalization ability. Hence, trial and error method should be the best way for selecting hidden neurons. The proposed model is a time series prediction model and is composed of two inputs, one is VHI time series data and another is potato yield time series data. The future values of the time series y(t) (Potato yield) is predicted from the past values of that time series and past values of a second time series x(t) (VCI & TCI). This form of prediction is called nonlinear autoregressive with exogenous (external) input, or NARX and can be written as-

$$y(t)= f(y(t-1),y(t-2),\ldots,y(t-d),x(t-1),x(t-2),\ldots x(t-d)) \quad (5)$$

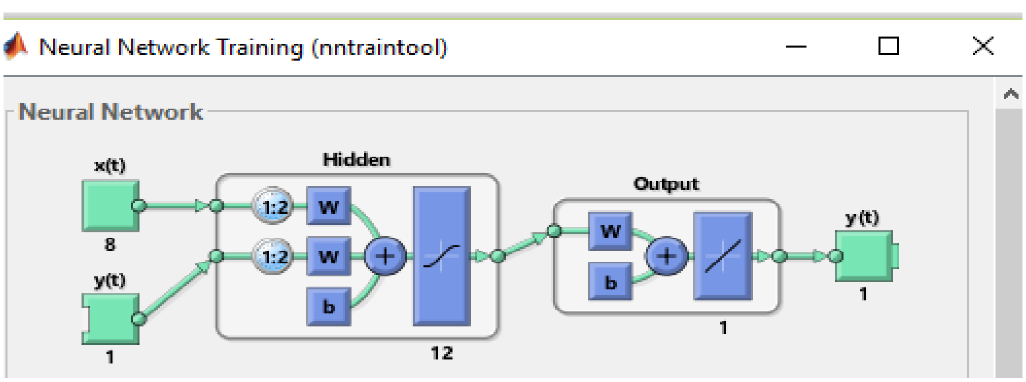


Figure 7: NARX Neural Network Potato yield prediction model simulated diagram

Figure 7 shows the NARX neural network diagram. It is a two-layer feedforward network with sigmoid transfer function in the hidden layer and linear transfer function in the output layer. The number of neurons in the hidden layer is 12 and output layer is 1. The number of output neuron is equal to the number of elements in the target vectors (the number of categories). The neurons number can be changed if the network training performance is poor. This model is used to predict potato yield in Bangladesh.

### 6.1 Back-propagation

Back propagation or BP is the most common neural network learning algorithm and used for the proposed model. The back propagation algorithm uses supervised learning, which means that the algorithm is provided with examples of the inputs and outputs that the network is expected to compute, and then the error (difference between actual and expected results) is calculated. The idea of this algorithm is to reduce this error, until the ANN learns the training data [24]. In back-propagation algorithm, there are two phases in its learning cycle, one to propagate the input patterns through the network and the other to adapt the output by changing the weights in the network. The flow of information is in the forward direction. The nodes in the BP neural network receive input information from external sources, and then pass to hidden layer which is an internal information processing layer and is responsible for the information conversion; further nodes in the output layer provide the desired output information. After that, the anti-propagation of error is carried out by contrasting the actual output with desired output. Each weight is revised and back propagated layer by layer from output layer to hidden layer and input layer. This process will be continued until the output error of network is reduced to an acceptable level or the predetermined time of learning is achieved. Weight adjustments are made to reduce error. [25].

### 6.2 Neural network performance

ANN performance for feedforward networks is evaluated using the measure of mean square error (mse)-the average squared error between the actual or target outputs ($y_a$) and the predicted or network outputs ($y_p$). It is defined as follows,

$$F = mse = \frac{1}{N}\sum_{i=1}^{N}(y_a - y_p)^2$$

Where; $N$ denotes the number of samples
$y_a$ denotes the actual yield
$y_p$ denotes the predicted yield
$e_y = (y_a - y_p)$-denotes the error value

ANN is the most proved for forecasting applications. The reason is that, ANN methodology solves the complex relationships between the independent and dependent variables by a mathematical mapping algorithm without detailed mathematical modeling.

### 6.3 Train the network

Training is a procedure whereby a network is adjusted to do a particular job. A neural network can be trained to perform particular function by adjusting the values of weights between elements so that a particular input leads to a specified output [21]. This process is repeated until the validation error is within an acceptable limit. Once trained, the ANN recognizes the functional relationship between inputs and targets. Gradient descent is the simplest backpropagation training algorithm. It updates the network weights and biases in the direction in which the performance function decreases most rapidly, the negative of the gradient. One iteration of this algorithm can be written as,

$$\mathbf{x}_{k+1} = \mathbf{x}_k - \boldsymbol{\alpha}_k \mathbf{g}_k$$

Where $\mathbf{x}_k$ is a vector of current weights and biases, $\mathbf{g}_k$ is the current gradient, and $\boldsymbol{\alpha}_k$ is the learning rate. This equation is iterated until the network converges. Training function '**trainlm**' is used for this time series prediction model. The fastest training function for neural network toolbox software and back propagation algorithm is '**trainlm',** it is the default training function for feed forward network. It updates weights and bias values according to Levenberg-Marquardt backpropagation algorithm (**trainlm**). During training the input vectors and target vectors are randomly divided into three sets, for this research, data are divided into 70% for training, 15% for validate and 15% for test of the network. Training data set are used for computing the gradient and updating the network weights and biases. Neural network training automatically stops when generalization stops improving, as indicated by an increase in the mean square error of the validation samples. Training multiple times will generate different results due to different initial condition and sampling; because of every attempts of training the data are divided randomly into learning, validation and testing. So every time train the data, we get different values of mean square error (MSE) depending upon which input data are chosen for training [23].

### 6.4 Levenberg-Marquardt algorithm

Levenberg-Marquardt algorithm (LMA) provides a numerical solution to the problem to minimize a non-linear function. This algorithm is remarkably efficient and strongly recommended for neural network training. The LMA was designed to approach second-order training without having to compute Hessian Matrix.

$$\mathbf{H} = \mathbf{J}^{T}\mathbf{J}$$

And the gradient can be computed as

$$\mathbf{g} = \mathbf{J}^{T}\mathbf{e}$$

Where **J** is the Jacobian matrix that contains first derivatives of the network error with respect to the weights and biases, and **e** is a vector of network errors.

The Levenberg-Marquardt algorithm has this approximation to the Hessian matrix in the following Newton- like update.

$$\mathbf{x}_{k+1} = \mathbf{x}_{k} - [\, \mathbf{J}^{T}\mathbf{J} + \mu\mathbf{I}\, ]^{-1}\, \mathbf{J}^{T}\mathbf{e}$$

Where the scalar $\mu$ is zero, this is just Neuton's method, using the approximate Hessian matrix. When $\mu$ is large, this becomes gradient descent with a small step size. Thus $\mu$ is decreased after each successful step and is increased only when a tentative step would increase the performance function. In this way, the performance function is always reducing at each iteration of the algorithm.

### 6.5 Dynamic neural network

Dynamic neural networks are good at time series prediction. A dynamic neural network has feedback or time delay, the inputs to the network would normally be a sequence of input vectors that occur in a certain time order. Prediction is a kind of dynamic filtering, in which past values of one or more times series are used to predict future values. Dynamic neural networks, which include tapped delay lines are used for nonlinear filtering and prediction. The network uses tapped delay lines to store previous values of the inputs. Figure 8 shows a delay block and a tapped delay line,

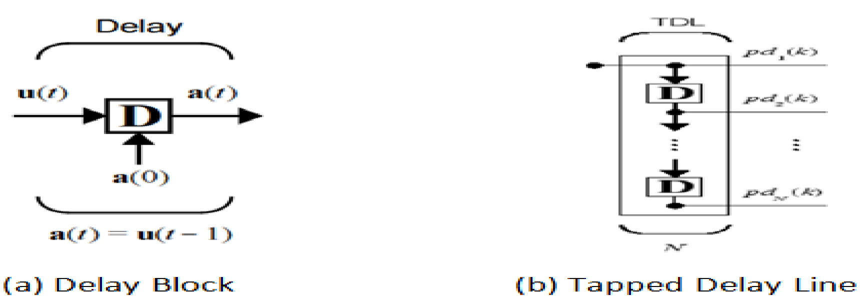


Figure 8: (a) Delay Block (b) Tapped Delay Line of a time series prediction model

The delay output **a**($t$) is computed from its input **u**($t$) according to

$$\mathbf{a}(t) = \mathbf{u}(t\text{-}1)$$

Thus the output is the input delayed by one-time step. The input signal enters into the tapped delay line from the left and passes through $N$-1 delays.

### 6.6 Performance Analysis (Validation)

The performance plot shows the value of the performance function versus the iteration number. Figure 9 shows the performance graph of the proposed model is plotted between mean square error (mse) and epochs. It plots training, validation and test performance of the network. The plot shows the mean square error of the network starting at a large value and decreasing to a smaller value. In other words, it shows that the network is learning. The figure clearly shows that the best validation check occurred at epoch 4. Training stopped when the validation error increased for six iterations, which occurred at iterations 6 before overfitting. The validation and test curves are very similar. If the test curve had increased significantly before the validation curve increased, then it is possible that some over fitting might had occurred.

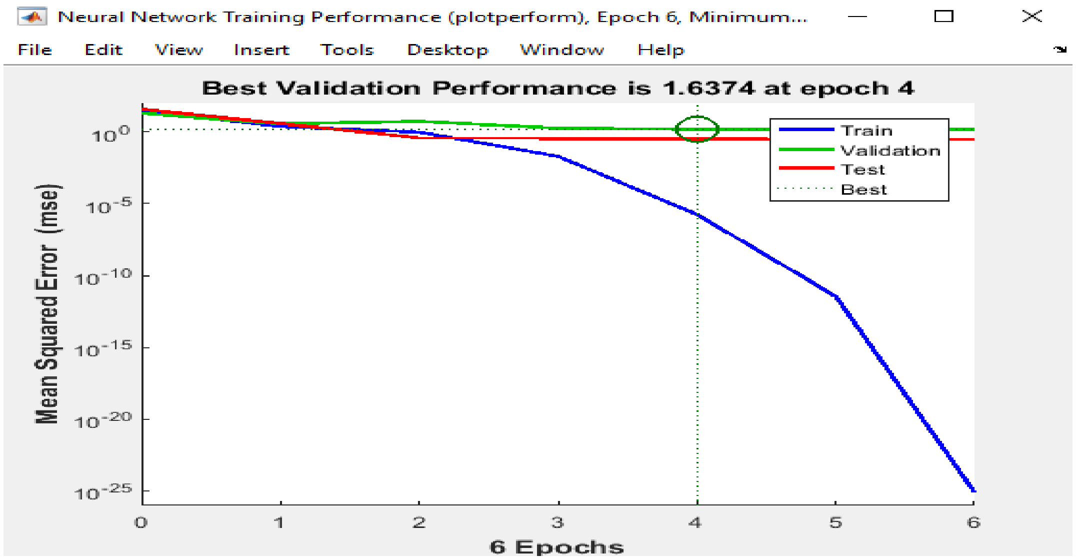


Figure 9: Performance Plot with best validation epochs

Performance plot shows that training, validation and testing errors all decreased until iteration 4. It does not appear that any over fitting has occurred, since neither testing or validation error increased before iteration 4. Best validation performance occurred at epoch 4. Therefore, the network response is satisfactory.

### 6.7 Regression Analysis

Regression is a statistical measure that attempts to determine the strength of the relationship between one dependent variable and a series of other changing variables (knows as independent variables). Regression plots in figure 10 shows a linear regression between the network outputs with respect to targets for training, validation and test sets. Regression values measure the correlation between the networks outputs and the corresponding targets. If the training were perfect, the network outputs and the targets would be exactly equal, but the relationship is rarely perfect in practice. The results is shown in the following regression plot,

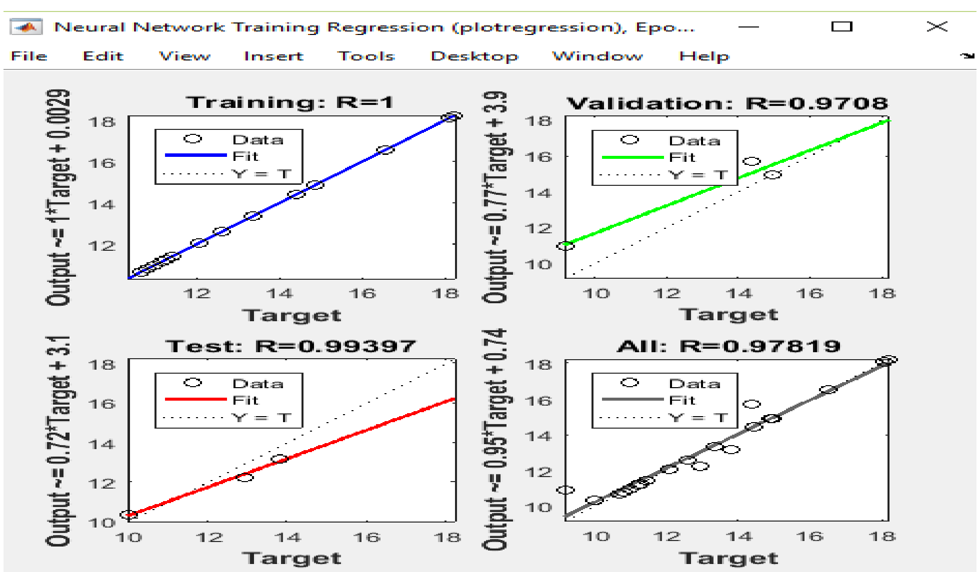


Figure 10: Regression plot for training, validation and test data

The four axes represent the training, validation, testing and all data. The dashed line in each axis represents the perfect result: outputs=targets. The solid line represents the best fit linear regression line between outputs and targets. The regression (R) value is an indication of the relationship between the outputs and targets. An R value to 1 indicates that there is an exact linear relationship between outputs and targets. If R is close to zero, then there is no linear relationship between outputs and targets, means a random relationship. Axes show that there are good fit for training, validation and test data. The R value for each case is greater than 0.97 and for total response is 0.97. Therefore, it is proved that the ANN model for potato yield prediction is a successful model.

**6.8 Comparison of Actual and Predicted Data**

The actual data is the total potato yield data in Bangladesh and is used as the target data for the network (prediction model). The predicted data is the output data of the network and this data is also known as the final result of the simulated model. The network output is computed, after the network has been trained. Table 2 shows the value of actual data, predicted data, the error and % error of prediction. The % error of prediction is given by

$$\% \textit{ error} = 100 \times (\textit{Actual yield} - \textit{Predicted yield}) / \textit{Actual yield}$$

Table 2: Actual and predicted Potato yield with error of prediction in Bangladesh

| Year | Actual/Target | Predicted | Error of Prediction | % error of prediction |
|---|---|---|---|---|
| | Potato Yield Ton/Hectare | | | |
| 1988 | 10.3381 | | | |
| 1989 | 9.7859 | | | |
| 1990 | 9.1410 | 8.7353 | 0.4057 | 4.43 |
| 1991 | 9.9867 | 9.9868 | -0.000067084 | -0.00067 |
| 1992 | 10.7931 | 10.7931 | -0.000047961 | -0.00044 |
| 1993 | 10.6786 | 10.6786 | 0.00000053773 | 0.00000496 |
| 1994 | 10.9570 | 11.2581 | -0.3011 | -2.748 |
| 1995 | 11.1665 | 11.1665 | -0.0000089948 | -0.00008051 |
| 1996 | 11.2740 | 11.2740 | -0.0000066251 | -0.00005872 |
| 1997 | 11.2551 | 11.2586 | -0.0035 | -0.031097 |
| 1998 | 11.3972 | 11.3972 | -0.000021912 | -0.000192 |
| 1999 | 11.2809 | 11.2809 | 0.0000093648 | 0.000008297 |
| 2000 | 12.0585 | 12.0585 | 0.0000064093 | 0.000005307 |
| 2001 | 12.9162 | 12.9162 | 0.000014038 | 0.00010862 |
| 2002 | 12.6010 | 12.6010 | 0.0000059585 | 0.00004722 |
| 2003 | 13.8021 | 13.1739 | 0.6282 | 4.55 |
| 2004 | 14.4312 | 14.4312 | 0.00000014522 | 0.00000097 |
| 2005 | 14.8805 | 14.8805 | 0.000015452 | 0.00010383 |
| 2006 | 14.3847 | 14.3847 | 0.000012650 | 0.00008794 |
| 2007 | 14.9768 | 13.7406 | 1.2362 | 8.25 |
| 2008 | 16.5373 | 16.5373 | 0.000021126 | 0.00012771 |
| 2009 | 13.3367 | 13.3367 | 0.000027517 | 0.00020627 |
| 2010 | 18.2298 | 18.2289 | 0.0009 | 0.00493697 |
| 2011 | 18.0930 | 18.0930 | 0.0000071398 | 0.00003941 |

The data of table 2 can be used to calculate the accuracy of the model. From table it is seen that the error of prediction is very small and it is less than 10%. These values indicate that, the neural network model has high accuracy for predicting the potato yield in Bangladesh. Therefore, the results obtained with ANN model are very encouraging. For more efficient of way of comparing the target and predicted data a graph is plotted with the two types of data. Figure 11 is a comparison graph between the actual and predicted potato yield. This graph shows high degree of similarity between actual and predicted value, hence providing that ANN model is quite accurate in prediction.

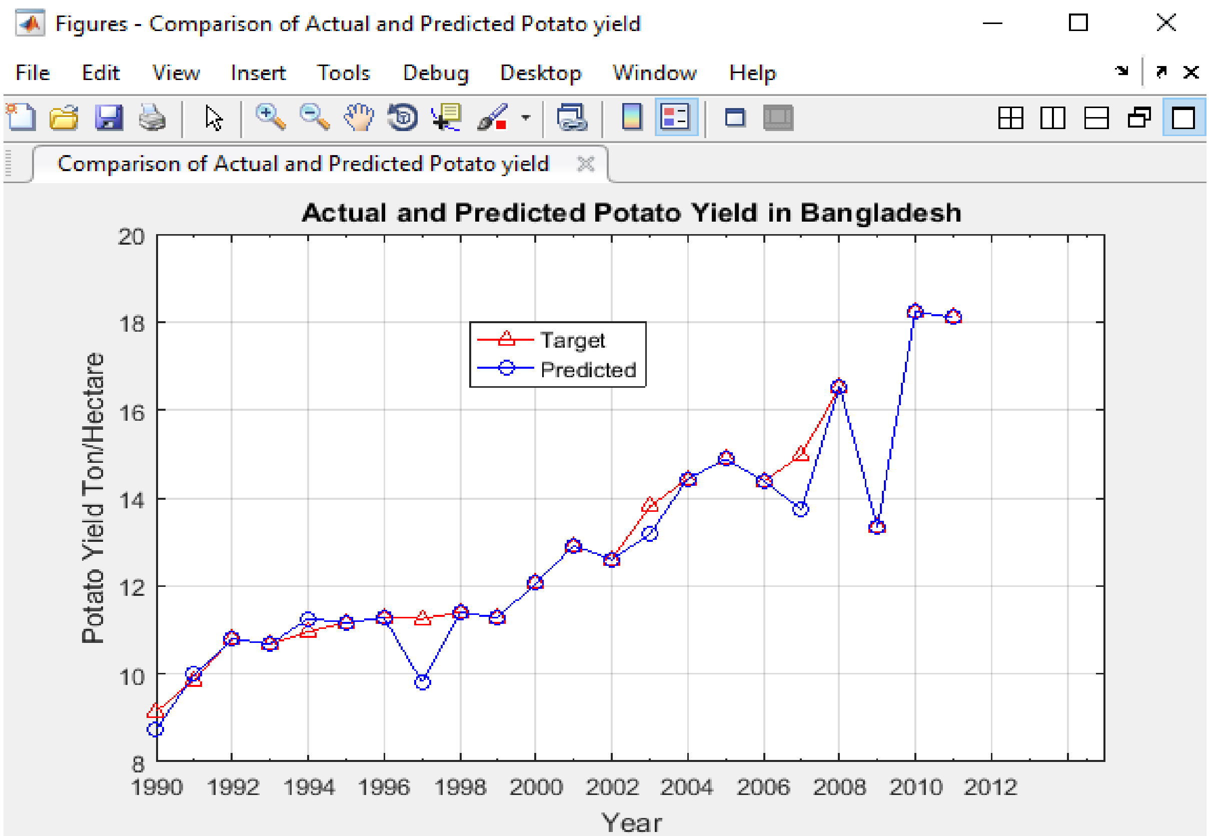


Figure 11: Comparison of Actual and Predicted Potato yield in Bangladesh.

## 7. CONCLUSION

Potato is the third largest food grain in area acreage after rice and wheat and second in production after rice is cultivated in almost all agro-ecological regions of Bangladesh. Farmers are now cultivating potato as a source of cash income. According to Bangladesh Bureau of Statistics in 2004 potato production was 3.9 million metric tons and in 2014 the production was 8.9 metric tons, the production is more than double within 10 years. This indicates that potato production is highly profitable. In terms of profitability, farmers are interested to cultivate potato and potato production is increasing almost every year. Besides this, in potato cultivation, storage and marketing activities a tot of employments and economic facilities are highly related. This study develops a prediction model to predict potato yield before harvest by using satellite data and artificial neural network. The result obtained from this model showed the potentiality of the ANN for predicting and the error of prediction is less than 10%. Therefore, this prediction model can serve as an important tool to the planners, policy makers, economists, analysts, academics, educationists, researchers, NGOs and others stakeholders and can play an important role in planning and decision making process to face in any future uncertainty.

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