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A Prediction of Total Amount of River Flow Rate Following a Spell of Rainfall by Using Radar Echo Data

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Abstract: - This paper describes an application of neural network for prediction of total amount of river flow rate from the meteorological radar echo data. A neural network system is developed through a case study on a dam for hydropower plant located the upper district of the Yahagi River in Central Japan. The prediction system has 6 input nodes corresponding to the rainfall amounts from radar echo data, four ground rainfall gauges and the base flow rate. The output from the system is the predicted total amount of river flow. In addition, the same concept applies to estimating of runoff ratio. It is found from our investigations that predictions of total amount of river flow rate and estimation of runoff ratio are improved by utilization the radar echo data.

Key-Words: - Neural network, Radar echo data, River flow rate, Prediction, Runoff ratio

1 Introduction

It is desirable from the viewpoint of the preservation of the global environment that the clean energy stored in water reservoirs is converted into electric energy as effectively as possible in hydropower plants. The hydropower energy as the natural energy is many quantities, and it is the high energy density. In order to convert the hydropower energy into electric energy effectively, it is necessary to forecast the river flow rate in the upper district of the hydropower plant.

For the purpose, we have developed a practical forecasting method of time variation of river flow rate following rainfall upstream of a dam. The method is based on the artificial neural network theory[6][7]. The rain data as input information of the neural network was obtained from the observed value of ground rain gauge at several points on the wide area. But the distribution of ground rainfall on the mountain region is not uniformly. Therefore, it is not possible to know the amount of rainfall on the upper district of the dam, as input data of the neural network.

In meteorological stations and power system operation center, a rainfall region can be observed by meteorological radar[1], The meteorological radar echoes indicate the spatial distribution of the raindrop density and are interpreted to the rainfall amount by using the so-called radar equation. However, the radar equation is not almighty for all types of the rainfalls because the coefficients in the radar equation are determined as average values from experiences[2]-[5].

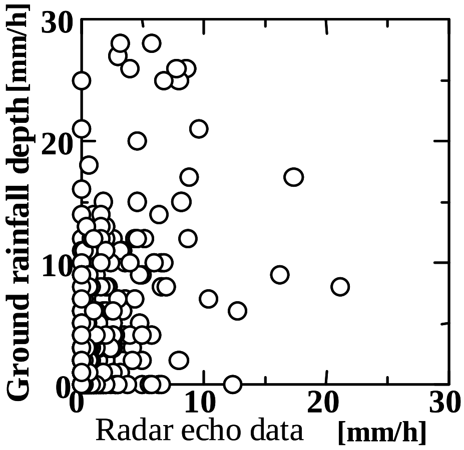
This paper describes an application of a neural network for the prediction of the total volume of the river flow. A prediction system for this purpose is developed through a case study on a dam for hydropower plant located the upper district of the Yahagi River in Central Japan.

In order to predict the total volume of the river flow, the system has 6 input nodes corresponding to the rainfall amounts from radar echo data, four ground rainfall gauges and the base flow rate. The output from the system is the predicted total amount of river flow. In addition, the same concept applies to estimating of runoff ratio. It is found from our investigations that prediction of total amount of river flow rate and estimation of runoff ratio are improved by utilization the radar echo data.

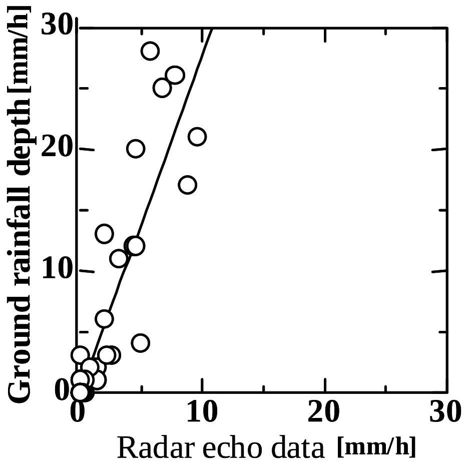
2 Radar Echo Data and Ground Rainfall Depth

For the examination of the prediction method of the total amount of the river flow rate, we used the upper district of the Yahagi River in Central Japan as a case study. We used the meteorological radar echo data in order to improve the total amount of the river flow rate. The radar system has an output power of 250kW and a frequency of 5,330 MHz and it is built on the top of Mt. Mikuni located at long.137°11'31" E and lat.35°15' N in Central Japan. The upper district of the Yahagi River has 105 radar meshes and four rainfall gauges as shown in Fig. 1. The basin of the Yahagi River is gradually elevated from west to east.

The correlation between rain gauge data and radar ones was investigated for 23 rainfalls from 1991 to 1993. In Fig.2(a), for instance, rainfall amounts observed by the ground rain gauge A are together plotted against radar data in the corresponding mesh No.11 for all 23 rainfalls. Little correlation appears



(a) 23 rainfalls from 1991 to 1993



(b) Rainfall on Septempber 18, 1991

Fig. 2 Correlation between ground rainfall depth and radar echo data at point A

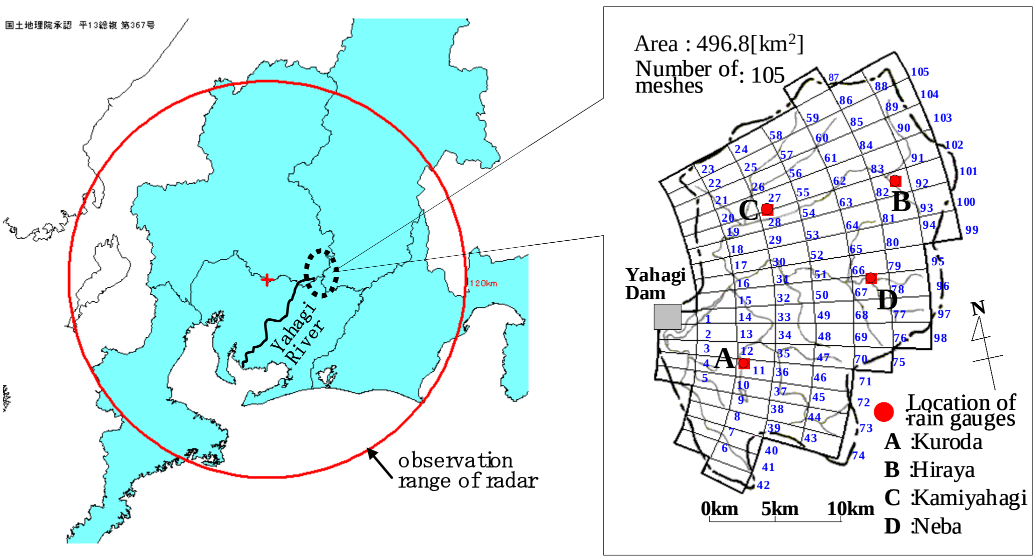


Fig. 1 Rainfall gauges and radar meshes on upper district of Yahagi River in Central Japan

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between both data. However, a spell of rainfall has the good correlation between both data as shown in Fig. 2(b) as an example. It is concluded the different correlation between both data exits in each of spell of rainfall. This fact suggests the radar data give us relative distribution of the ground amount of rainfall.

3 Prediction of Total Amount of River Flow Rate

3.1 Prediction System by Using Rain Gauge Data

An artificial neural network system was constructed to predict the total amount of river flow rate from the rain gauge data as shown in Fig. 3. The system consists of three layers; an input layer, a hidden layer an output layer. The input data to the neural network are the base flow rate and the total values of the accumulated rainfall amount on the river basin. Thus the input layer has two nodes in total. The output layer has a single node. The output from the neural network is predicted total amount of river flow rate. Three nodes are adopted for the hidden layer. A sigmoid function is used to present the relationship between the input and output of each neuron.

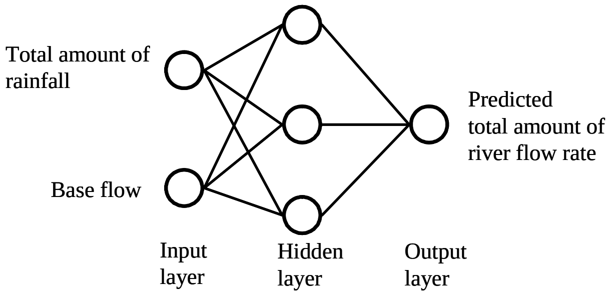

Fig. 3 Prediction system of total amount of river flow rate

3.2 Predicted Results of Total Amount of River Flow Rate by using Rain Gauge Data

The operation of the neural network system for total amount of river flow rate is tested by 14 rainfall data from 1991 to 1993. These rainfalls are effective as hydraulic power energy. The training of the neural network is carried out by using nine rainfall data in 14 ones. The five data of remainder is used to assess the performance of the neural network on the accuracy of the predicted total amount of river flow rate.

Table 1. Predicted results of total amount of river flow rate

	No.	Date of rain start (y.m.d)	Total amount of rainfall by thiessen method	Base flow [m^3/s]	Total amount of river flow rate		Error [%]
					Observed value [t]	Predicted value [t]	
used for the training	1	1991.06.22	62905870	19.5	23573160	25813617	9.5%
	2	1991.07.15	36797590	36.8	20244600	21381821	5.6%
	3	1991.07.27	24785640	22.5	12687840	11735354	-7.5%
	4	1991.08.29	59340370	9.1	22450320	23889125	6.4%
	5	1991.09.13	107130980	17.0	42095520	42408188	0.7%
	6	1991.09.18	86977320	45.0	52402680	50719839	-3.2%
	7	1992.05.13	50116750	14.0	23788800	19598062	-17.6%
	8	1992.06.05	35315340	12.7	11971080	14148175	18.2%
	9	1992.06.30	22391020	17.5	8192160	11197873	36.7%
Average absolute error							11.7%
used for evaluation	10	1992.08.07	68926420	10.2	20152800	28641422	42.1%
	11	1992.09.25	25882720	11.5	8017920	11826526	47.5%
	12	1993.06.23	33704980	20.1	15732360	13777458	-12.4%
	13	1993.08.17	34099400	48.2	29192760	39476481	35.2%
	14	1993.09.03	60651580	21.3	19854000	24787485	24.8%
Average absolute error							32.4%

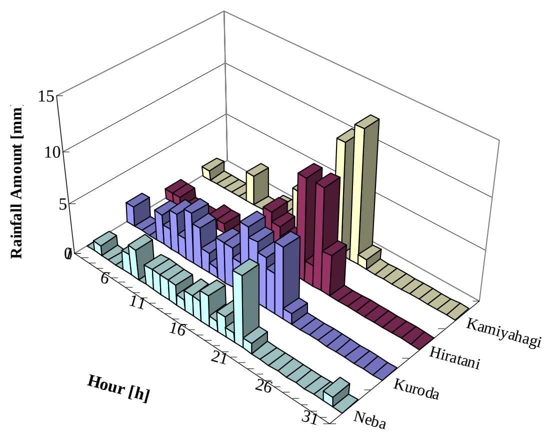

Fig. 4 Rainfall ondition on Sept. 25th. 1992

The predicted results of the total amount of river flow rate are shown in Table 1. The nine rainfalls in the upper part of the table are correspondent to the rainfall with the training. The five rainfalls in the lower part of the table are correspondent to the rainfall without training. The average absolute error is 32.4%. In one of the cause of the error, it is considered that the rainfall distribution is not uniform on the whole basin.

As an example with the large error in Table 1, the time variation of the rainfall on Sept. 25th, 1992 is shown in Fig. 4. The figure indicates the time variation of the rainfall amount distribution observed from the four rain gauges A, B, C and D on the upper district of the Yahagi Dam, This data is greatly different in the every each point of the rain gauges.

3.3 Prediction System by Using Radar Echo Data

The radar echo data offer many advantages over the ground rain gauge data because it can easily understanding the rainfall value at every mesh on the river basin. The prediction system for total amount of river flow rate by using radar echo data is shown as Fig. 5. This is consists of three layers; as input layer, a hidden layer and output layer.

The input data to the neural network are a total rainfall amount by using radar echo data, four ground rain gauges and base flow rate. Thus, the input layer has six nodes in total. The output layer has a single node. The output from the neural network is the predicted total amount of river flow rate. Seven nodes are adopted for the hidden layer.

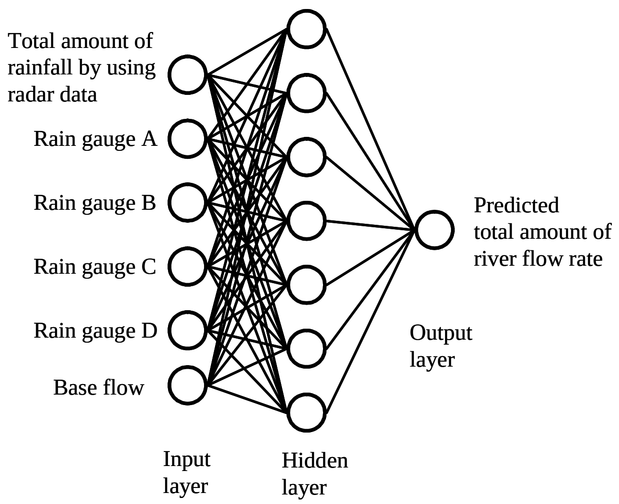

Fig. 5 Prediction system for total amount of river flow rate by using radar echo data

3.4 Predicted Results of Total Amount of River Flow Rate by Using Radar Echo Data

The operation of the neural network system for total amount of river flow rate is tested by same data at subsection 3.2. The training of the neural network is carried out by using nine rainfall data in 14 ones. The five data of remainder is used to assess the performance of the prediction system by using radar data.

Table 2. Predicted results of total amount of river flow rate by using radar data

	No.	Date of rain start (y.m.d)	Total amount of rainfall by radar data	Base flow [m^3/s]	Total amount of river flow rate		Error [%]
					Observed value [t]	Predicted value [t]	
used for the training	1	1991.06.22	12436647	19.5	23573160	24470332	3.8%
	2	1991.07.15	12717428	36.8	20244600	21334826	5.4%
	3	1991.07.27	11500602	22.5	12687840	11991066	-5.5%
	4	1991.08.29	10592845	9.1	22450320	23510581	4.7%
	5	1991.09.13	16004802	17.0	42095520	43767678	4.0%
	6	1991.09.18	22384062	45.0	52402680	49983496	-4.6%
	7	1992.05.13	12810137	14.0	23788800	23340781	-1.9%
	8	1992.06.05	9345402	12.7	11971080	11849656	-1.0%
	9	1992.06.30	3692868	17.5	8192160	9108594	11.2%
Average absolute error							4.7%
used for evaluation	10	1992.08.07	7604289	10.2	20152800	25590333	27.0%
	11	1992.09.25	2307133	11.5	8017920	9128870	13.9%
	12	1993.06.23	8444783	20.1	15732360	13507603	-14.1%
	13	1993.08.17	11758169	48.2	29192760	26530583	-9.1%
	14	1993.09.03	7971344	21.3	19854000	20373830	2.6%
Average absolute error							13.3%

Table 3. Comparison of prediction error

Date of rain start (y.m.d)	Prediction error	
	Used rain gauge data only	Used radar data
1992.08.07	42.1%	27.0%
1992.09.25	47.5%	13.9%
1993.06.23	-12.4%	-14.1%
1993.08.17	35.2%	-9.1%
1993.09.03	24.8%	2.6%
Absolute average	32.4%	13.3%

The predicted results are shown in Table 2. In case of the rainfall data used in training of the neural network, the average absolute predicted error of total amount of river flow rate is 4.7% as shown in the upper part of table. The predicted error of total amount of river flow rate in the lower part is within 15% on 4 examples in five examples. The absolute value average of the predicted error is 13.3%.

The predicted results of the total amount of river flow rate obtained by with and without radar data are shown in Table 3. In comparison with the case in which only ground rainfall gauge data was used, the predicted error by using the radar data becomes small on four

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examples, and it is found that predicting accuracy of the total amount of river flow rate is improved by utilization of the radar echo data.

4 Estimation System of Runoff Ratio

4.1 Runoff ratio

When the rain fell in the basin, it does now flow all to the river. The component, which escapes to the river within the rainfall, is called the effective rainfall. On the other hand, the component, which does not escape to the river within the rainfall, is called loss amount of rainfall. The ratio of effective rainfall and total amount of rainfall is called runoff ratio.

$$\text{Runoff ratio} = \frac{\text{Effective rainfall}}{\text{Total amount of rainfall}} \quad \cdots\cdots (1)$$

By conditions of the vegetation and the soil, the runoff ratio is greatly different, since the following greatly change: evaporation of the rainfall and infiltration capacity to the underground.

4.2 Estimation System

The same concept at subsection 3.3 can be applied to the estimation system of runoff ratio. Thus, estimation system is shown in Fig. 6. The input data to the neural network are a total amount of rainfall amount by using radar data , four ground rain gauges and base flow rate. Thus, input layer has six nodes in total. The output layer has a single node. The output from the neural network is the estimated runoff ratio. The hidden layer has seven nodes.

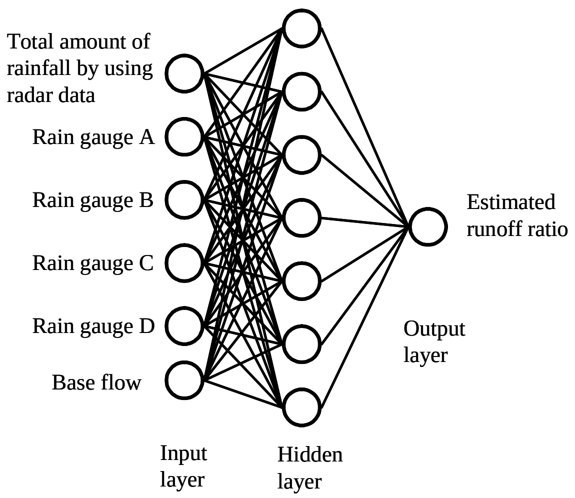

Fig. 6 Estimation system for runoff ratio by using radar echo data

Table 4. Estimated results of runoff ratio by using radar data

	No.	Date of rain start (y.m.d)	Total amount of rainfall by radar data	Base flow [m^3/s]	Runoff ratio: Observed value	Runoff ratio: Predicted value	Error [%]
used for the training	1	1991.06.22	12436647	19.5	0.37	0.48	30.3%
	2	1991.07.15	12717428	36.8	0.61	0.65	6.9%
	3	1991.07.27	11500602	22.5	0.52	0.48	-7.2%
	4	1991.08.29	10592845	9.1	0.41	0.45	10.3%
	5	1991.09.13	16004802	17.0	0.41	0.41	-0.5%
	6	1991.09.18	22384062	45.0	0.70	0.72	3.0%
	7	1992.05.13	12810137	14.0	0.63	0.57	-10.1%
	8	1992.06.05	9345402	12.7	0.41	0.38	-7.1%
	9	1992.06.30	3692868	17.5	0.40	0.47	16.9%
Average absolute error							10.2%
used for evaluation	10	1992.08.07	7604289	10.2	0.29	0.47	60.4%
	11	1992.09.25	2307133	11.5	0.32	0.53	64.8%
	12	1993.06.23	8444783	20.1	0.68	0.62	-8.3%
	13	1993.08.17	11758169	48.2	0.78	0.79	1.1%
	14	1993.09.03	7971344	21.3	0.35	0.39	11.6%
Average absolute error							29.2%

4.3 Estimated Results

The operation is same process at subsection 3.4. The estimated results are shown in Table 4. In this case, the average estimated error of runoff ratio is 10.2% as shown in the upper part of the Table 4. The estimated error of runoff ratio in the lower part is within 15% on three examples in five examples. The absolute value of the estimated error is 29.2%.

The estimated results of the runoff ratio obtained by with and without radar data are shown in Table 5. In comparison with the case in which only ground rainfall gauge data was used, the average estimated error by using the radar data becomes small, and it is found that estimating accuracy of the runoff ratio is improved by utilization the radar echo data..

Table 5. Comparison of estimation error

Date of rain start (y.m.d)	Estimation error: Used rain gauge data only	Estimation error: Used radar data
1992.08.07	50%	60%
1992.09.25	-13%	65%
1993.06.23	-29%	-8%
1993.08.17	-28%	1%
1993.09.03	83%	12%
Absolute average	40.6%	29.2%

5 Conclusion

The meteorological radar echo data are successfully used to predict the total amount of river flow rate and to estimate the runoff ratio on the upper district of the hydropower plant by neural network systems.

In this paper, the total amount of river flow rate prediction and the runoff ratio estimation was carried out on the upper district of the Yahagi River in Central Japan. By utilizing the rainfall data obtained from the radar, it was possible to attempt the improvement in the prediction or estimation accuracy. In the future, the proposal technique is examined for other river.

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