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Analysing variability and trends in different sources of irrigation in India: A time series perspective

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Abstract
Irrigation is an artificially supplying and systematically distribution of water for agriculture and horticulture in order to obtain higher or qualitatively better production when rainfall is scarce or during off monsoon. The present paper explains the changing pattern of net irrigated area by different sources of irrigation in India i.e. canals, tanks, wells (tube wells and other wells) and total net irrigated area (NIA) through the use of statistical analysis of time series. A time series modelling approach is used to forecast the future values. For the study, data with respect to canals, tanks, wells and total NIA are collected from Ministry of Agriculture & Farmers Welfare, Govt. of India for the period of 72 years (1951-2022). This study is accomplished by using a Box-Jenkins ARIMA time series model in SPSS and STATA Software and R codings. The efforts are made to forecast the future net irrigated area by different sources for a period upto ten years as accurate as possible. This paper entails on the best fitted ARIMA model and its forecasting. Validity of the model has also been tested. It is found that ARIMA (0, 1, 4) fitted best for canals, ARIMA (1, 0, 1) for tanks and ARIMA (1, 0, 3) for total NIA whereas for well irrigation ARIMA (1, 0, 2) is the best fitted model. ARIMA models are selected on the basis of satisfying the best fitted model criteria. This paper has made an attempt to assess the contribution of different sources of irrigation which shows that the use of well irrigation is effectively increasing as an important source of irrigation.

Keywords: Time series, ARIMA, modelling, forecasting

Introduction

Agriculture is the most important sector of Indian economy, where more than 58% population depends on agriculture. Irrigated agriculture has made a major contribution to food production and food security throughout the world. The farmers get water for their crops either from rainfall or from artificial irrigation such as wells, tanks and canals. The importance of irrigation for agricultural production growth in India hardly wants any emphasis. Improved reliability of facility of water supply through canals, tanks or through groundwater (wells) has significantly contributed to the increase in agricultural productivity in India. Recent studies show that the irrigation needs to play a bigger role towards a goal of achieving a better agricultural productivity and also the national food security. (Persaud and Stacey, 2003; Kumar 1998, GOI 1999; Bhaduri *et al*., 2012) [9, 8, 6, 2]. India's irrigation covered crop area was about 22.6 million hectares in 1951, and it increased to a potential of 90 million hectares at the tip of 1995, integral of canals and wells. The irrigation infrastructure includes a network of canals from rivers, ground (well) water, tanks and various rain water harvest merchandise for agriculture activities. As per the land use statistics 2018-19, the total geographical region of the country is 328.7 million hectares, of which reported net sown area is 139.3 million hectares and the net irrigated area is 71.6 million hectares. (Ministry of Agriculture and farmers Welfare, Annual Report, 2022-23). In India, there is three major sources of Irrigation: Canals, Tanks and Wells.

Canals: Canals are the main source of irrigation in India, especially in northern part i.e. Uttar Pradesh, Andhra Pradesh, Punjab and Haryana of India. Canals are big water channels taken out from rivers to carry water to places which are pretty much far away from the river.

Tanks: Tank irrigation is a natural or man-made spring included as part of a structure. It is mainly known for harvesting and preserving the local rainfall and water from streams and rivers for later use, primarily for agriculture and drinking water. It is commonly used in southern part of India *viz*. Andhra Pradesh, Karnataka, Tamil Nadu and Maharashtra.

Well: Well irrigation is a principal method of irrigation used in India. Underground water is tapped for drinking purposes and at the same time it is also tapped for irrigating the cultivated land. It is also found that in such areas, production of crops done with the usage of well water is quite rewarding. Uttar Pradesh leads in well irrigation and is followed by Punjab, Haryana, Bihar, Gujarat and Andhra Pradesh. Two types of wells**:** Open wells and tube-wells.

Materials and Methods

Materials

All the data are used in the study relies on secondary data compiled from various published sources. Data with respect to net irrigated area by different sources of irrigation in India are selected from the period of 1950-1951 to 2021-22 from Ministry of Agriculture & Farmers Welfare, Govt. of India. Canal, tank and well are the major sources of irrigation in India on which the time series analysis is done.

Methodology

This present paper is attempting to analyse the various time series models and to estimate the best fitted models for net irrigated area under different sources. Also, to examine the nature of each series which has been subjected to get various descriptive statistical measures and trend models is also considered for study.

Descriptive Statistics

Descriptive statistics offer simple summaries about the data and the measures. The descriptive statistics study that used for study are maximum, minimum, mean, median, skewness, kurtosis etc. to describe the pattern of the series and draw a consensus under consideration.

Trend models

Different parametric models are tried to describe the series under consideration, which are briefly given here under:

- **Linear model:** It is one in which all the parameters appear linearly and it is formulated as $X_t = a + bt + e_t$.
- **Quadratic model:** It can be used to model a series which "takes off" or a series which "dampens". It expressed as $X_t = a + bt + ct^2 + e_t$.
- **Cubic model:** The equation of cubic model is a 3rd order of polynomial regression equation and it is represented as $X_t = a + bt + ct^2 + dt^3 + e_t$.
- **Exponential model:** The equation of exponential model is Xt = a [Exp (bt)] + et.
- **Growth Model:** The equation of growth model is given by (Xt) = $\exp(b_0+b_1t)+ e_t$

Time series data

A time series is a series of observations which are ordered in time. Time series forecasting is used to predict future values based on previously observed values. It consists of three basic model forms: (1) the Moving Average model MA (q), in which q is the order of the moving average; (2) an Auto Regressive model AR (p), in which p is the order of the auto regression; and (3) the Auto Regression Moving Average model ARMA (p,q).

Box–Jenkins models

It is that methodology which assess the present value of the series is any way related with its past values. Box – Jenkins (1970) analysis is a mathematical method of identifying, estimating, fitting, checking, and using integrated autoregressive, moving average (ARIMA) time series models. The method is appropriate for time series of medium to long length (at least 30 observations). It is used for forecasting which is technically known as the ARIMA methodology.

Autoregressive Integrated Moving Average Model (ARIMA)

ARIMA models are the most general class of models for forecasting a time series which can be made stationary by transformation or differencing. In fact, the easiest way for ARIMA models is as fine-tuned versions of random walk and random trend models: the fine-tuning consists of adding lags of the differenced series or lags of the forecast errors to the prediction equation, as needed to remove any last traces of autocorrelation from the forecast errors. Lags of the differenced series appearing in the forecasting equation are called "auto-regressive" (AR) terms, lags of the forecast errors is defined as "moving average" (MA) and a time series which needs to be differenced to be made stationary is said to be an "integrated" which is a stationary series. A non-seasonal ARIMA model can be classified as an "ARIMA" i.e. p,d,q model, where:

- p is the number of autoregressive terms,
- d is the number of non-seasonal differences, and
- q is the number of lagged forecast errors for prediction.

ARIMA in general form is as follows

$\Delta^d Z_t = c + (\varphi_1 \Delta^d Z_{t-1} + \ldots + \varphi_p \Delta^d Z_{t-p}) - (\theta_1 e_{t-1} + \ldots + \theta_q e_{t-q}) + e_t$

Where Δ denotes differences operator like
$\Delta Z_t = Z_t - Z_{t-1}$ (data form of first order differentiation)
$\Delta^2 Z_{t-1} = \Delta Z_t - \Delta Z_{t-1}$ (data form of first order differentiation)
Here, $Z_{t-1} \ldots Z_{t-p}$ are values of past series with lag 1… p respectively.

ARIMA consists of following steps are as follows

Identification: The problem is to find out the appropriate values of p, d and q. One of the important tools for identification are the autocorrelation function (ACF), the partial autocorrelation function (PACF), and the resulting correlograms, which are simply the plots of ACF and PACFs against the lag length.

Estimation: After identifying the appropriate values of p and q the next step is to estimate the parameters of the autoregressive and moving average terms included in the model. Sometime this calculation can be done by simple least squares.

Diagnostic checking: In this step one can see the whether the chosen model fits the data reasonably well.

Stationarity test: For stationarity test, two test is used i.e. Augmented-Dickey-Fuller (ADF) test and Kwiatkowski–Phillips–Schmidt– Shin (KPSS) tests are used to check whether the data series is stationary or not.

Model Formulation

The whole period under consideration (1951-2022) has been divided into three parts.

a) The model formulation period (1951-2019).
b) Model validation period (2020-2022).

c) Forecasting period up to 2029.

Model selection criteria

Box- Jenkins model best model is selected on the basis of maximum R^2, minimum root mean square error (RMSE), minimum mean absolute percentage error (MAPE), minimum of maximum average percentage error (MaxAPE), minimum of maximum absolute error (MaxAE), and minimum of Normalized BIC. Any model which has fulfilled most of the above criteria is selected. This section provides definitions of the goodness-of-fit measures used in time series modelling.

Diagnostic test of residuals

Jarque Bera (JB) test: The Jarque-Bera Test, a type of Lagrange multiplier test, is a test for normality. The JB test is always non negative.

The JB test is defined as

$$JB = \frac{n-k+1}{6}\left(S^2 + \frac{(C-3)^2}{4}\right)$$

Ljung-Box (LB) statistic: The Ljung- Box test (1978) is a diagnostic tool used to test the lack of fit of a time series model. The test is applied to the residuals of a time series after fitting an ARMA (p,q) model to the data.

It is given by $LB = n\,(n+2)\sum_{k=1}^{m}\frac{\hat{\rho}_k^2}{n-k}) \sim \chi^2 m$

Results

Table-1 displays descriptive statistics with respect to NIA by different sources of irrigation in India from 1951 to 2022. The descriptive statistics demonstrates the mean, maximum and minimum values along with other statistical properties. It is noticed that since 1951 the net irrigated area by canal has increased from 8.30 to 19.22 million hectares, registering a simple growth rate of almost 1.48% per annum with an average of 14.42. In case of tank, the net irrigated area has been increased from 1.59 to 4.78 million hectares registering a simple growth rate of almost -0.81% per annum with an average of 3.15, while in case of wells, the net irrigated area has been increased from 5.98 to 47.33 million hectares, registered with a simple growth rate of almost 9.66% per annum with an average of 23.40. It is observed that in case of total NIA has increased from 20.85 to 77.91 million hectares with an average of 44.83 and registered a simple growth rate of almost 3.75% per annum. It has been observed that the simple growth rate of well source of irrigation is much higher than other sources of irrigation. In case of well and total NIA has registered positive skewness and negative kurtosis, which means that there has been increasing order during early half of the study period and it's for a long time. The standard deviation of total net irrigated area is comparatively higher than well, tank and canal. The lowest standard deviation is observed in case of tank. In case of canal and tank, negative skewness and negative kurtosis has been registered which reveals that there is marginal and consistent in net irrigated area during the later phase of investigation. As per JB test result, it is confirmed that all three data series are normally distributed as canal, well and total NIA are significant but tank are non-significant. It has been concluded that data series of well was better balanced as compared to other sources.

Trend model fitting regarding net irrigated area by different sources in India

Various parametric regression models are applied to all dataset for path of movement of the series from knowing the above per se performance. All estimated parameter and goodness of fit by those models are presented in table-2. For testing parametric models, linear model is fitted best for canal, tank, well and total NIA on the basis of following criteria: significance of parameters at 5% level, maximum R^2 value and minimum value of RMSE. The coefficients of linear model are negatively significant in nature with maximum R^2 value and thereby indicating the tendencies of the series to decline in recent past. This is clearly a major concern towards irrigation sources. In case of canal, linear model is best fitted based on the parameter estimate and goodness of fit, it is found that that in canal, all parameters are significant with the value of R^2 (0.76) and minimum values of RMSE (1.32).While in tank, linear model is significant with the value of R^2 (0.83) and minimum values of RMSE (0.36).It is observed that in well irrigation, linear model is fitted with positively significant with the value of R^2 (0.98) and minimum values of RMSE (2.05) and for total NIA, negatively significant with the value of R^2 (0.99) and minimum values of RMSE (1.66). From figure-1, it seems that net irrigated area by wells among all other sources increases rapidly; due to this reason showing highest simple growth rate (table-2) among all other sources. But in case of tank, the figure-1 revealed that the net irrigated under tank decreased rapidly by the time that's why its simple growth rate was in negative value.

For applying the most time series models, the dataset must be checked of its stationarity. Augmented Dickey Fuller (ADF) test and KPSS test are applied for testing the stationarity. From table-3, it is observed that all the dataset are presented as non-stationary which is insignificant at 5% level of significance as the null hypothesis is not rejected as the p-value is greater than 0.05 that means the null hypothesis is not stationary.

The ACF and PACF graphs of the original series also clearly indicates that none of the series is stationary in nature and first order differencing is sufficient to make these stationary i.e., d=1. As per autocorrelation and partial autocorrelation consideration, the best fitted ARIMA (p, q, q) models are selected for different sources of irrigation in India and compared to each other as depicted in table-4. All the best fitted models are selected based on maximum R^2 value and minimum values of RMSE, MAPE, MAE, MaxAPE, MaxAE. Ljung Box test are done for randomness. It is found that ARIMA (0, 1, 4) are fitted best for canal, for tank ARIMA (1, 0,1) is fitted best and for total NIA ARIMA (1, 0, 3) whereas (1, 0, 2) is selected best fitted model for well source of irrigation due to high R^2 (0.997) and low values of RMSE (0.521), MAPE (1.583) and MAE (0.466). Residuals of this model also satisfied both the normality and randomness assumptions. All the estimated parameters are significant at 5% level of significance. From residual ACF and PACF plots of ARIMA models for all sources of irrigation and its total, it is as shown in figure-2. From this it is also confirmed that the 'good fit' for selected models.

Model validation and forecasting

Among the selected models, ARIMA models fit well for all dataset and finally used to forecast for corresponding variables. There are two kinds of forecast i.e. in sample forecast and out sample forecast. From table-5, it clearly observes that in sample forecast are from 2020 to 2022 and out sample forecast are from 2023 to 2029. In case of in sample forecast, the predicted values are for all dataset are almost close to actual values. The net irrigated area by canal is forecasted as 18.48 million hectares for the year 2027 and 18.74 million hectares for the year 2029. It is found that the net irrigated area by tank will be decreased 1.58 million hectares in the year 2029. In case of well, the net irrigated area will be increased 49.46 million hectares and 50.56 million hectares for the year 2027 and 2029 respectively. It is observed that the total NIA will be increased 78.36 in the year 2029. From figure-3, it is observed that the net irrigated area by canals, wells and total NIA are forecasted as increasing order except tank which is forecasted as decreasing order. The net irrigated area by wells has showed a definite increasing from 1951 to 2029.

Table 1: Descriptive statistics of net irrigated area by different sources of irrigation in India

Sources	Range	Max.	Min.	Mean	SD	Skew.	Kurt.	JB test	SGR%
Canal	10.92	19.22	8.30	14.42	3	-0.55	-1.11	0.02*	1.48
Tank	3.20	4.78	1.59	3.15	0.98	-0.11	-1.14	0.08	-0.81
Well	41.35	47.33	5.98	23.40	13.56	0.31	-1.34	0.04*	9.66
Total	57.06	77.91	20.85	44.83	17.09	0.05	-1.43	0.04*	3.75
Unit = Million Hectares (Mha.)									

Table 2: Fitting of linear and non-linear parametric models different sources of irrigation in India

Sources	Model	Parameter Estimates		Goodness of fit		Significant
		a	b_1	RMSE	R^2	
Canal	Linear	-233.06*	0.13*	1.32	0.76	0.00
Tank	Linear	94.15*	-0.04*	0.36	0.83	0.00
Well	Linear	1231.34*	0.63*	2.05	0.98	0.00
Total	Linear	-1388.66*	0.72*	1.66	0.99	0.00
*Significant at 5% level						

Table 3: ADF test for different sources of irrigation in India

Sources	ADF value	P val	Conclusion	KPSS value	P val	Conclusion
Canal	-1.363	0.833	Non stationary	1.422	0.01	Non stationary
Tank	-3.926	0.118	Non stationary	1.510	0.01	Non stationary
Well	-2.888	0.214	Non stationary	1.700	0.01	Non stationary
Total	-2.999	0.170	Non stationary	1.698	0.01	Non stationary
Unit = Million Hectares (Mha.)						

Table 4: Best fitted ARIMA models for different sources of irrigation in India

Sources	ARIMA Model	Stationary R^2	R^2	RMSE	MAPE	MAE	MaxAPE	MaxAE	NBIC	Ljung-Box	
										$\chi2$	P Val
Canal	0,1,4	0.642	0.964	0.55	2.52	0.47	9.73	1.56	-0.42	15.82	0.26
Tank	1,0,1	0.273	0.939	0.66	6.27	0.49	21.40	0.58	-0.42	16.70	0.21
Well	1,0,3	0.209	0.997	0.52	1.58	0.47	11.45	0.53	0.07	9.12	0.69
Total	1,0,2	0.292	0.995	1.01	1.62	0.66	6.19	3.24	0.82	18.27	0.14
Unit = Million Hectares (Mha.)											

Table 5: Model Validation and Forecasting for different sources of irrigation in India

Year	Canal		Tank		Well		Total	
	A	P	A	P	A	P	A	P
2020	18.54	18.02	2.01	1.91	46.49	45.54	75.47	73.02
2021	18.60	17.90	2.20	1.89	47.32	46.24	77.72	73.59
2022	19.21	17.97	2.20	1.79	47.10	46.75	77.91	73.88
2023	.	17.96	.	1.80	.	47.29	.	74.04
2024	.	18.09	.	1.76	.	47.83	.	74.58
2025	.	18.22	.	1.68	.	48.37	.	75.27
2026	.	18.35	.	1.69	.	48.92	.	76.02
2027	.	18.48	.	1.63	.	49.46	.	76.80
2028	.	18.61	.	1.57	.	50.01	.	77.57
2029	.	18.74	.	1.58	.	50.56	.	78.36
Note: A = Actual net irrigated area. P = Predicted net irrigated area Unit = Million Hectares (Mha.)								

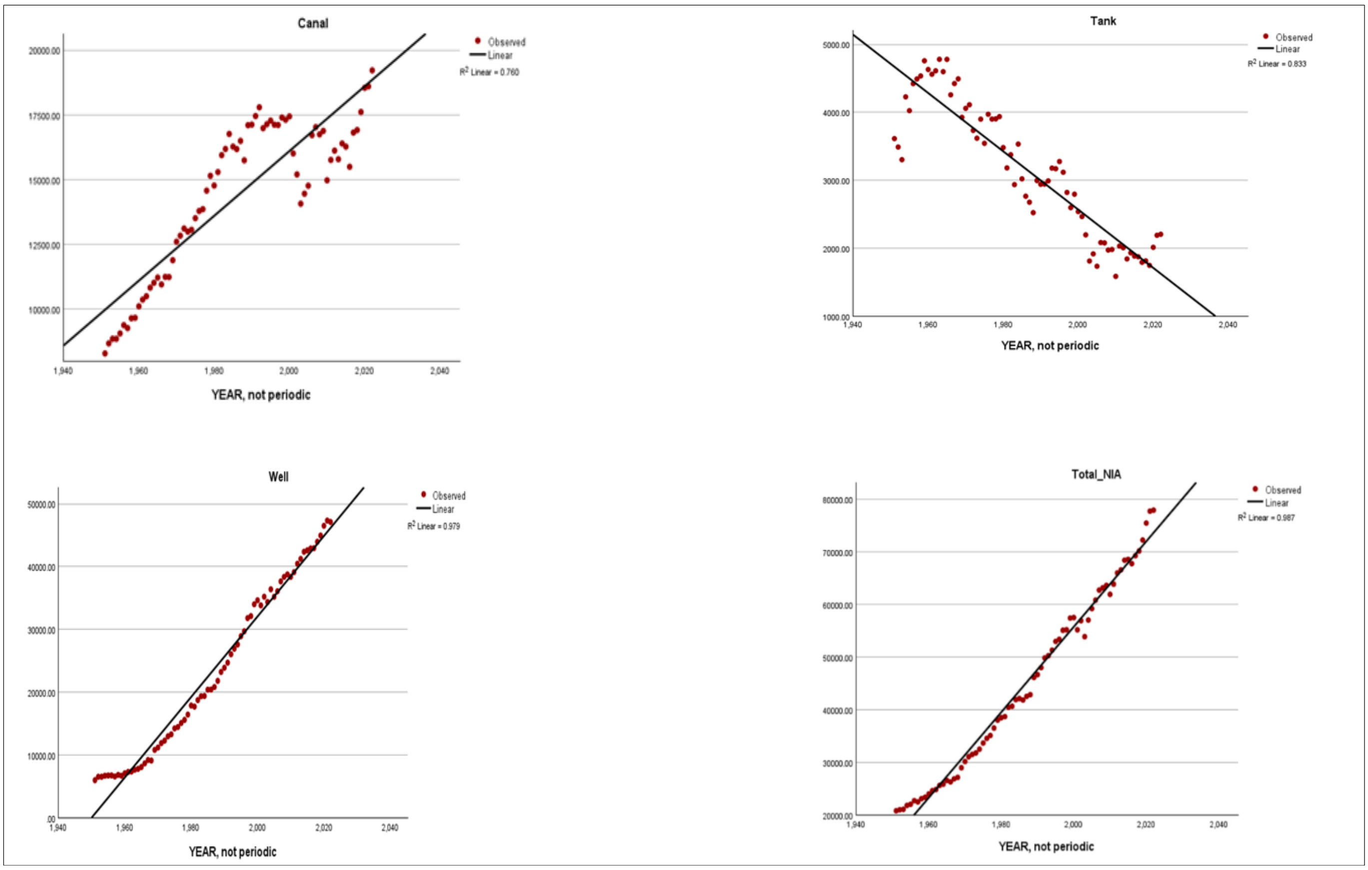

Fig 1: Observed and Expected trend of net irrigated area by different sources of irrigation in India:

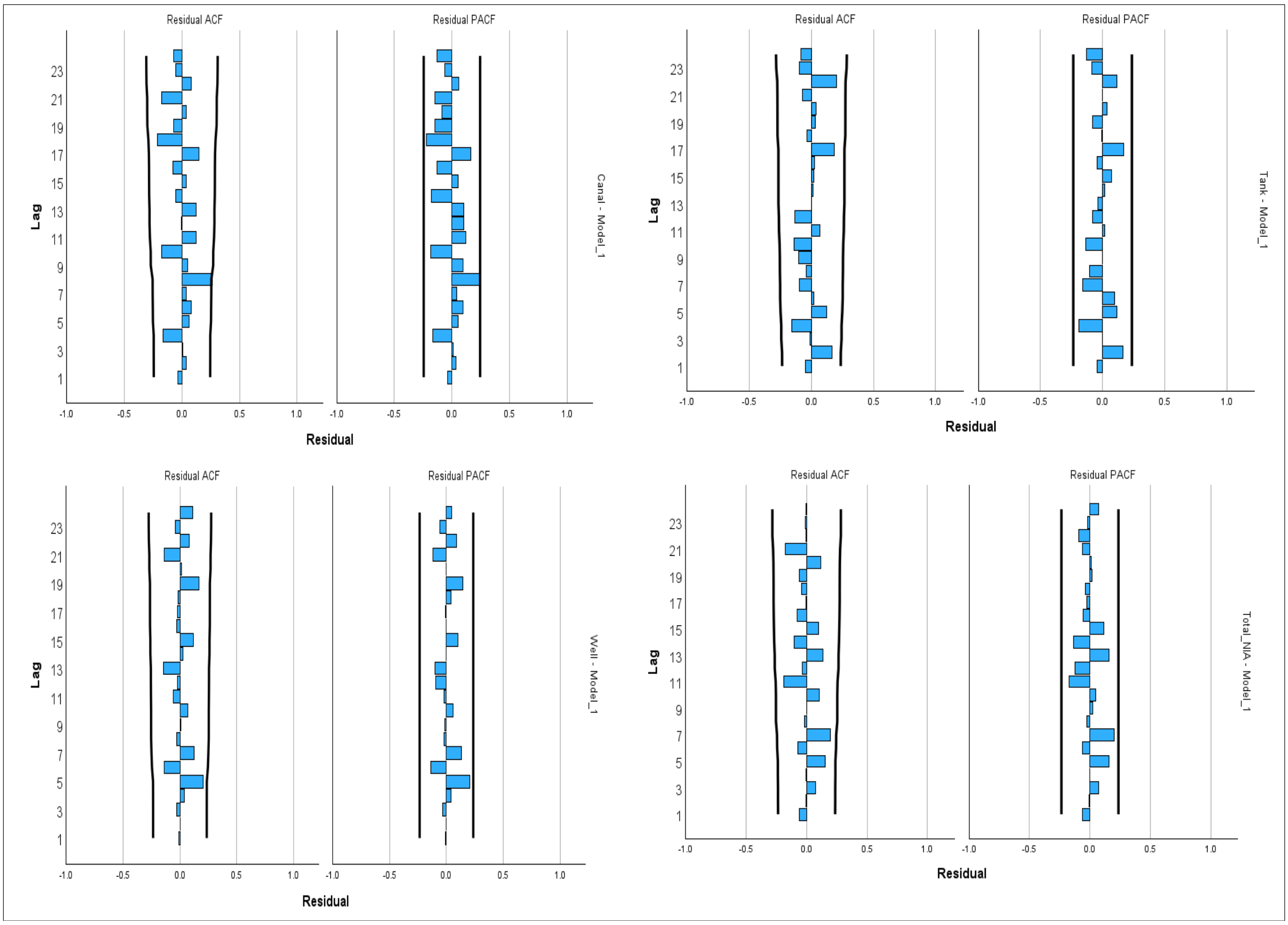

Fig 2: Model residual ACF and PACF plots of best fitted ARIMA models

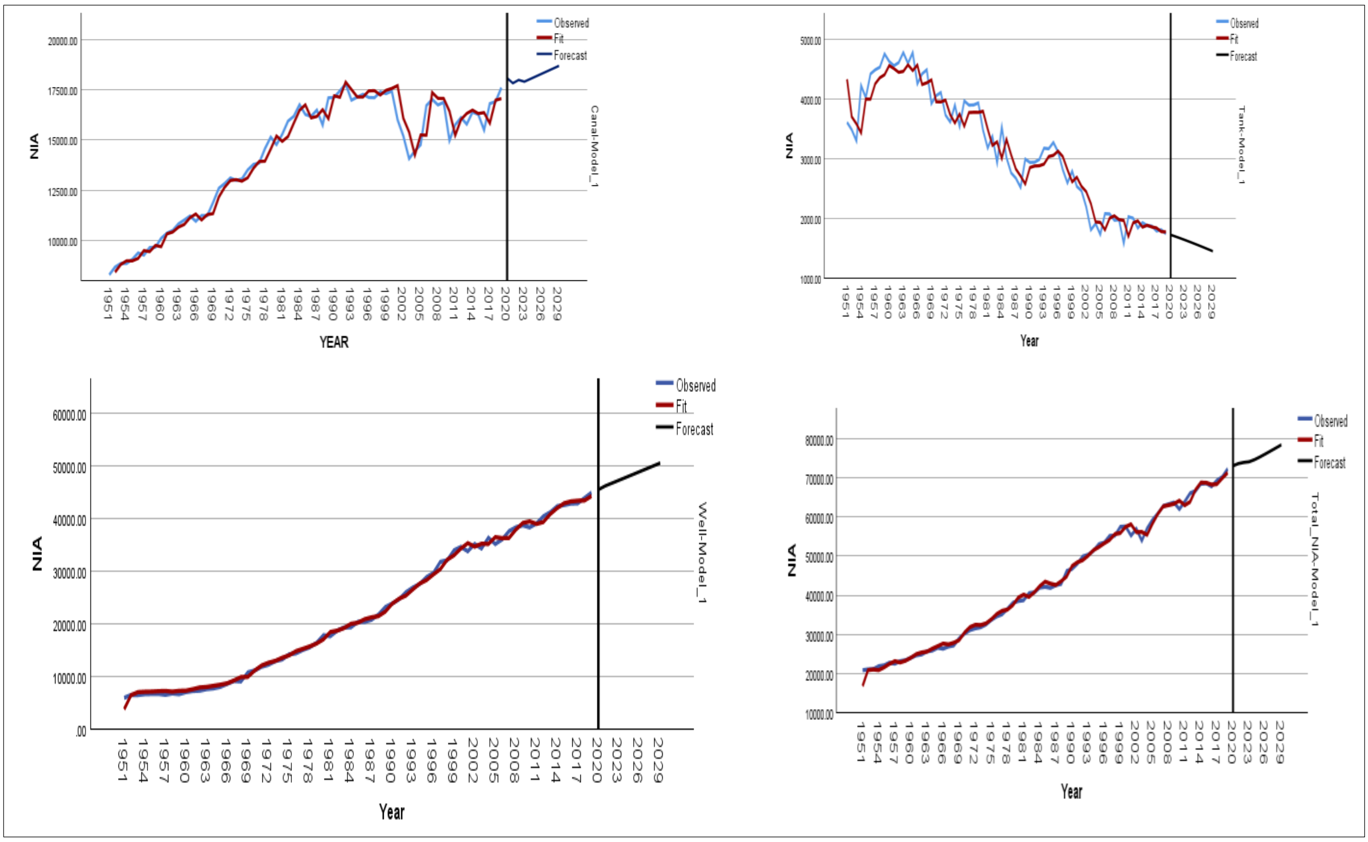

Fig 3: Forecasting of net irrigated area by sources of irrigation in India using best fitted ARIMA models

Discussion and Conclusion

In our study, we examined that the use of well source of irrigation has been increasing since 1951, as compared to other sources of irrigation i.e. canal and tank and becoming an important source of irrigation. There is a positive relationship between agriculture and well (groundwater) source of irrigation. After forecasting the data, it has been observed that in future there would be more demand of well source of irrigation for growing crops. Groundwater based irrigation allowed farmers to cultivate crops throughout the year, even during the dry season, resulting in increasing agricultural productivity and reduced vulnerability to weather fluctuations. Demand of tank and canal source of irrigation has been reduced because of irregularity of rainfall.

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