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Journal of Water Resources and Civil Engineering Technology

Aims and Scope

Journal of Water Resources and Civil Engineering Technology is peer reviewed journal for the presentation of original contributions and the exchange of knowledge and experience on the management of water resources. In particular, the journal publishes contributions on: Water resources assessment, development, conservation, planning and design of water resource systems; and operation, maintenance and administration of water resource systems etc.

The topics covered in this journal are:-

1. Water demand and consumption;
2. Applied surface and groundwater hydrology;
3. Water management techniques;
4. Simulation and modeling of water resource systems;
5. Forecasting and control of quantity and quality of water;
6. Economic and social aspects of water use;
7. Legislation and water resources protection

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Contents

Groundwater Level And Conductivity Monitoring In Bist-Doab, Punjab, India

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ABSTRACT

Groundwater, a vital element to sustain life, is highly exploited within India. Particularly in Punjab, the rate of decline of groundwater level is rapid in parts of the Indo-Gangetic plains including the districts of Amritsar, Kapurthala, Jalandhar, Ludhiana, Patiala and Sangrur. The four districts, also known as Bist-Doab region of Punjab, were chosen for a programme of continuous monitoring of water level and conductivity.

In the present study, data loggers were installed for monitoring groundwater level in 6 shallow (<60 m) and deep piezometers (>120 m) at Saroya, Tanda, Bhogpur, Kapurthala, Sultanpur Lodhi and Nakodar during August, 2013 and for monitoring conductivity in 4 shallow piezometers (<60 m) at Saroya, Bhogpur, Kapurthala and Sultanpur Lodhi during December, 2013. Preliminary analysis from the first year of data indicates that in deep piezometers water level starts rising from the month of November and declines from the month of April. In the shallow piezometers, preliminary analysis indicate that the groundwater level at Saroya, Tanda, Bhogpur and Kapurthala declines during the Kharif season (June to October) and groundwater level at Sultanpur Lodhi and Nakodar was almost constant. The conductivity of the groundwater was different in all the shallow aquifers as in Saroya and Sultanpur Lodhi, but almost constant over the period of monitoring.
Keywords - Groundwater level, conductivity, fluctuations, Bist-Doab, Punjab

INTRODUCTION

The Indo-Gangetic basin has the rich and reliable sources of groundwater supplies within the alluvium which has been extensively exploited for meeting the ever increasing demands for industrial, agricultural and urban use. However this is leading to areas with declining groundwater level (Rodell et al. 2009). Such is the case in Punjab, where the rate of decline of groundwater levels has increased during 1980-2005 (Singh 2011), and is now projected to fall by a further 21 meters in 60% of central Punjab during next 2 decades (Sidhu et al. 2010) particularly in the districts of Amritsar, Kapurthala, Jalandhar, Ludhiana, Patiala and Sangrur (Krishan et al. 2014a). These trends have been reported in several other studies carried out in different parts of Punjab and Indo-Gangetic basin where the emphasis is laid on decreasing groundwater level and deteriorating groundwater quality (Chopra 2014a, b; Krishan and Chopra 2015; Krishan et al. 2015a,b; Krishan et al. 2014a-h; 2013a-c; Lapworth et al. 2014 a-b; Lohani et al. 2015; MacDonald et al. 2013, 2014; Rao et al. 2014; Sharma et al. 2014). But in northeastern part the Kandi region comprising of districts Hoshiarpur and Nawanshahr reported to be high rainfall areas of the state. In the present study, 4 districts viz. Jalandhar, Kapurthala, Hoshiarpur and Nawanshahr also known as Bist-Doab region of Punjab were chosen for continuous monitoring of water level and conductivity.

2. STUDY AREA

Punjab State, underlain by Quaternary alluvial deposits of the Indo-Gangetic basin, has an area of 50,362 sq.km. which constitutes 1.57% of total area of country and is drained by 3 major rivers – Beas, Satluj and Ravi. The study was carried out in Beas-Satluj Doab area of Punjab having a total area of 9060 sq. km. 17.6% of total area of Punjab covering Hoshiarpur, Nawanshahr, Jalandhar, Kapurthala districts. The area lies between 30051'N and 30004'N latitude and 74057' and 76040'E longitude. It is bounded by Shivaliks in the north-east, the river Beas in the north east-south west and the river Satluj in south east-south west. There is a choe ridden (ravine-ridden) belt in the area bordered by the Shivaliks called the Kandi area. This area is a bhabhar, or a piedmont plain, lying at the foothills of the Shivaliks and formed by the coalescence of various alluvial fans resulting from the deposition of sediments by various choe at the foothills. The economy of the study area is primarily agro based and the farmers shifted the cropping pattern from the Maize-Wheat or Sugarcane-Maize-Wheat to Wheat-Rice cropping pattern (Krishan et al. 2014b; Statistical abstract of Punjab 2013).

The study area has a continental climate. Temperature in summers ranges from 30 to 32oC and maximum can be as high as 45oC. Winters are moderately cold with normal temperatures falling between 10 and 15oC. The area nearest the Shivaliks receives more rainfall (1200mm at Dhar Kalan) than plains that are far away from it. High rainfall and poor vegetation cover are responsible for soil erosion in the Shivalik foot hill zone (Sehgal et al. 1988).

3. EXPERIMENTAL PROGRAM

In the present study, data loggers were installed for monitoring groundwater level in 6 shallow (<60 m) piezometers of Punjab Water Resources and Environment Directorate (PWRED), Chandigarh and 6 deep piezometers (>120 m) of National Institute of Hydrology (NIH), Roorkee at Saroya, Tanda, Bhogpur, Kapurthala, Sultanpur Lodhi and Nakodar during August, 2013 and for monitoring conductivity, in 4 shallow piezometers (<60 m) of PWRED, Chandigarh at Saroya, Bhogpur, Kapurthala and Sultanpur Lodhi during December, 2013 but the readings were recorded from September, 2014 onwards. The location of the installation of the piezometers in given in fig. 1. Before installing the loggers the age of groundwater was determined at Nuclear Hydrology Laboratory of NIH, Roorkee using tritium tracer technique.

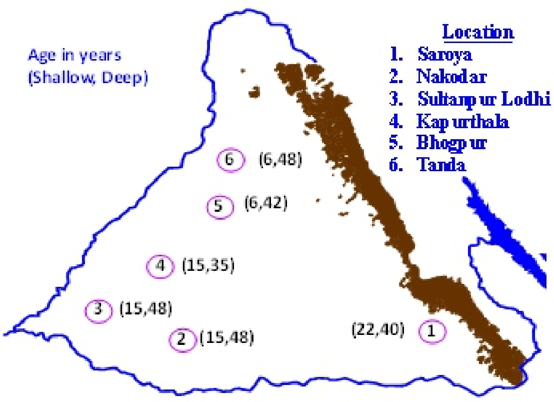
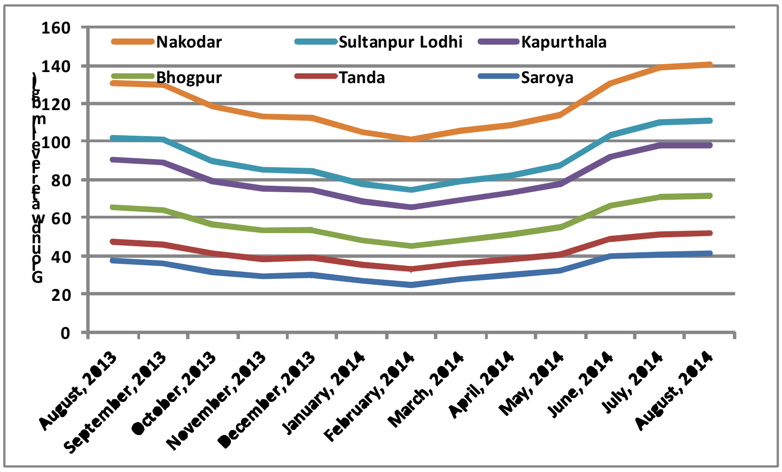


Fig. 1. Locations of paired shallow and deep piezometers where continuous loggers are installed to monitor water levels and conductivity (shallow sites)

4. RESULTS AND DISCUSSION

Preliminary analysis of the first year of data indicate that in deep piezometers, it was observed at all the sites the water level starts rising from the month of November and it again starts declining from the month of April (Fig. 2), while in shallow piezometers, it has been observed that the groundwater levels decelined at Saroya, Tanda, Bhogpur and Kapurthala during the Kharif season (June to October) but groundwater level at Sultanpur Lodhi and Nakodar was almost constant (Fig. 3). Similar results were obtained by Krishan et al. (2014c).



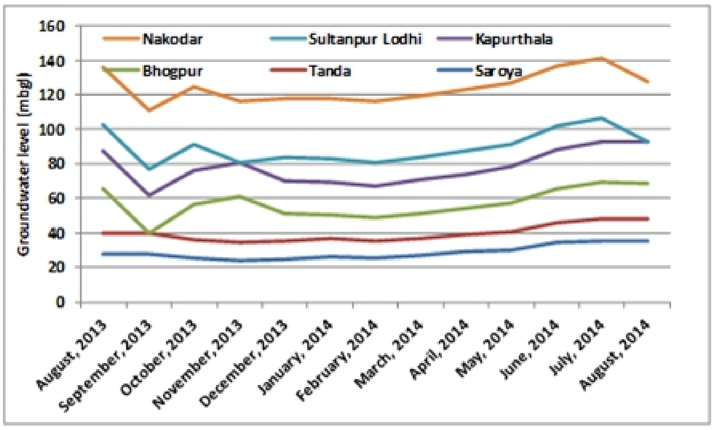


Fig. 3: Water level Variation in Shallow Piezometers Bist-Doab, Punjab

The conductivity of the groundwater behaved differently in all the shallow aquifers. In Sultanpur Lodhi, it decreased from September, 2014 to October, 2014 and then it was almost constant. In other stations Saroya, Bhogpur and Kapurthala a small increase in conductivity was observed from February, 2015.

The north-east portions of Hoshiapur and Nawanshehar, there are deeper groundwater tables, due to the change in topography, and this region considered the recharge area for the deeper plain aquifer system. The transition from the Kandi belt to the plains and sudden change in slope results in a dense network of drainage that recharges the plain aquifers. This area has higher rainfall (900 mm/y) and higher areal and surface water recharge, middle portion has lower rainfall (700 mm/y) and recharge from irrigation and seepage from canals and southwest prtion has lower rainfall (600 mm/y), shallow groundwater and limited recharge potential. Some parts of Nawanshahr and Jalandhar districts are irrigated using canals from the R. Satluj, however, most of the study area is irrigated using shallow (0-50 m) groundwater (>90%). The groundwater table is shallow in the confluence area with associated water logging and salinity issues (Lapworth et al., 2014a,b).

The study carried out for mean residence time by Lapworth et al (2014a) on the basis of results obtained using chlorofluorocarbon (CFC-12) groundwater age tracers show that median shallow groundwater mean residence times (MRTs) of 25 years and 30 years under post-monsoon and pre-monsoon conditions. Deep groundwater (>100 mbgl) had median MRTs of 45 years irrespective of recharge conditions. Deep groundwater MRTs are much younger than would be expected under natural groundwater flow regimes, where groundwater residence times of the order of ca.102-103 years or more might be expected in the deeper plains aquifers, some 50 km down-gradient of the recharge zone.

The variations in water level and conductivity can be understood by the research work carried out by Lapworth et al (2015) where it was reported that the widespread occurrence of modern tracers (Choroflurocarbons (CFCs), noble gases) in deep groundwater in >10 numbers of sites out of 16 sites had >10% modern recharge which suggests that there is low aquifer anisotropy. The deep aquifers are recharged by a significant component of modern recharge via vertical leakage. The contrasting isotope signatures of precipitation and surface waters in this area clearly demonstrate that both shallow and deep groundwater recharge is dominated by meteoric sources, rather than surface water sources including canal irrigation water. Stable isotope and noble gas results at all depths conform to modern meteoric and annual average temperature conditions, with no evidence of a significant regional component of recharge from canal leakage. They further reported that the depleted water isotope signatures in the deep groundwater relative to the shallow groundwater can be explained by recharge sources from the deep groundwater having a component of groundwater recharged some distance up gradient from the sampling point at a higher elevation. Alternatively, this may be a signature of modern groundwater irrigation and the recycling of groundwater over the last four decades leading to a small enrichment in the shallow aquifer system. Even at a depth of 160 m groundwater isotope signatures are consistent with modern meteoric sources.

5. CONCLUSIONS

The results have shown fluctuation in water level and conductivity during different time period of the year due to variation in source of recharge and usage of the bore wells. The deep aquifers are recharged by a significant component of modern recharge via vertical leakage. The contrasting isotope signatures of precipitation and surface waters in this area clearly demonstrate that both shallow and deep groundwater recharge is dominated by meteoric sources. The groundwater is used more for irrigating the Kharif crops and hence the groundwater level is found low in this season due to more extraction. Further long term monitoring is required for assessing the variations.

ACKNOWLEDGEMENT

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Prediction Of Live Storage Of Water Resources Using Neural Network Time Series Model, Case Study On Mettur Dam

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A B S T R A C T

The optimal usage of water from a dam reservoir requires a comprehensive knowledge of future availability of water resources. In this case the amount of water that will be available in the future is important. Also, there is need to examine flow of water at the dam from a short-term perspective. This is necessary to avoid overflowing and to minimize damage. A number of techniques have been developed in recent years to analyze and predict availability of water storage in the dam.

At present there is water dispute between the States of Tamil Naidu and Karnataka because of lack of water availability in Mettur dam due to Kabini Dam in Karnataka during lean seasons. This case study predicts the live storage of Mettur dam to assess optimum water availability in both the dams so that they can be utilized more effectively by the farmers and general public.

In this paper weekly data of live storage of Mettur Dam from year 2001-2013 has been used which was obtained from Central Water Commission (CWC), New Delhi, India and Nonlinear Autoregressive (NAR) neural network is proposed to predict live storage of Mettur Dam. In order to improve the generalization of neural network, Levenberg-Marquardt algorithm is employed to train neural network. Testing and validation have been carried out to authenticate results obtained from NAR neural network.

In the present study coefficient of determination (R^2) and Root Mean Square Error (RMSE) has been taken as the performance measure of neural network. High values of R^2 near to 1 and low values of RMSE of the predicted values clearly demonstrates the high accuracy and reliability of NAR neural network model for predicting the live storage of dam.

Keywords: Water Resource Planning, Reservoir Operation, Neural Network, Time series

1. INTRODUCTION

With the rapid growth in developing countries like India there is a need of proper data driven water resource planning. Water is a scare resource and further growing demand is making it more scare and reservoirs are the most important and effective water storage facilities in modifying uneven distribution of water both in space and time. They not only provide water, hydroelectric energy and irrigation, but also smooth out extreme inflows to mitigate floods or droughts. To make the best use of the available water, the optimal operation of reservoirs in a system is undoubtedly very important.

Reservoir operation requires a series of decisions that determine the accumulation and release of water over time. In the face of natural uncertainty, forecasts of future reservoir storage can be helpful in making efficient operating decisions. In recent years, data driven modelling is emerging. These data serves as a source of information for the development of model and to build a rule to simulate the operation of hydrological systems, Rainfall modelling, Reservoir operation and planning (Araghinejad 2014; Singh et al. 2007; Singh et al. 2015; Wang and Altunkaynak 2012). Thus, artificial intelligence tools such as genetic algorithms, artificial neural network and fuzzy logic are increasingly used as soft computing techniques to solve modelling issues. Jain et al. (1999) and Coulibaly et al. (2001) has predicted inflow in a reservoir using neural network modelling. Chandramouli and Raman (2001) have used neural network models for multireservoir planning. Neelakantan and Pundarikanthan (2000) have used for neural network for reservoir operations.

2. DESCRIPTION OF STUDY AREA

The Mettur Dam is one of the largest dams in India built in 1934. It was constructed in a gorge, where the Kaveri River enters the plains. It provides irrigation facilities to parts of Salem, the length of Erode, Namakkal, Karur, Tiruchirappali and Thanjavur district for 271,000 acres (110,000 ha) of farm land.

The total length of the dam is 1,700 m (5,600 ft). The maximum level of the dam is 120 ft (37 m) and the maximum capacity is 93.4 tmc ft. and Coordinates are 11°48′00″N, 77°48′00″E. There are two Hydro Electric Power Stations at Mettur called Dam and Tunnel Power House respectively. Dam power house having capacity of 40MW and Tunnel Power station having capacity of 200MW.

At present there is water dispute between the States of Tamil Naidu and Karnataka because of lack of water availability in Mettur dam due to Kabini Dam in Karnataka during lean seasons (Richards and Singh 2002). This case study also helps us to predict the optimum water to be in maintained in both the dam so to keep both dam functional and fulfill the needs of farmers and general public.

Figure 1 Location of Mettur Dam (Source OpenStreetMap.com and Google earth)

3. TIME SERIES MODELLING

Time series modeling involves techniques that relate time series data as dependent variables to the predictors, which all are a function of time. Many examples of time series data exist in the field of water resources and environmental engineering, including stream flow data, rainfall data, and time series of total dissolved solids in a river.

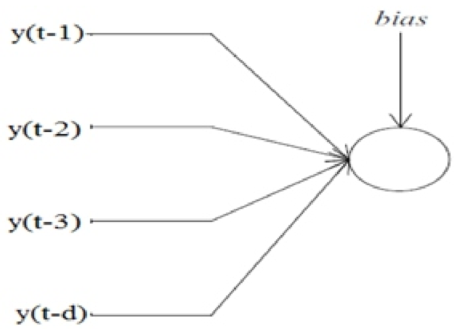
3.1 Non-Linear Auto Regression (NAR) Neural Network

NAR (Non-linear Auto Regression) Neural Network is dynamic neural network in which past values of one or more time series are used to predict future values. It includes time delays for non-linear filtration and prediction. NAR neural network is a feed forward time delay neural network. It predicts the value of series y(t) based on past d values of y(t), d is termed as delay, so expression for NAR neural network is

$$y(t) = f(y(t-1), y(t-2) \dots\dots\dots . y(t-d)) \quad (1)$$

NAR neural network gives non-linear input output mapping. NAR models are much more accurate than ARIMA (Auto Regressive Integrated Moving Average) model and ARMA (Auto Regressive Moving Average) model for dam live storage data set since these models are not capable of handling all the non-linearity's which the data contains.

At present NAR neural network are applied in many fields such as financial analyst predicts future values of stock, bond or other financial instruments using past values of it. An engineer predicts the impending failure of jet engine and these dynamic models could be applied for analysis, simulation, monitoring and control of a variety of systems, including manufacturing systems, chemical processes, robotics and aerospace and civil engineering systems (Araghinejad 2014; Bose and Liang 1996).



In this paper NAR neural network has been applied to predict the live storage of Mettur dam which has a non-linear relationship with input values due to seasonal variation. Past values of live storage of Mettur dam act as inputs for predicting the future live storage of reservoir.

Table 1 Weekly live storage of Mettur dam

Date (mm/dd/yyyy)	Live Storage (tmc)
07/07/2001	39.552
07/15/2001	44.567
07/22/2001	37.504
07/31/2001	29.735
08/07/2001	30.759
08/15/2001	26.557
08/22/2001	20.906
08/31/2001	18.222
09/07/2001	12.148
09/15/2001	7.84

Total data of 496 weeks is divided into 3 parts

(i) Training (70%): These are presented to the network during training, and the network is adjusted according to its error.

(ii) Validation (15%): These are used to measure network generalization, and to halt training when generalization stops improving.

(iii) Testing (15%): These have no effect on training and so provide an independent measure of network performance during and after training.

3.2 Performance parameters

In order to determine which network structure is optimal, the performance of a calibrated model is evaluated. ANN model performance is usually assessed using a quantitative error metric. The following performance measures were used to evaluate the efficiency of the network in all the cases.

a) Coefficient of Multiple Determination (R^2)
b) Root Mean Square Error (RMSE)

Coefficients of Determination (R^2) value represents the proportion of variation in the dependent variable that is explained by the independence variables. Higher value of R^2 indicates that the model explains variation in the dependent variable.

$$R^2 = 1 - \frac{\sum_i (Y_i - f_i)^2}{\sum_i \left(Y_i - \hat{Y}\right)^2} \tag{2}$$

Mean Squared Error (MSE) is one of many ways to quantify the difference between values implied by an estimator and the true values of the quantity being estimated.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} \left(\hat{Y} - f_i\right)^2} \tag{3}$$

$$\hat{Y} = \frac{1}{n}\sum_{i}^{n} Y_i \tag{4}$$

Where Y_i represent i^{th} observed data, $\hat{Y}$ represents mean of the observed data and f_i represent i^{th} predicted data

3.3 Model architecture

One of the most parameter in NAR Neural Network Architecture is number of delays units. This delay unit act as an input for input output mapping of NAR Neural Network.

Table 2 Number of delays

Delays	R^2	RMSE
2	0.969	4.35
3	0.968	4.72
4	0.97	3.98
5	0.972	3.98
6	0.97	4.03

Model with 5 delay units have highest R^2 value and lowest RMSE value as shown in Table 2 so it is best suited to this data.

4. RESULTS

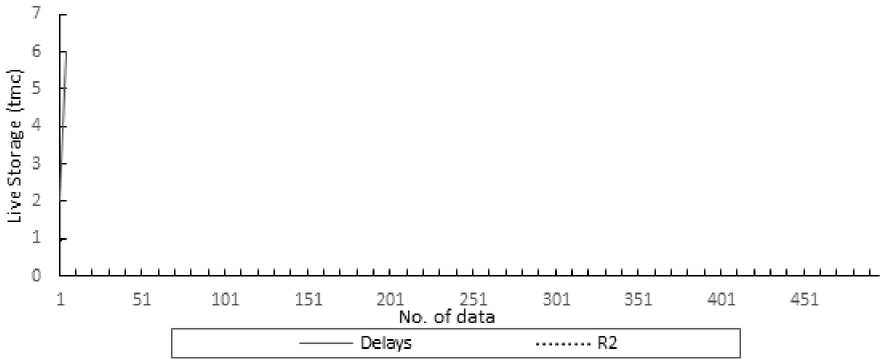


Figure 3 Plot of Observed – Predicted Live storage

Plot of observed and predicted live storage as shown in Fig. 3 represents that NAR neural network time series prediction are accurate without much error as compared to the observed live storage. Fig 4 represents normal distribution of error with highest frequency near zero error and high R value in all training validation and Testing set so it represents the accuracy of predicted live storage.

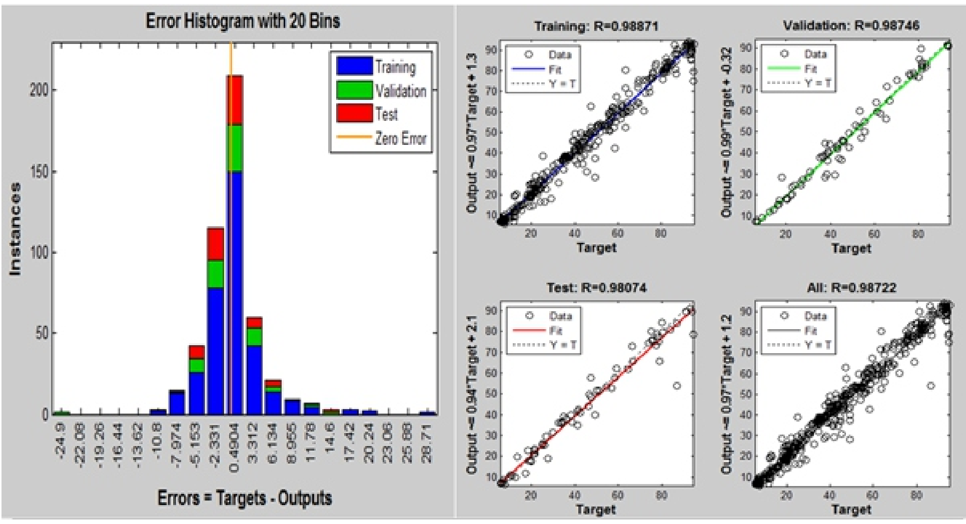


Figure 4 Error Histogram and Regression Analysis

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Review of Impact and Mitigation of Hydraulic Transients in Hydro Power Plant

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A B S T R A C T

Water hammer, which is synonymously used with the term hydraulic transient, is a pressure (acoustic) wave phenomenon created by relatively sudden changes in the liquid velocity of pipelines.In pipelines, sudden change in the flow (velocity) can occur as a result of (1) turbine and inlet valve operation, (2) vapor pocket collapse, or (3) Impact of water following the rapid expulsion of air out of a vent or a partially open valve. The main components of this disturbance are pressure and flow changes that bring about propagation of pressure waves throughout the system. The velocity of this wave may exceed 1000 m/s, which may lead to severe damages[1,7].

Significant disturbances may occur in a hydro power plant and causes a sudden change in the flow rate of the system during some operation conditions such as load rejection, load acceptances, and instant load rejection[2,4,13]. This would, in turn, create fluid transients in the hydraulic conveyance system, namely the penstocks, resulting in unacceptably high or low pressures in the penstocks depending on the triggering mechanism of the transients. Eventually, if not protected adequately, the penstock may burst or collapse dramatically, resulting in substantial damages and even loss of lives[13]. Transient analysis of the penstock and turbines must be carried out before undertaking the design and construction of a hydro power plant. In this paper Impacts of hydraulic transient on the power plants are analyzed and presented.

Keywords - Water hammer, Hydropower plant, Hydraulic transient, Penstock

INTRODUCTION

Hydraulic transients are the time-varying phenomena that follow when the equilibrium of the steady flow in a system is disturbed by a change of flow that occurs over a relatively short period. Transient are important in hydraulic system because they can cause (1) rupture of pipe and pump casings; (2) pipe collapse; (3) vibrations; (4) excessive pipe displacements, pipe fitting and support deformation and/or failure; and (5) vapour cavity formation[2].

The study of hydraulic transients is generally considered to have begun with the works of Joukowsky (1898) and Allievi (1902). The historical development of this subject makes for good reading (Wood F., 1970). A number of pioneers made breakthrough contributions to the field, including R. Angus and John

Parmakian (1963), who popularized and refined the graphical calculation method. Benjamin Wylie and Victor Streeter (1993) combined the method of characteristics with computer modeling[3]. The field of fluid transients is still rapidly evolving worldwide.During operation of the hydropower plant, load changes, mechanical failures and erroneous human interventions often lead to sudden changes in flow parameters. Following such changes, unacceptably high or low pressures may occur in the penstocks depending on the triggering mechanism of the transients. Even the penstock even burst or collapse and lead to catastrophic failures. During transient conditions, the turbines of the hydro power plants also faces cyclic stresses, asymmetric forces on the runner, and wear and tear, all of which reduce the operating life of the components and the plants[9].

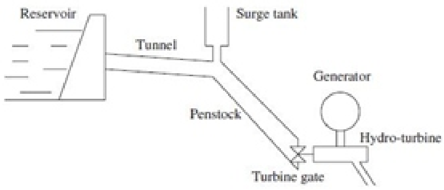


Fig.1 Schematic of a hydro power plant (Nand Kishore et al. 2007)

There are many hydropower accidents caused by water hammer that have resulted in substantial damages and loss of lives in the history of water power. These accidents are discussed in this paper briefly with some transient control devices.

2. CAUSES OF HYDRAULIC TRANSIENT

Following events in a hydro power plant operation may cause hydraulic transient[5].

I. Pump startup or shutdown.
ii. Valve opening or closing (variation in cross sectional area);
iii. Changes in boundary conditions (e.g. losing overhead storage tank, adjustments in the water level at reservoirs, pressure changes in tanks, etc.)
iv. Rapid changes in demand conditions
v. Changes in transmission conditions
vi. Pipe filling or draining- air release in pipe
vii. Check valve or regulator valve action
viii. Emergency closure of the unit
ix. Waves on the surface of dam reservoir due to the earthquake, winds and landslides.

3. EFFECT OF HYDRAULIC TRANSIENT ON HYDRO POWER PLANTS

Bonin (1960) describing damage to a water turbine in the oigawa power station, Japan in 1950 caused by a penstock failure seems to be a rare exception. The failure at oigawa was caused by a water hammer due to a sudden closure of a butterfly valve. Three people were killed as a result of flooding in the machine chamber. Arrington (1999) presented several very serious failures- a rupture of the lower needle valve body at the Bartlett Dam (U.S.) and a breach in the steel penstock at the Oneida station hydro power plant (U.S)both caused by valve slamming creating pressure surges. As a consequence, five people were killed[6].

This paper describes the most important results of investigations carried out in connection with a penstock rupture having less severe consequences. The rupture took place at the Lapino hydropower plant operated by the ENERGA Gdansk Energy Company. The power plant was built in 1927 in Poland. It is operated both as a run-of-river and storage hydropower plant of 2 MW total power, rated head 13.8 m and discharge 22 m^3/s. in December 1997, the steel penstock supplying water to the turbines ruptured. The machine hall was flooded up to a height of 2.5 m above the floor level. The investigation was consist of material tests of the ruptured penstock shell, analysis of the stress in the shell, analysis of hydraulic transients under condition of failure, and testing of penstock and generator sets after repair. In the case under consideration, excessive water hammer caused by rapid flow cut-off was recognized as the direct cause of the penstock burst. In order to evaluate the possible root cause of failure or damage of the plant, the failure was subjected to an extensive investigation covering the following[6]:

- Nondestructive tests of the remaining penstock shell, with a particular focus on the weld joints.
- Material test of the ruptured penstock shell.
- Analysis of the stress in the shell of the ruptured penstock section.
- Analysis of the hydraulic transients under condition of failure

3.1 Nondestructive tests of the remaining penstock shell, with a particular focus on the weld joints

A crack was found in the weld joints at the corner connection between the penstock and the inlet pipe to turbine set. This crack appeared along the longitudinal weld joint as well as in the main material of the inlet pipe. After sandblast cleaning, the unbroken penstock shell was subject to a visual inspection, during which the main attention was focused on to the weld joints. Various longitudinal cracks of the weld seams were discovered, mainly in the region of fusion into the penstock material. After inspection it was concluded that the joints defects were not permissible and could not guarantee the safe operation of the power plant[6].

Fig.2 Macroscopic Picture of Cracked Weld Joint (Source: A. Adamkowski-2001)

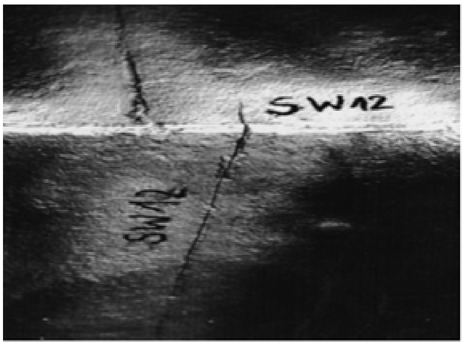


Fig.3 Cracking of Penstock due to Hydraulic Transient-Inside View (Source: A. Adamkowski-2001)

3.2 Material tests of the ruptured penstock shell

The investigation revealed that the penstock shell was made with ordinary carbon steel with 22% of the maximum content of carbon. Further macroscopic and microscopic metallographic investigations of the main material and welding seams showed the following characteristics[6]:

- The weld joint material contained more defects, including gas bubbles, cold droplets, and oxides, in the region of the first fusion into the native material.
- There were micro cracks both in native material and in weld seams.
- The weld joint material contained more defects, including gas bubbles, cold droplets, and oxides, in the region of the first fusion into the native material.

On the basis of metallographic tests and measurements of wall thickness of the penstock shell, the effect of surface corrosion can be estimated as surface uniform and taking place at a moderate rate. A higher rate of corrosion was observed in some places of the weld joints.

3.3 Analysis of stress in penstock

An analysis was carried out on a broken penstock segment with the help of commercial computer code, ADINA based on FEM to analyze the state of stress. The obtained results show a very unfavorable distribution of stresses in the analyzed segment of the penstock shell as shown in the fig.4. The connection of the inlet pipe with the main branch of the penstock is distinctive by a significant concentration of the stresses[6].

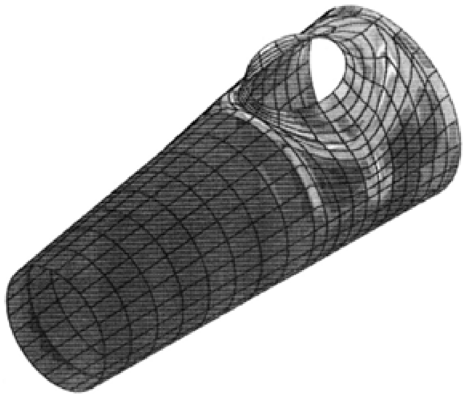
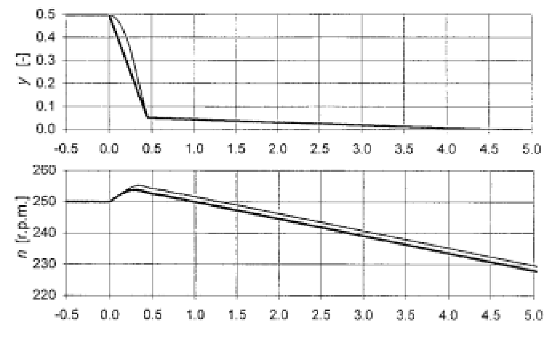


Fig.4 Distribution of Equivalent Stresses in Broken Segment of penstock(Source: A. Adamkowski-2001)

3.4 Hydraulic transients under failure conditions

To establish the causes of failure, a computer simulation of hydraulic transients occurring during the rupture was carried out. The simulation was performed using the HYDTRA computer code which is developed for simulate the water hammer in flow system of hydraulic turbo machinery.Sample results of the calculations are presented in fig. 5; whereas, Fig.6 brings together the obtained results in the form of a relationship between the maximum pressure at the breach section of the penstock and the wicket gate closure time T for the linear closure considered[6].

The results imply that the estimated values of critical breach pressure (250-300 kPa) can be exceeded if the closure time of the wicket gate from 50% opening is less than values given for the tested closure methods (Fig. 6); closer according to the linear function, T < (0.3-0.35) s; closure according to the quadratic linear function, T < (0.4-0.55) s; closure according to the quadratic function, T < (0.5-0.65) s.



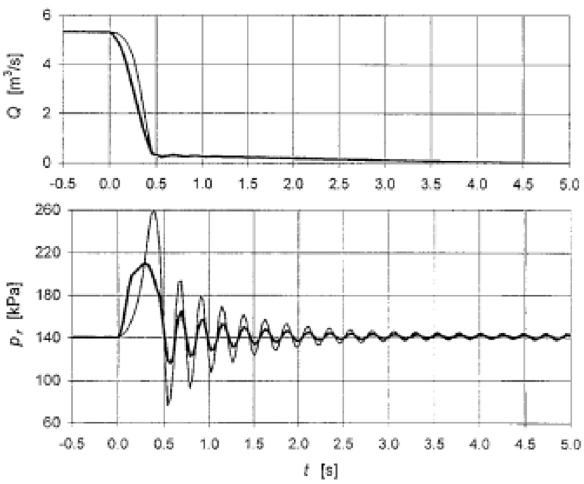


Fig.5 Exemplary Transients Calculated for Failure Conditions (Heavy Line, Linear Closure Law of Wicket Gates; Light Line, QuadraticLinear Closure Law of Wicket Gates)
(Source: A. Adamkowski-2001)

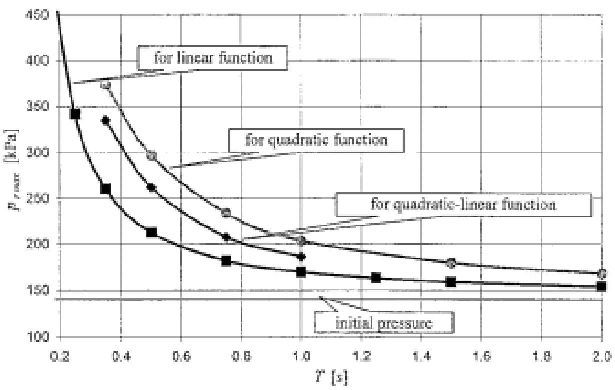


Fig.6 Evaluation of Effect of Wicket Closure Method on Maximum Pressure in Breach Section under Conditions of Failure (Source: A. Adamkowski-2001)

Recently, the accident due to the transient in hydro power plant was reported in Russia. It was Sayano-Shushenskaya hydroelectric power plant accident. The hydroelectric power station is located on the Yenisei River in Russia. Before the accident, it was the largest power plant in Russia and the sixth largest hydroelectric power plant in the world. At the accident day (17 August 2009), the station suffered a catastrophic pressure surge in turbine 2. The sudden water pressure surge, which is caused by water hammer, resulted in the ejection of turbine 2 with all equipment, a total weight some 900 tones, from its seat. The other turbines also suffered from severe damage. Turbine room roof fell, and water immediately flooded the engine and turbine rooms and caused a transformer explosion. On 23 August 2009, authorities said 69 people were found dead while 6 people are still listed as missing[10].

Before Accident After Accident

Fig.4 Sayano- Shushenskaya hydroelectric power plant accident (Source: Wikimedia)

3.5 Causes behind the disaster of the Sayano- Shushenskaya hydroelectric power plant[10]

- Sudden closing of the unit's wicket gate.
- Heavy water hammer in the spiral case and penstock, causing their collapse.
- Upward force, resulted from the water hammer, destroying the civil structure over the spiral case and the penstock.
- Heavy reverse water hammer (draft tube) causing elevation of the turbine cover, shaft etc.

4. Protective measures against water hammer

If properly controlled, positive and negative waterhammer pressures will be harmless. Many means exist for controlling the maximum and minimum pressures. Some of are as under:

i. Flywheels can significantly reduce the speed rise of turbine during transient states. However, this measure does not decrease the water hammer pressure in the penstock. It helps protecting mechanical equipment in the plant. By means of this tool, as well as ensuring safe operations, maintenances and repair cost can be reduced and even lifetime of the equipment can be extended .

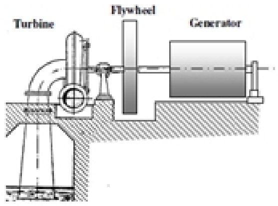


Fig. 5 Typical turbine flywheel installation(Source: Hanif Chaudhry, 1976)

ii. Pressure relief valves are very effective in reducing water hammer pressures in the penstock.

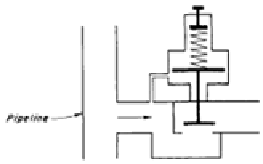


Fig. 6 Pressure Relief Valve (Source: Hanif Chaudhry, 1976)

iii. Safety membranes also play a major role in reducing the maximum surge pressures occurred during water hammer. They have little effects on reducing the turbine speed like valves and they can be used as a standalone protective measure in small hydro power plant (SHP).

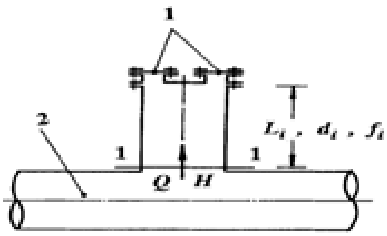


Fig. 7 Arrangement of safety membranes (1 = membranes and 2 = penstock)
(Source: Fusheng 1996)

iv. Surge tank is an open standpipe or a shaft connected to the conduits of a hydro electric power plant or to the pipeline of a piping system. This is also referred to as a surge shaft or surge chamber. The main function of surge tank is to reduces the pressure fluctuations by reflecting the incoming pressure waves. For example, the waterhammer waves produced in a penstock by load changes on a turbine are reflected back at the surge tank.

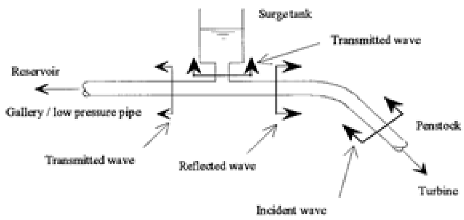


Fig.8 Installation of Surge Tank on Penstock(Source: Hanif Chaudhry, 1976)

Table 4.1 gives the general characteristics of the various protection schemes. If properly controlled, positive and negative pressure surges will be harmless, and many means exist for controlling the maximum and minimum pressures. This table gives information about basic protective means. The relative merits and shortcomings, as well as the costs, for providing alternative protection should be considered. The best solution may be combination of two or more methods.

Table 4.1 Comparison and General Characteristics of Waterhammer Protection Devices[12]

Device	**When to Use**	**Protects Against High Pressure**	**Protects Against Low Pressure**	**Operating Reliability**	**Specials Required**	**Problems in Restarting**	**Frequency of Application**	**cost**
Surge Tank	High head with long tunnels/penstock	Yes	Yes	Very good	None	None	Very often	Very high
Air vessel	High head with long tunnels/penstock	Yes	Yes	Good	Air compressor	Routine control	Rarely	Not very high
Increased inertia $GD^2(WR^2)$	All types	Yes	Yes	Excellent	None	None	Often	Not very high
Air Valves	Protection of penstocks	No	Yes	Poor	Frequent maintenance and control	Routine control	Very often	low
Rupture Membrane	As a last measure of protection	Yes	No	Good	Arrange outlet for water discharge	Replace membrane	Rarely	Very low
Pressure regulator valves	All types	Yes	No	Very good	Air in large quantities if Howell-Buner type valve	None	Often	low
Aeration Pipes	Protection tunnel/penstock	No	Yes	Good	None	None	Often	Low

5. CONCLUSION

In the present study, some of the accidents due to the hydraulic transient are described. All transients events induce changes in most operating parameters (e.g. discharge, head, rotational speed, and voltage) in the power plant. The effect of water hammer is not totally eliminated in hydro power plant. But their effects on the component are reduced with in a safe limit. The prevention of surges or water hammer should be one of the foremost considerations in the minds of water works engineers.However, and for that reason adequate protection should always be provided against the destructive consequences of excess overpressure. To achieve this goal, the components of the hydro power plants must be designed with protective measures against undesirable unsteady flow effects.It is also desirable to check the quality of material used and to analyze various conditions of operation by using current computational methods.

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Fluoride and Nitrate Groundwater Contamination in Rajasthan, India: A Review

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ABSTRACT

Rajasthan is the driest state of India, in which out of 15 basins only 2 basins (Chambal and Mahi) are perennial. Due to unavailability of surface water in the state, groundwater plays an important role for all uses particularly as a drinking water source. The state dependence on ground water is 91% for drinking water. This precious source is facing the problem of salinity, fluoride and nitrate contamination in most of the districts of the state. Based on the WHO (World health organization) guidelines for drinking-water quality, about 56% of the water sources are un-potable in the state. All 33 districts are partially or fully affected by fluoride contaminant. Jalore, Jaipur, Ajmer, Nagur, Pali, Jodhpur and Sirohi districts are worst affected by fluoride with average concentration of 2mg/l (Maximum permissible limit of Indian drinking water standard IS 10500:1991 is 1.5mg/l). Due to the higher level of fluoride in drinking water, several dental and skeletal diseases have been reported in the state. Nitrate is the second most common contaminant found in groundwater of Rajasthan due to anthropogenic activities. Almost all of Rajasthan suffers from the problem of high nitrate concentrations. Barmer, Churu and Jaisalmer districts are more affected with nitrate concentration. Maximum value of nitrate is observed in Chittaurgarh district as 1392 mg/l (Maximum permissible limit of Indian drinking water standard IS 10500:1991 is 100mg/l). The removal of these contaminants can be done by using membrane and adsorption techniques. It is concluded from the literature review that there is an instant need to take action in this region to prevent the population from the hazardous effects of these contaminants.

Keywords - Basins, Contaminant, Groundwater, Fluoride, Nitrate and Remediation.

INTRODUCTION

Rajathan is the largest state in the country having area of 3.42 lakh Sqkm, having 10.4% of country's area and 5.5% of nations population but having only 1% of country's water resources. The state has extreme geographic and climatic conditions. Due to unavailability of surface water, groundwater became the major source of drinking water. The state dependence on groundwater is 91% for drinking water (Singh et al., 2011; Saxena et al., 2014). Groundwater is one of the primary sources for drinking and irrigation in Rajasthan state (Khanna et al., 2008). The excessive and improper use, over exploitation and unwise use of groundwater have depleted groundwater availability, and also made its quality inferior and scarce (Srinivas et al., 2015). It has been seen from the present status of drinking water detailed out of 237 blocks in Rajasthan that only 49 are safe in terms of groundwater exploitation while 101 are critical and semi critical and 86 are over exploited (Mohapatra et al., 2009; Chouhan and Flora, 2010; Perumal et al., 2013).

This precious source is facing the problem of salinity, fluoride and nitrate contamination in most of the districts of the state. Based on the WHO (World health organization) guidelines for drinking-water quality, about 56% of the water sources are un-potable in the state (Khanna et al., 2008). Although fluoride is one of the important life elements to human health and essential for normal mineralization of bones and formation of dental enamel with presence in small quantity, but at a higher concentration i.e. more than 1.5 mg/l might cause harmful effects on human health (Singh et al., 2014). The Bureau of Indian Standard (BIS) suggested a fascinating limit of one milligram per litre of it in drinking water, which may be extended to 1.5 mg/l as permissible limit, if no other and totally different supply of drinking water is accessible (BIS, 1991/2003). The favourable factor which contributes to rise of fluoride in ground water is presence of fluoride rich rock salt system in the state. Fluoride enters into soil through weathering of rocks, precipitation and impure water, mainly from waste run-off and fertilizers. Drinking water is the largest contributor to the daily fluoride intake. The food when derived from plants grown in the contaminated soil also becomes another source of fluoride intake (Perumal et al., 2013). Due to the higher fluoride level in drinking water, several cases of dental and skeletal diseases have been reported in the state (Hussain et.al., 2012).

Another contaminant which is commonly found in groundwater of Rajasthan is Nitrate. The contamination of groundwater from nitrate has become an environmental and health problem in developed and developing countries. Nitrate pollution is caused by the intensive use of nitrogen fertilizers, crop irrigation with domestic wastewater and use of manure (Rocca et al., 2007; Shrimali and Singh 2001). Nitrogenous fertilizer rapidly converts into $NO3^-$ form in soils, which is readily available to plants, but is highly soluble and hence easily leachable to deep soil layers. When quantity of nitrogen added to the soil exceeds the amount that the plants can use, the excess $NO3^-$ does not get adsorbed by soil particles therefore leaches out from the root zone by water percolating through the soil profile and ultimately accumulates into the groundwater (Suthar et al., 2009). The nitrate concentration in groundwater is influenced by rainfall. Where the amounts of rainfall are low, the concentration tends to be high because the diluting effect is reduced (Saxena et al., 2014). The annual rain fall in Rajasthan ranges between 150mm to 900 mm (Khanna et al., 2007 and CGWB Jaipur, 2015). Nitrate occurs naturally in such areas owing to the low rain fall and poor vegetation (Ayyasamy et al., 2009). As per the BIS Standard for drinking water the maximum permissible limit of nitrate concentration in groundwater is 100 mg/l. Concentration of nitrate above 50 mg/l in drinking water should generate concern due to the health implications (Hemant, 2013). Infants under one year old are particularly at risk from excessive amounts as it causes methaemoglobinaemia, commonly called blue baby syndrome. This is due to blocking of the oxygen-carrying capacity of haemoglobin, when approximately 70% of the total haemoglobin have been converted to methaemoglobin. Infants are most prone to nitrate contamination because they have under developed metallic enzyme, relatively small blood volume and greater reactivity of fetal haemoglobin (Saxena et al., 2014). This review article presents the status of groundwater with special reference to the concentration of fluoride and nitrate in Rajasthan state, India and also focuses on available remediation techniques.

2. STATUS OF FLUORIDE IN RAJASTHAN

As per WHO report, 20% of the fluoride affected villages in the world are in India. Out of 33,211fluoride affected villages in country, Rajasthan has 16,560 villages, which is more than 50%. Around 10% of fluoride affected habitation in the world is in Rajasthan only (Singh et al., 2011). All 33 districts are partially or fully affected by fluoride contaminant. Jalore, Jaipur, Ajmer, Nagur, Pali, Jodhpur and Sirohi districts are worst affected by fluoride with average concentration of 2mg/l (Singh et al., 2011; Hussain et al., 2012). High fluoride concentration can be seen on both sides of Aravalli range in Tonk-Alwar-Bhilwara region in the east of Rajasthan, whereas, Nagor-Jodhpur-Pali- Jalor belt in the west of the range also shows very high concentration of fluoride that renders water unusable for human drinking. Apart from specific localized pockets, the areas around Jhalwar-Kota-Baran-Bundi- Chittaurgarh region, and that around Churu, Bikaner, Barmer and Jaisalmer have shown low concentration of fluoride as compared to other part of the state in groundwater (figure :1). Maximum value of fluoride has been observed at Bharatpur district as 8.70 mg/l

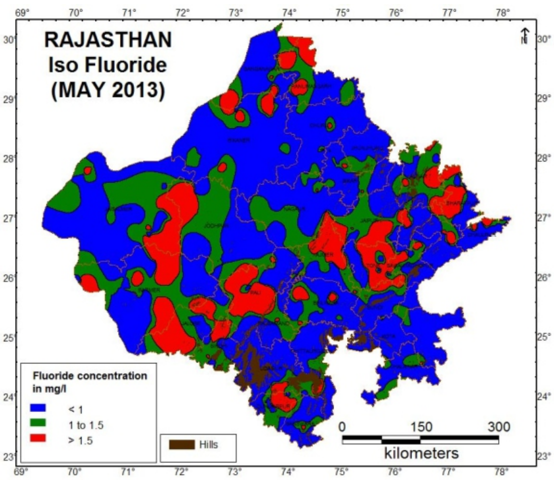

Figure 1: Fluoride distribution in Rajasthan

Table 1 Occurrence of excess fluoride in Rajasthan

Villages having excess fluoride	Districts of Rajasthan (fluoride>1.5 mg/l)
Upto 10 %	Shri Ganganagar, Bundi, Kota, Chittor Garh, Jhalawar
10 to 20 %	Bikaner, Jhunjhunu, Udaipur, Dungarpur
20 to 40 %	Churu, Sikar, Karoli, Dausa, Alwar, Jaipur, Bharatpur, Swaimadhopur, Dholpur, Banswara, Serohi, Badmer, Jhodpur, Pali, Ajmer
>40 %	Jaisalmar, Nagaur, Jalore, Bhilwara, Tonk

(Source: Singh *et al.,* 2011)

3. STATUS OF NITRATE IN RAJASTHAN

The state of Rajasthan is heavily affected by nitrate contamination of groundwater. Almost all of Rajasthan suffers from the problem of high nitrate concentrations, ranging from 40 to1000 mg/l (Ayyasamy et al., 2009).The state shows, high concentration of Nitrate in groundwater. The red colour dots show regions in Fig. 2 with >500 mg/l of Nitrate in groundwater which is considered unsuitable for drinking and agriculture. Major part of western Rajasthan falls under high Nirtrate category and most part of Bhilwara-Rajsamand-Udaipur-Dungarpur belt has high Nitrate concentration. In other parts also, pockets of high Nitrate concentration are found widely distributed all over. Low to moderate concentrations of Nitrate are found in the areas around Jhalawar-Bundi-Baran belt, around Bikaner, south of Jaisalmer and scattered areas in rest of eastern Rajasthan. Maximum value of nitrate in Rajasthan has been observed as 1392 mg/l in Chittarurgarh district.

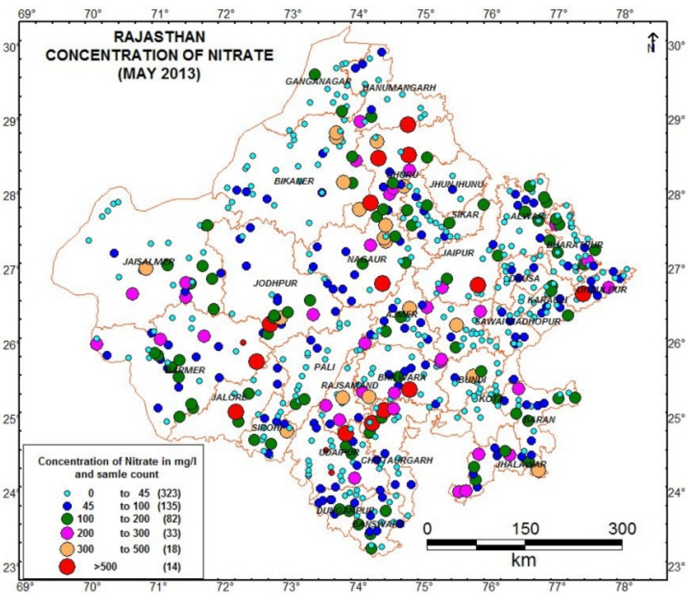

Figure: 2 Nitrate distribution in Rajasthan

4. HEALTH EFFECTS OF FLUORIDE

Fluoride is essential for normal maintenance of teeth and bones. However, prolonged exposure to high concentration of fluoride is found to be deleterious to teeth, bones and other organs (Perumal et al.,2013). Fluoride is considered beneficial to human health if taken in limited quantity (0.5 to 1.5 mg/l). Fluoride contamination is a major health hazard in many parts of the world. Health disturbances caused by chronic exposure to high concentration of fluoride is referred to as fluorosis. (Hussain et al., 2012). It is also known to cause dental, skeletal fluorosis, osteosclerosis, thyroid, kidney changes and cardiovascular, gastrointestinal, endocrine, neurological, reproductive, developmental, molecular level, immunity effects, if concentration is higher than 1.5 mg/l in drinking water (WHO, 1998).

Table 2 Fluoride Concentration and its Harmful Effects

S. No	Fluoride in drinking water (mg/l)	Effect
1.	0.002 mg/l in air	Injury to vegetation
2.	1 mg/l in water	Dental caries reduction
3.	2 mg/l or more in water	Mottled enamel
4.	3.1 to 6.0 mg/l in water	Osteoporosis
5.	8 mg/l in water	10% osteoporosis
6.	20–80 mg/day or more	Crippling skeletal fluorosis in water or air
7.	50 mg/l in food or water	Thyroid change
8.	100 mg/l in food or water	Growth retardation
9.	More than 125 mg/l in food or water	Kidney change
10.	2.5 – 5.0 gm in actual dose	Death

(Source: Hussain *et al.*, 2012)

4.1. Dental fluorosis

Dental fluorosis is caused in human being consuming water containing more than 1.5 mg/l of fluorides, particularly from birth to the age of eight. Due to excessive fluoride intake, enamel loses its lustre. In its mild form, dental fluorosis is characterized by white, opaque areas on the tooth surface and in severe form, it is manifested as yellowish brown to black stains and severe pitting of the teeth (Meenakshi and Maheshwari, 2006).

4.2. Skeletal fluorosis

Prolong intake of water having fluoride > 8 mg/l causes skeletal fluorosis (Singh et al., 2011). It affects children as well as adults. Fluoride mainly gets deposited in the joints of neck, knee, pelvic and shoulder bones and makes it difficult to move or walk. The symptoms of skeletal fluorosis include sporadic pain, back stiffness, burning like sensation, pricking and tingling in the limbs, muscle weakness, chronic fatigue, abnormal calcium deposits in bones and ligaments (Meenakshi and Maheshwari, 2006).

Fluoride above 4 mg/l in drinking water may cause a condition of dense and brittle bones known as osteoporosis. It affects tens of millions of people worldwide and is responsible for as many as 75% of all fractures in people over the age of 45. Costly and disabling fractures of spine, hip, wrist and other bones can be preceded by years of undetected bone loss. It is found that as many as 20% of those who suffer from osteoporosis related hip fractures die within 6 months. Women are at four times greater risk of developing osteoporosis than males (Hussain et al., 2012).

4.3 Other health problems

Besides skeletal and dental fluorosis, excessive consumption of fluoride may lead to muscle fibre degeneration, low haemoglobin levels, deformities in Red Blood Cells, excessive thirst, headache, skin rashes, nervousness, neurological manifestations, depression, gastrointestinal problems, urinary tract malfunctioning, nausea, abdominal pain, tingling sensation in fingers and toes, reduced immunity, repeated abortions or still births, male sterility, etc. It is also responsible for alterations in the functional mechanisms of liver, kidney, digestive system, respiratory system, excretory system, central nervous system and reproductive system (Meenakshi et al., 2006 and Singh et al., 2011).

5. HEALTH EFFECTS OF NITRATE

High nitrate levels found in drinking water have been proven to be the cause for numerous health conditions across the world such as gastrointestinal cancers, methaemoglobinaemia, alzheimer's disease, vascular dementia, multiple sclerosis in human beings. The nitrate concentration in groundwater is influenced by rainfall. Where the amounts of rainfall are low as in the state of Rajasthan, the concentration tends to be high because the diluting effect is reduced (Saxena and Saxena, 2015). Elevated nitrate concentrations occurring in groundwater present a serious threat to infants and livestock. The most common cause of nitrate generated health hazards is high levels of nitrates in drinking water. High nitrate levels may be present in drinking-water due to the use of manure and fertilizers on agriculture land. The natural levels of nitrates and nitrites from the environment are normally a few milligrams per litre, although high levels may occur naturally in some areas. Intense farming practice may increase this to more than 50 mg/l (WHO). Levels greater than 50 mg/l, are known to have been associated with methaemoglobinaemia in bottle fed infants (Maheshwari et al., 2012).

5.1 Methaemoglobinaemia

Methaemoglobinaemia is characterized by reduced ability of blood to carry oxygen because of reduced levels of normal haemoglobin. Infants are most often affected, and may seem healthy, but show signs of blueness around the mouth, hands, and feet, hence the common name “blue baby syndrome”. These children may also have trouble breathing as well as vomiting and diarrhoea. In extreme cases, there is marked lethargy, an increase in the production of saliva, loss of consciousness and seizures. Some cases may be fatal. In the body, nitrates are converted to nitrites. The nitrites react to haemoglobin in the red blood corpuscles (RBCs) to form methaemoglobin, affecting the body's ability to carry enough oxygen to the cells of the body. Bottle-fed infants less than three months of age are particularly at risk. The haemoglobin of infants is more susceptible and the condition is made worse by gastrointestinal infection. Older people may also be at risk because of decreased gastric acid secretion. Methaemoglobinaemia is now rare in most of the industrialized countries due to control of nitrate contamination in water supplies, although occasional cases continue to be reported from rural areas. It is a risk in developing countries, for example where the drinking water is from shallow wells in farming areas. There is no reliable estimate of the extent of the problem worldwide.

5.2 Livestock Losses

Nitrate poisoning is characterized by a brown colouration of the blood of the affected animal and the colour change can also seen on mucous membranes and other body parts. At sun-lethal levels of nitrate (but often above 100 ppm as N) abortion and poor milk production have been recorded for lactating cows. In several instances poisoning has been identified as the cause of stock losses. This generally happened after periods of very heavy rainfall when some months after the event, groundwater that was perfectly suitable for potable use becomes laden with nitrate and other salts.

6. REMOVAL TECHNIQUES FOR FLUORIDE AND NITRATE CONTAMINATION

The objective of fluoride removal meant the treatment of contaminated water to bring down fluoride concentration to acceptable limits. The defluoridation techniques can be divided into three groups –

- Based on chemical reaction with fluoride
- Based on absorption process
- Based on ion exchange process

The traditional method of removing fluoride from drinking water is treating with lime and the accompanying precipitation of fluorite. The precipitation and coagulation processes with iron (III), activated alumina, alum, sludge and calcium have been widely investigated. In addition, ion exchange, reverse osmosis and electro dialysis have also been studied for the removal of excess amounts of fluoride from drinking water but these techniques are costly and not suitable in rural areas of Rajathan (Singh et al., 2014; Bhatnagar et al., 2011 and Yadav et al., 2009). Nalgonda technique is one of the popular techniques widely used for defluoridation of water in developing countries (e.g. India, Kenya, Senegal and Tanzania). The process comprises the addition of prescribed quantities of alum, lime, and bleaching powder to raw water, followed by rapid mixing, flocculation, sedimentation, filtration, and disinfection. After adding alum and lime to the raw water, insoluble aluminium hydroxide flocs are formed, sediment to the bottom and co-precipitate fluoride and bleaching powder ensures disinfection during the process. The entire operation of a commonly used “fill and draw type” defluoridation unit for small community (around 200 people) can be completed within 2–3 hours, with a number of batch performances in a day. However, some disadvantages of this technique have also been reported by few researchers, e.g. high residual aluminium concentration (2–7 mg/l) in the treated water than the set WHO standard: 0.2 mg/l (Bhatnagar et al., 2011).

Many technologies are available for treating nitrate from groundwater, such as reverse osmosis; ion exchange; chemical denitrification; electrodialysis, distillation, adsorption and biological denitrification. WHO has suggested biological denitrification and ion exchange as nitrate removal methods, while ion exchange, reverse osmosis, and electrodialysis are approved by US Environmental Protection Agency (EPA) as Best Available Technologies (BAT) to treat $NO3^-$ contaminated water (Bhatnagar and Sillanpaa, 2011). Although these techniques are effective in removing nitrate from water, most of them are limited in factual application for the remediation. The main products of such chemical reduction are ammonium ions that are potential toxic to aquatic organisms at high concentrations. One of the most promising approaches being studied is biological denitrification. Microcosm studies demonstrated that nitrate may be biodegrable with special bacterial strains on natural isolates under aerobic and anaerobic condition (Liu et al., 2013).

Another technology which has been found successful in removing different types of inorganic anions, e.g., fluoride, nitrate, bromated and per chlorate from waters is adsorption by using various materials as adsorbents. Different type of adsorbents can be used for the removal of these contaminants like Carbon based sorbents (activated carbon), Natural sorbents (clay and zeolite sorbents), Agricultural waste sorbents (rice hull, coconut shell, wheat residue), Industrial west sorbents (fly ash, red mud, slag), etc.

7. CONCLUSIONS

This review has attempted to cover the groundwater contamination by fluoride and nitrate in Rajasthan state. Based on the literature reviewed, the following concluding remarks can be made that the level of fluoride and nitrate contamination in groundwater of Rajasthan are beyond the permissible limit as per BIS and WHO standards. Literature reported that fluoride bearing rocks are abundant in the state, as a result, fluoride leaches out and contaminates the adjacent water and soil resources. A high concentration of fluoride ions in groundwater up to 8.70 mg/l is found in Bharatpur district while the permissible limit is 1.5 mg/l as per BIS. Literature shows almost all parts of the state are severely affected by fluoride contamination. Several dental and skeletal diseases have been reported in the state due to high fluoride concentration in groundwater. Another problem which is facing by the groundwater sources of the state is nitrate contamination. The nitrogenous fertilizers and organic wastes containing high $NO3^-$ (livestock excreta, sewerage, organic garbage, etc.) is the main sources of $NO3^-$ in groundwater in this state. Maximum value of nitrate is observed in Chittaurgarh district as 1392 mg/l. The study indicates that the groundwater, used by the people residing in villages of Rajasthan, is not potable. So, the proper environment management plan must be adopted to control groundwater pollution immediately. Based on the literature review, it is recommended to use water only after treatment for drinking purpose by the individuals to prevent adverse health effects. Different treatment technologies have also been discussed and based on literature review it is concluded that Nalgonda technology is best suited for fluoride removal and adsorption for nitrate removal.

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An Integrated Approach for Groundwater Flow Modelling using MODFLOW and Radial Basis Function Neural Network

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ABSTRACT

Accurate prediction of groundwater level is important for efficient use and management of groundwater resources. During summer season, rapid fluctuation in the groundwater level within a day occurs in the areas of high pumping and elevation. During tides, sea water intrusion occurs in the areas near to the sea which causes sudden variations in the groundwater levels. In the above contexts, short duration groundwater level predictions had gained wide importance across different parts of the world especially in the coastal areas. Previous studies shows that Neural Networks can be successfully used for short time horizon (daily) groundwater level forecasting and Visual MODFLOW for long term (monthly) groundwater level forecasting. Since daily measurement of groundwater level is tedious and laborious, an integrated approach for daily groundwater level prediction using MODFLOW and Neural Networks is used in the present study. In this paper, initially a groundwater flow model is developed for Athiyannoor Block Panchayath of Trivandrum district using monthly groundwater level data in Visual MODFLOW. Model is calibrated and from the monthly simulations, daily groundwater level data is taken. Using the daily groundwater level data, a Radial Basis Function Neural Network (RBFNN) model is developed. The inputs to the RBFNN model include daily recharge, evapotranspiration, pumping rate and groundwater level at the previous time step. The performance characteristics indicate that RBFNN model is highly efficient for daily groundwater level forecasting.

Keywords: Groundwater level, MODFLOW, Radial Basis Function Neural Networks (RBFNN)

INTRODUCTION

Water is one of the most significant natural resource which supports both human needs and economic development. Tremendous increase in the agricultural, industrial and domestic activities in recent years has increased the demand for good quality water to meet the growing needs. Groundwater is mostly preferred to meet this growing demand because of its lower level of contamination and wider distribution. The heavy demand for groundwater sometimes leads to excessive groundwater withdrawals, which is often reflected in a serious imbalance between groundwater draft and recharge at a later stage (Varalakshmi et al. 2012). Such excessive withdrawal of groundwater without much recharge which is called groundwater mining has produced problems such as seawater intrusion in coastal aquifers and dry well formations in the inland areas. Such problems can be avoided by forecasting groundwater levels for future periods based on present scenario conditions. Groundwater level is known as "the pulse of the earth" and the most important indicator of the groundwater dynamics (Cheng and Hong 2013). During summer season, rapid fluctuation in the groundwater level within a day occurs in the areas of high pumping and elevation. During tides, sea water intrusion occurs in the areas near to the sea which causes sudden variations in the groundwater levels. Hence short duration groundwater level prediction has more significance in different parts of the world especially in coastal areas.

There are two types of models extensively used for groundwater level predictions viz. Deterministic models and Empirical models. Deterministic models assume that the future reactions of the system are determined by physical laws governing the system i.e, future groundwater level is determined by groundwater flow equation in an aquifer system. Numeric models are popular among deterministic models. Numeric models describe the entire flow field of interest at the same time, providing solutions for as many data points as specified by the user. The area of interest is subdivided into many small areas (referred to as cells or elements) and a basic groundwater flow equation is solved for each cell usually considering its water balance (water inputs and outputs). The solution of a numeric model is the distribution of hydraulic heads at points representing individual cells. The basic differential groundwater flow equation for each cell is replaced by an algebraic equation which is solved numerically, through an iterative process thus called numeric models (Kresic 1996). Finite difference based MODFLOW is an example for such models. Empirical models are solely based on the data available and Neural Networks are the part of such models. Because of highly nonlinear characteristics between the groundwater level and its factors, Neural Networks are widely used in studying variation of groundwater level. Compared to the traditional prediction methods of groundwater level, Neural Network models have strong nonlinear mapping ability, flexible network structure and are highly fault-tolerant (Xu Chang et al. 2013). Even though both the models are efficient for groundwater level prediction, MODFLOW is good for long term groundwater level prediction and Neural Networks are good for short term groundwater level predictions (Mohanty et al. 2013). Since daily measurement of groundwater level is tedious and laborious, an integrated approach for daily groundwater level prediction using MODFLOW and Neural Networks can be done.

In this paper, initially a groundwater flow model was developed in MODFLOW using monthly groundwater level data and from monthly simulations, daily groundwater level data was taken. Using this daily groundwater level data, a Radial Basis Function Neural Network (RBFNN) model was developed, which can accurately predict daily groundwater levels.

2. METHODOLOGY

Methodology comprises of two parts viz., development of groundwater flow model using MODFLOW software and development of RBFNN model for daily groundwater level forecasting.

2.1 Groundwater flow modelling using Visual MODFLOW

In this study numerical model for the groundwater flow is developed using MODFLOW software to analyse the temporal variation of groundwater level in an aquifer system. MODFLOW utilizes a numeric solution for the equation governing groundwater flow through porous media for mathematical computations and simulations as shown in equation 1.

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial H}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial H}{\partial z}\right)-W=S_s\frac{\partial H}{\partial t} \quad (1)$$

Where K_{xx} ,K_{yy}, K_{zz} are values of hydraulic conductivity along the X, Y and Z axes. 'H' is the hydraulic head; W is the volumetric flux per unit volume and represents source or sink of water; S_s is the specific storage of porous material and t is the time.

The concept development is the first step in the groundwater flow modelling in which thorough understanding of the hydrogeology and dynamics of groundwater flow in the study area is made. Then real physical boundaries of the study area need to be specified. If such boundaries don't exist, hydraulic boundaries have to be considered. Model grid is then generated in which study area is discretized in to cells or blocks. Then input parameters such as elevation, groundwater level, hydraulic conductivity (horizontal and vertical), specific storage, porosity, recharge, evapotranspiration, pumping rate and river stage have to be given. Then boundary conditions such as no flow boundaries and constant head boundaries need to be specified. After that initial conditions are specified, then model is made to run and calibration should be done by trial and error method. The values of the aquifer parameters such as hydraulic conductivity and specific storage are changed until observed groundwater level values becomes very close to simulated values. The calibration is completed when Normalised Root Mean Square Error (NRMSE) becomes less than 10%. Then model predictions can be carried out.

2.2 Groundwater level forecasting using RBFNN

The Radial Basis Function Neural Network (RBFNN) is a feed-forward structure. Radial basis function networks have an input layer, a hidden layer of radial units and an output layer of linear units. The hidden layer performs a fixed nonlinear transformation with no adjustable parameters. This layer consists of a number of nodes and parameter vector called a center, which can be considered the weight vector of the hidden layer. The standard Euclidean distance is used to measure how far an input vector is from the center. For each node, the Euclidean distance between the center and the input vector of the network input is computed and transformed by a nonlinear function that determines the output of the nodes in the hidden layer. The output layer then combines these results in a linear form. A Radial Basis Function Neural Network is shown in Figure 1.

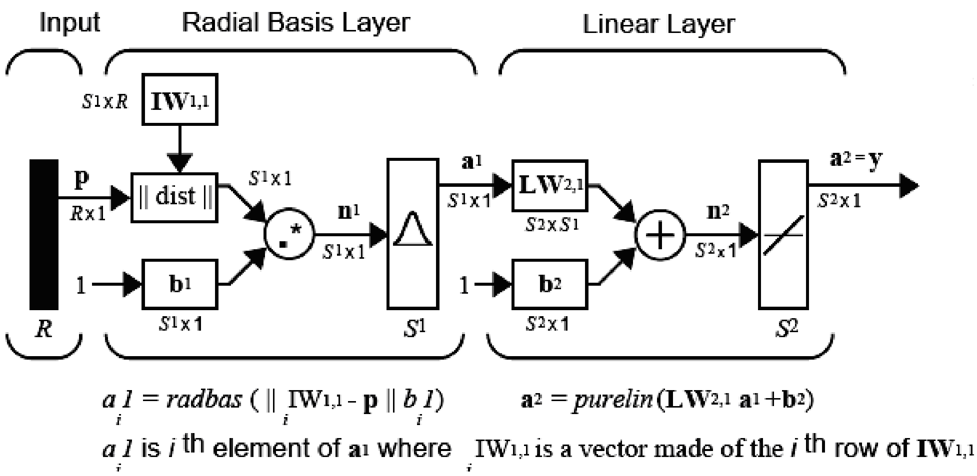


Figure 1 Radial Basis Function Neural Network
(Source: MatLab Manual, 2007)

where, R – number of elements in the input vector

S^1-number of neurons in layer 1

S^2-number of neurons in layer 2

The output y of an RBFNN is computed by the equation 2.

$$y = f(u) = \sum_{i=1} w_i R_i(x) + w_0 \tag{2}$$

Where w_i - connection weight between the hidden neuron and output neuron, w_0 is the bias, x is the input vector and R_i is the radial basis function. Radial Basis Function Neural Networks comprises a single hidden layer of linearly independent functions $\{\Phi_1, \Phi_2 .... \Phi_m\}$ that forms a basis for an m-dimensional function space. A wide class of nonlinear mappings $f_m : R^N \rightarrow R$ belonging to so generated linear space, i.e. $f_m \in span\{\Phi_1, \Phi_2 .... \Phi_m\}$, can be obtained by means of RBFNN structure. Its transfer function is given by the following linear regression equation 3.

$$f_m(x) = \sum_{k=1}^{m} w_k \Phi_k(x) + w_0 \tag{3}$$

Where $\Phi_k(x) = \Phi(\|x - c_k\| / s_k)$ are the basis functions (also termed the kernels) being translated dilations of a radially symmetric prototype function Φ: $R_N \rightarrow R$ and w_k, k = 0,1,…….,m are the adjustable weight coefficients of linear regression, s_k is the dilation factor. Architecture of RBFNN is shown in Figure 2.

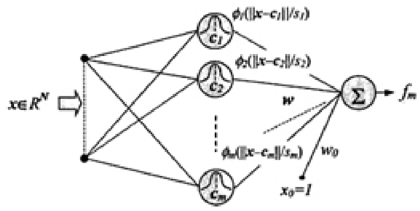
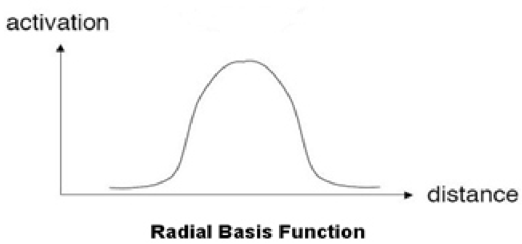
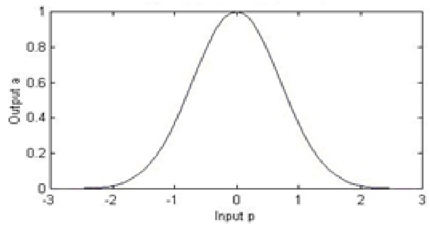


Figure 2 Architecture of Radial Basis Function Neural Network (RBFNN)
(Source: Matlab manual, 2007)

Different types of radial basis functions could be used, but the most common is the Gaussian function. Radial Basis Function and its transfer function is shown in Figure 3.



(a) Radial Basis Function



(b) Transfer function

Figure 3 Radial Basis Function and its transfer function (Source: Matlab manual, 2007)

The radial basis function for a neuron has a center and a radius (also called a spread). The radius may be different for each neuron and with larger spread; neurons at a distance from a point have a greater influence.

The various parameters used to estimate the performance of the various models are the Root Mean Square Error (RMSE), Correlation Coefficient (r), Mean Absolute Error (MAE) and Standard Error of Estimate (SEE). The smaller the value of RMSE, MAE and SEE, the better will be the performance of the model. The Correlation Coefficient should be close to unity for better performance of the model.

3. STUDY AREA

Athiyannoor Block Panchayath located at South Western part of Trivandrum district that covers approximately

38 km^2 is the study area which is considered as over exploited due to the stage of ground water development and significant decline in water level (SGWB 2009). Later this block Panchayath was categorized as semi critical (CGWB 2011). High concentration of water extracting structures (pumping wells) from the phreatic aquifer system is the root cause for the over exploitation of groundwater in Athiyannoor area. Different recharge facilities are present in different parts of the study area in which the pumping wells exists. Neyyar river is flowing through the study area and it flows near to the Thirupuram pumping well. Puvar canals are flowing nearer to Parachakkulam, Athiyannoor and Kollamkonam pumping wells. Vellayani lake flows nearer to Kadavinmoola pumping well. Puthalam pumping well is located at the hill foot so that it intercepts water from high elevations. In Karichal area, a radial collector well is provided for groundwater recharge. Venganoor pumping well is located in a sloping terrain. No any additional recharge facilities are provided in Kumili, Athiyannoor and Pulinkudi areas, so that recharge occurs in these areas from rainfall only. These are the hydrogeological features of the study area. Major formations include Warkalai formation, coastal alluvium, laterite and precambrian crystalline.

Ten pumping wells from the study area were considered for the analysis and all of them are operated by Kerala Water Authority. One observation well is considered near each pumping well. The study area is shown in Figure 4.

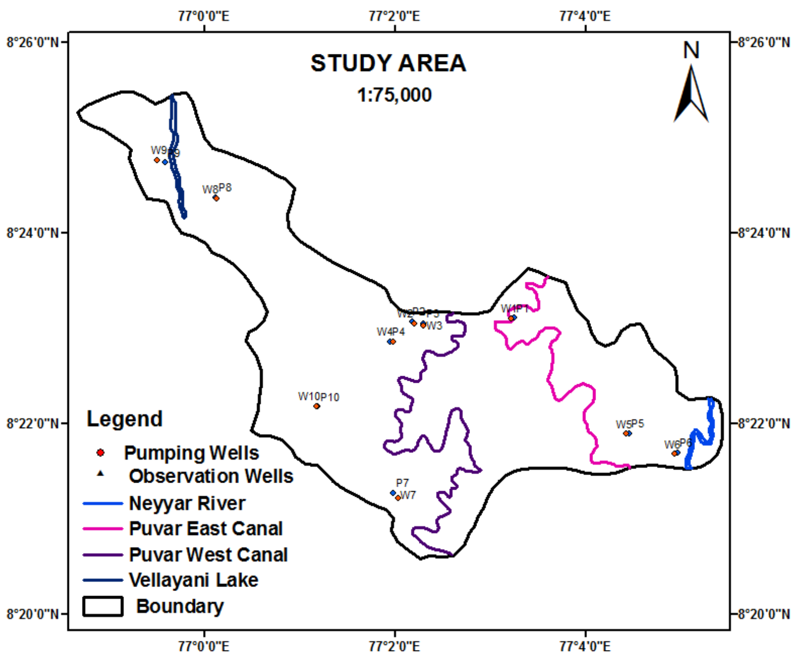


Figure 4 Study area

4. DATA COLLECTION

The pumping wells and their pumping rates were collected from Kerala Water Authority and are given in Table 1. Weekly water level data were directly measured from all the 10 observation wells from 4/1/2014 to 31/3/2015 were used for modelling. The rainfall and meteorological parameter values were collected from the site www.accuweather.com.

Table 1 Pumping wells and pumping rates
(Source: Kerala Water Authority, 2013)

Sl. No.	Name of the Pumping Well	Observation well designation	Pumping Rate (lpm)
1	Parachakkulam Pumping Well (P_1)	W_1	400
2	Kollamkonam Pumping Well (P_2)	W_2	700
3	Athiyannoor Pumping Well (P_3)	W_3	1500
4	Puthalam Pumping Well (P_4)	W_4	2500
5	Kumili Pumping Well (P_5)	W_5	2500
6	Thirupuram pumping Well (P_6)	W_6	1700
7	Karichal Pumping Well (P_7)	W_7	2800
8	Venganoor Pumping Well (P_8)	W_8	1350
9	Kadavinmoola Pumping Well (P_9)	W_9	1600
10	Pulinkudi Pumping Well (P_{10})	W_{10}	1100

5. RESULTS AND DISCUSSION

The developed groundwater flow model was calibrated and simulated. From the monthly simulations daily groundwater level data was taken. Then a RBFNN model was developed using daily groundwater level data.

5.1 Groundwater flow modelling using MODFLOW

A conceptual model of the study area was developed based on the hydrogeologic information and field investigation. Lithological investigation reveals that study area consist of an unconfined aquifer (Warkalai formation) for a depth of 30m. Since all the pumping wells and observation wells are within 30m from ground surface, the study area was modelled as a single layer with thickness 30m. The study area was discretized in to 60X60 cells. The recharge values were estimated by Rainfall Infiltration Factor (RIF) method. For the Warkalai formation RIF of 0.25 (Report of groundwater resource estimation committee, 2009) was taken, which is multiplied by total rainfall in order to get the recharge. Evapotranspiration values were computed using Penman's method. Pumping test was conducted at Kumili Pumping Well of the study area. Hydraulic conductivity of 47 m/day was obtained from Jacob's method. The river heads were properly assigned. Model was then calibrated under transient condition. Then groundwater levels were simulated for the 10 observation wells for one year at monthly time step. The calibration chart is given in Figure 5. Comparison of observed and simulated monthly groundwater levels in W_1, W_4, W_6, W_{11}, W_{20} and that in W_8, W_{13}, W_{15}, W_{22}, W_{31} are shown in figures 6(a) and 6(b) respectively. It shows that NRMSE obtained is 1.193%, which is less than 10%. The calibrated value of hydraulic conductivity was found to be 7 m/day. From the monthly simulations of groundwater level, daily groundwater level data were taken.

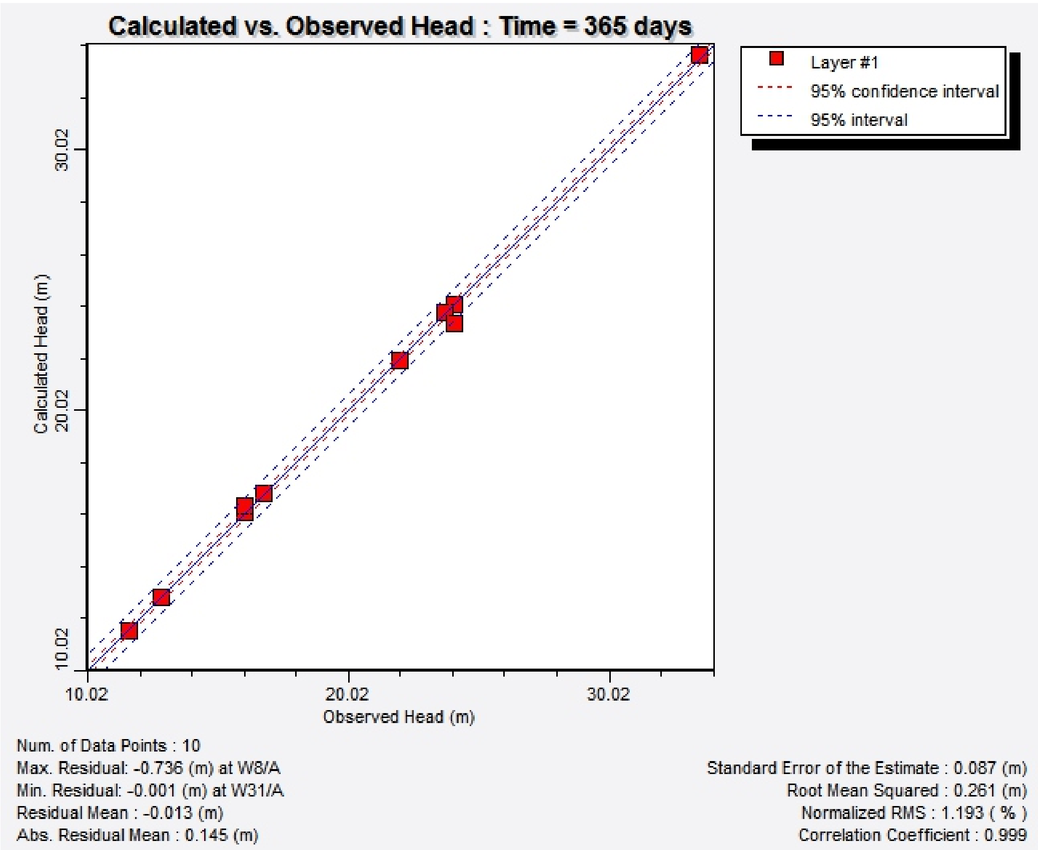


Figure 5 Calibration chart for monthly groundwater level data

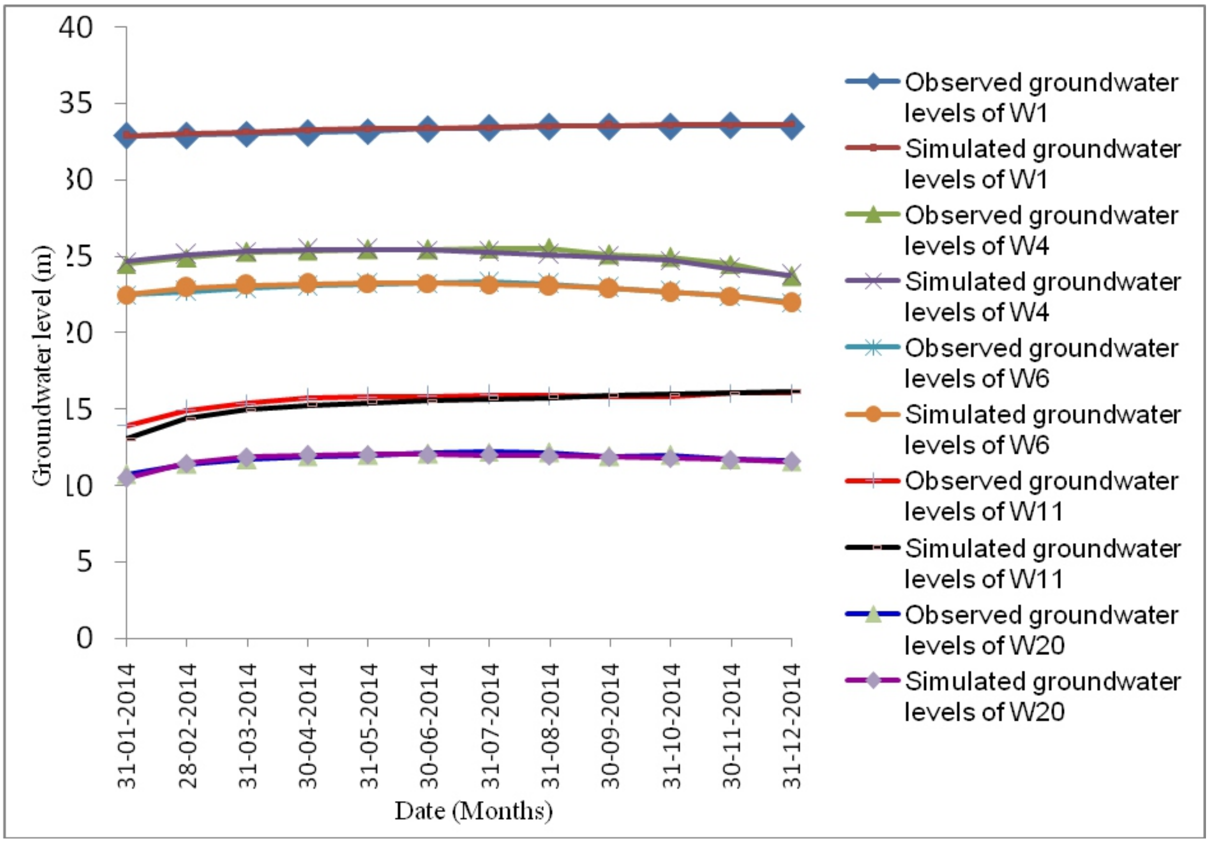


Figure 6(a) Comparison of observed and simulated monthly groundwater levels in W_1, W_4, W_6, W_{11} and W_{20}

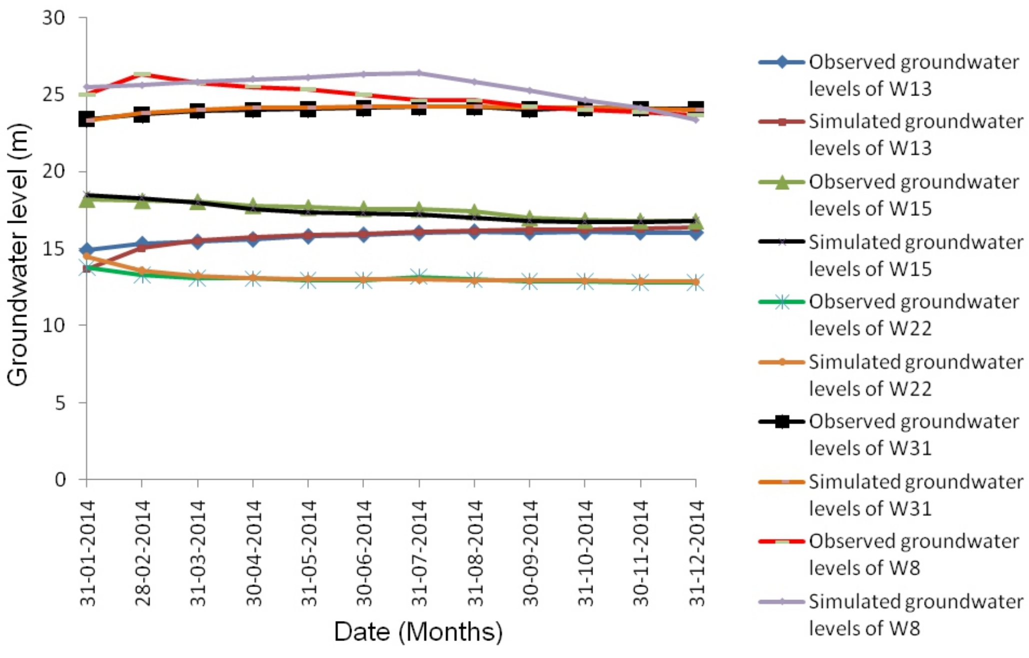


Figure 6 (b) Comparison of observed and simulated monthly groundwater levels in W_8, W13, W_{15}, W_{22}, W_{31}

From the simulations, it is clear that MODFLOW is good for groundwater flow modelling since all the hydraulic and hydrogeological parameters are incorporated in to it. Hence it act as an excellent simulation tool for the modelling.

5.2 Groundwater flow modelling using RBFNN

A RBFNN model was developed for daily prediction of groundwater levels in the study area. The input parameters used for the study were recharge, evapotranspiration, pumping rate and groundwater level of previous time step. The output was the groundwater level. Out of 365 daily values of input and output parameters, 292 values were used for training and 73 values were used for testing. A MatLab program was used to develop the RBFNN model. The neurons in the input layer were fixed as 4 and that of output layer was fixed as 1. The number of neurons in the hidden layer and the spread (radius) of the function were varied to obtain the best network. The network with the least RMSE was chosen as the best network. The details of best network architecture, spread and RMSE obtained are shown in Table 2. Comparison of observed and simulated groundwater levels in W_6 and W_{11} during training is shown in figures 7 and 8. The comparison of observed and predicted groundwater levels during testing is shown in figures 9 and 10. Performance of all the ten observation wells during testing is shown in Table 3. The parameter R^2 in the scatter plots indicates the coefficient of determination.

Table 2 Performance of RBFNN model during training

Observation Well	Architecture	Spread	RMSE
W_1	4-20-1	1	0.0057
W_2	4-20-1	1.5	0.0213
W_3	4-20-1	1	0.0145
W_4	4-20-1	1.7	0.0207
W_5	4-20-1	1.55	0.0032
W_6	4-20-1	1	0.0086
W_7	4-20-1	1.8	0.0068
W_8	4-20-1	1.8	0.0091
W_9	4-20-1	1	0.0256
W_{10}	4-20-1	1.2	0.0147

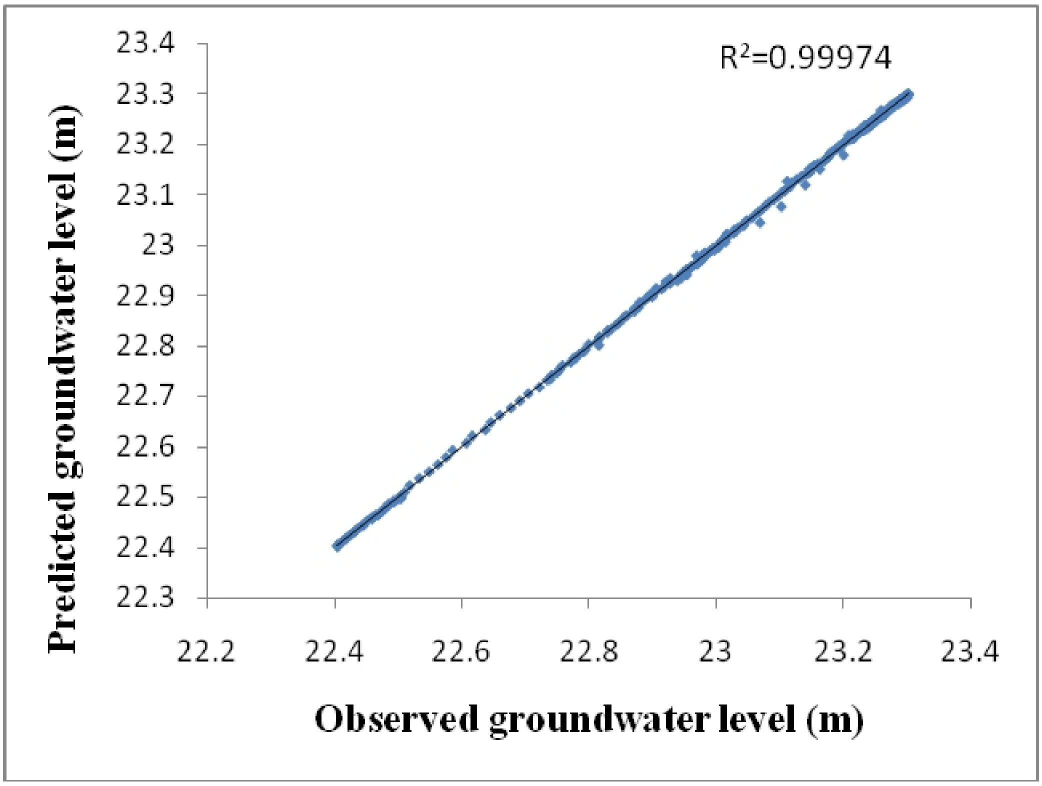


Figure 7 Comparison of observed and simulated groundwater levels in W_6 during training

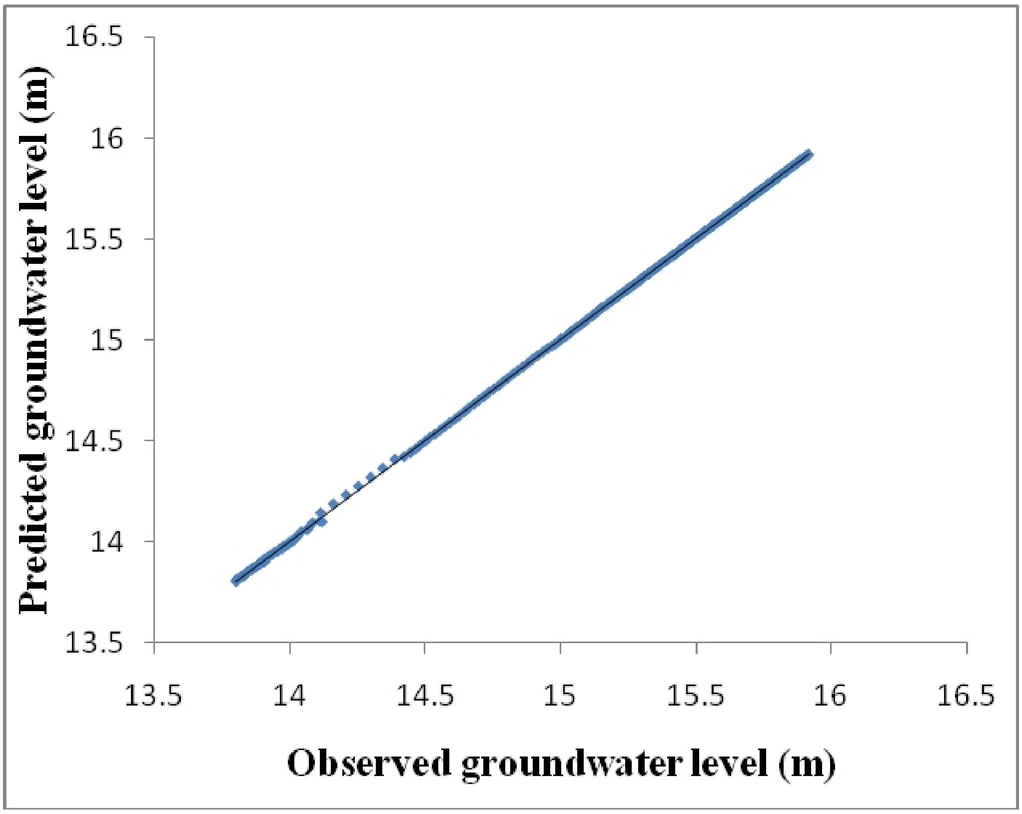


Figure 8 Comparison of observed and simulated groundwater levels in W_{11} during training

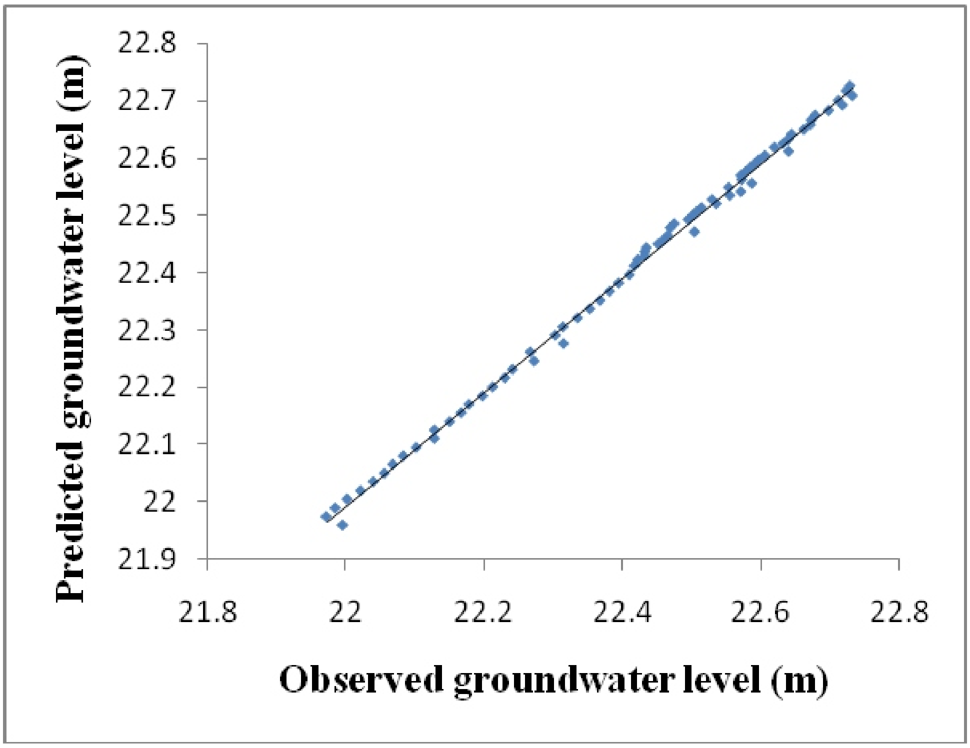


Figure 9 Comparison of observed and predicted groundwater levels in W_6 during testing

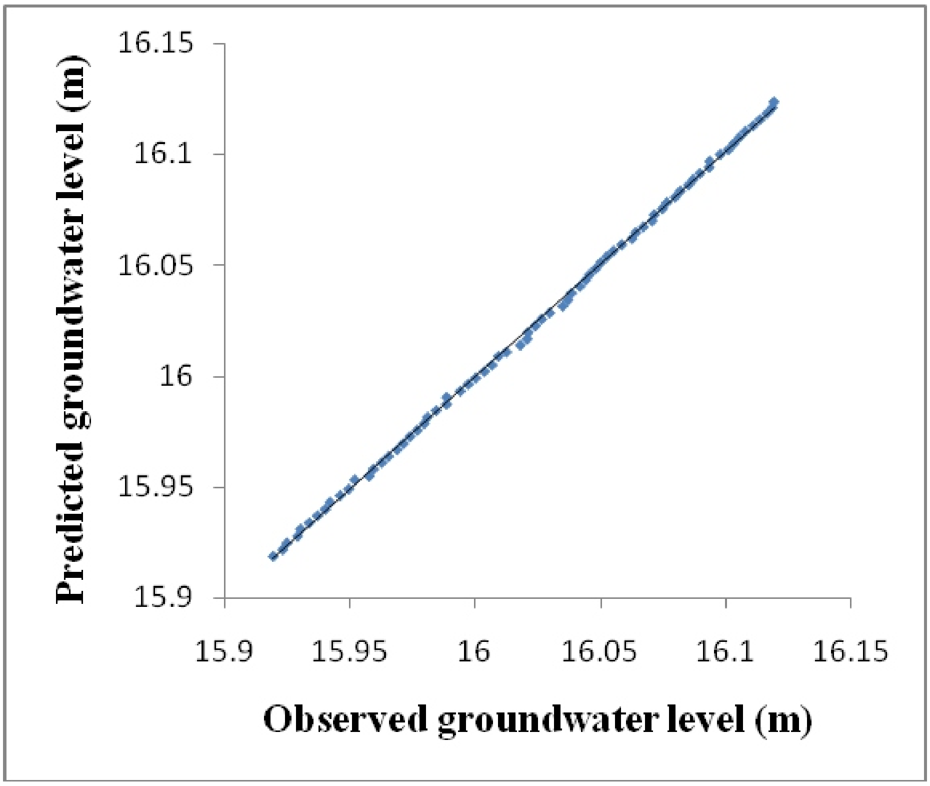


Figure 10 Comparison of observed and predicted groundwater levels in W_{11} during testing

Table 3 Performance characteristics of RBFNN model during testing

Observation Well	RMSE	MAE	SEE	AARE	E (%)	r
W_1	0.0024	0.0021	0.0024	0.0046	97.57	0.9973
W_2	0.0481	0.0329	0.0372	0.0996	97.03	0.9988
W_3	0.0139	0.0092	0.014	0.03	99.6	0.9989
W_4	0.0187	0.0078	0.0189	0.0239	97.53	0.9908
W_5	0.0016	0.0001	0.0016	0.0004	99.93	0.9997
W_6	0.0025	-0.001	0.0025	-0.0047	96.69	0.9901
W_7	0.0035	0.001	0.0036	0.0046	95.16	0.9842
W_8	0.0064	-0.0042	0.0065	-0.0258	99.02	0.9977
W_9	0.0004	0	0.0019	0.0002	96.94	0.9988
W_{10}	0.0007	0.0001	0.0007	0.0002	97.62	0.9884

High correlation coefficient (r) of 0.99 and low value of RMSE, MAE, SEE and AARE is obtained for all the ten observation wells during testing. Hence RBFNN model is efficient for daily groundwater level forecasting. This study reveals that lag 1 groundwater level data has significance on daily groundwater level forecasting.

7. CONCLUSION

A groundwater flow model is developed for Athiyannoor Block Panchayath of Trivandrum district using MODFLOW and RBFNN. MODFLOW is good for monthly simulations of groundwater level since all the hydraulic and hydrogeologic parameters are incorporated in to the model. But RBFNN model is good for prediction of daily groundwater levels in each well of the study area. So initially a groundwater flow model is developed in MODFLOW. From monthly simulations, daily groundwater level data is taken and a RBFNN model was developed. RBFNN model was properly trained and tested using daily groundwater level data. The performance characteristic shows that the developed model is efficient for the daily groundwater level forecasting. Thus an integrated approach for groundwater flow modelling using MODFLOW and RBFNN is efficient for daily groundwater level forecasting.

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