Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.2546

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **5 (1):** 753-758 (2017)

Research Article

International Journal of Pure & Applied Bioscience

OPEN ACCESS

Development of Autoregressive Time Series Model for Rainwater Harvesting Watershed of Gomti Catchment Sultanpur

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Received: 7.02.2017 | Revised: 18.02.2017 | Accepted: 20.02.2017

ABSTRACT

Snow, rain, hail and sleet are precipitated upon the surface of the earth as meteorological water and may be considered as the original source of all the water supplied. Water accumulates mainly by direct runoff from precipitation i.e., rain or snow melting. The amount of available surface water depends largely upon rainfall. Surface and groundwater are main sources of irrigation water. Three aspects should be considered in appraising water resources which are the quantity, the quality, and the reliability of availability of water. Rainwater, rivers, lakes, streams, ponds and springs are natural sources of water. Dams, wells, tube wells, hand-pumps, canals, etc. are man-made sources of water. The WSM uses river basins as the spatial element of modeling. For each basin, all surface reservoirs, along both the main river and its tributaries, are aggregated into an "equivalent basin reservoir," and all groundwater sources are aggregated into a single groundwater source. Water demands in each basin are estimated separately for agricultural and non-agricultural uses (the latter including industrial and municipal uses) as well as committed flow for the environment. This aggregation assumes full water transfer capacity within each basin; water in one sub basin may be used for other sub basins where needed. Although defined in the model at the basin scale, water demands in the real world are generally located in proximity to the water source, and full water transfer between sub basins and different water supply systems is often constrained by engineering and economic feasibility. To avoid the potential "aggregation fallacy" created by this degree of basin aggregation, the concept of maximum allowable water withdrawal (MAWW), The MAWW for a basin depends on source availability (including surface and groundwater), the physical capacity of water withdrawal for agricultural, domestic and industrial uses, in stream flow requirements for navigation, hydropower generation, recreation, environmental purposes, and water demand. Total water withdrawal in each basin is constrained by its MAWW, which prevents water withdrawal beyond the basin's engineering capacity. With this constraint, the river basin aggregation method should be valid for modeling water supply and demand at the basin scale but this method is mainly used for global modeling. For detailed single basin scale studies, spatial distribution of water supply and demand should be explicitly implemented with any analytical framework. The model is designed to simulate water demand and supply year by year (up to 30 years) for each basin or aggregated basin used in impact water. The model assumes that non-agricultural water demand, including municipal and industrial water demand and committed flow for in stream uses, is satisfied as the first priority, followed by livestock water demand.

Key words: *Basin reservoir, Hydropower, Livestock water demand, Water simulation*

INTRODUCTION

Water is an important constituent of the soil. It fills a part of the soil pore space, serves in the nutrition of plants and microbes and also in the profile, development. It dissolves the salts present in soil, and when in excess runs off with soil as sediment, polluting the streams and lakes. Knowledge of the physical properties of water is, thus, essential for an understanding of its state, functions and behaviour in soil-plant system. When plants are under water stress causes stomata closure, which interrupt in energy dissipation and result in rise of leaf temperature. The leaf or canopy temperature is used as an indicator of plant water stress[3,4]. Kirda[5] showed the water stress tolerance of crop at different growth stages under deficit irrigation scheduling. A study in Turkey was conducted to develop baseline equations, which can be used to quantify crop water stress index (CWSI) for evaluating crop water stress in three winter wheat genotypes and to schedule irrigation and to predict yield. Luquet *et al*[7]., assessed the limitations of water stress indices using directional thermal infrared (TIR) measurements and 3D simulations. Mahan *et al*[8]., determined the temperature and time thresholds for BIOTIC irrigation of peanut. The foregoing discussion reveals that the application of canopy–air temperature difference based approach is appropriate for crop water stress determination as it is a non-destructive, non-contact, reliable, provides considerably precise estimation and represents actual crop water demand. Therefore, present study has been undertaken to establish crop water stresses of wheat grown in sub-humid subtropical region for irrigation scheduling using infrared thermometry.

MATERIALS AND METHODS

Study area

The watershed area is situated between 80 ° 45’ to 81 °50’ longitude east and 26° 22’ to 26 ° 31’ north latitude on Sultanpur to Kumarganj. The shape of watershed is approximately square. The length of watershed about 9.00 Kms East to West and 8.00 Kms North to South. The general slope of watershed is from North to South towards Gomti River and West to East, two Nalas flow in watershed area and they work as drainage line. The watershed area comprises 21 villages. The watershed area is situated on distance of 31 Kms from Sultanpur district headquarters at Sultanpur, Kumarganj road; Infrastructures such as cooperative society, live stockman centre and hospital are available at the radius of 1 to 10 Km, of watershed. The watershed has an area 5478 ha. Out of which 4996.00 ha taken for treatment. In which 3725.00 ha area is under cultivation in which 1018 ha area is irrigated by means of wells, private tube wells and canal, this is about 27.25% of cultivated area.

Water Simulation model

The model is based on a watershed; WSM generates projections of water demand and water supply based on changes in water supply infrastructure and water allocation and management policy. The model is designed to simulate water demand and supply year by year (up to 12 years) for each basin or aggregated basin used in IMPACT-WATER. The model assumes that non-agricultural water demand, including municipal and industrial water demand and committed flow for in stream uses, is satisfied as the first priority, followed by livestock water demand. The effective water supply for irrigation is the residual claimant, simulated by allowing a deficit between water supply and demand. The model is applied for a monthly water balance within one year, and is run through a series of years by solving individual years in sequence and connecting the outputs from year to year. The ending storage of one year is taken as the initial storage of the next, with assumed initial water storage for the base year. For those basins with large storage capacity, inter year flow regulation will be active.

Cite this article: Pandey, S.K., Cutting, N.G. and Srivastva, S., Development of Autoregressive Time Series Model for Rainwater Harvesting Watershed of Gomti Catchment Sultanpur, *Int. J. Pure App. Biosci.* **5(1):** 753-758 (2017). doi: http://dx.doi.org/10.18782/2320-7051.2546

The time series of climate parameters is derived from 12-year historic records for the period 1991–2003. In addition to a basic scenario that overlays the single historic time series over the 1991–2013 projection period, a number of alternative scenarios of hydrologic time series are generated by changing the sequence of the yearly historic records. These scenarios are used in WSM to generate alternative scenarios of water availability for irrigation. The model is run for individual basins but with inter basin and international flows simulated.

Assessment of water resources and demand/use

Under a formal water allocation system, which is designed to harmonise numerous water uses from a single water source or water sources system (such as a watershed and its tributaries), the design of water rights conditions can become very important as a way of managing the multiplicity of uses. The design of these mutually impacting use conditions requires the evaluation of the water sources as a whole and the assessment of the impacts of all water users on the water body.

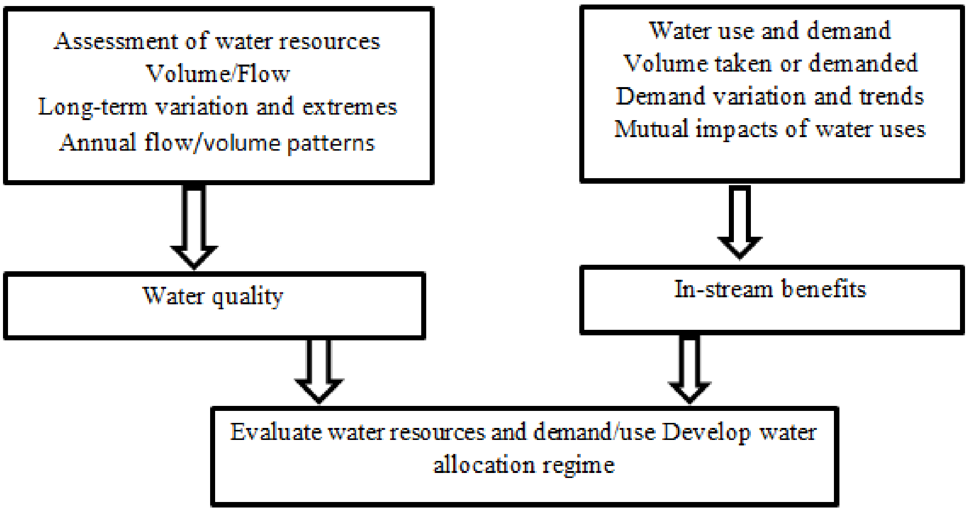

Fig: 1: Process for evaluating impacts of water use

Irrigation Water Demand

Irrigation water demand is assessed as crop water requirement based on hydrologic and agronomic characteristics. Net crop water demand (NCWD) is a basin in a year is calculated based on an empirical crop water requirement function[2]:

$$NCWD = \sum_{cp}\sum_{ct} kc^{cp,ct} \cdot ET_0^{ct} \cdot A^{cp} = \sum_{cp}\sum_{ct} ETM^{ct,cp} \cdot A^{cp} \qquad (1)$$

In which cp is the index of crops, ct is the index of crop growth stages, ET0 is the reference evapotranspiration [L], kc is the crop coefficient, and A is the crop area. Part or all of crop water demand can be satisfied by effective rainfall (PE), which is the rainfall infiltrated into the root zone and available for crop use. Effective rainfall for crop growth can be increased through rainfall harvesting technology. Then net irrigation water demand (NIRWD), with consideration of effective rainfall use and salt leaching requirement, is:

$$NIRWD = \sum_{cp}\sum_{st} \left(kc^{cp,st} \cdot ET_0^{st} - PE^{cp,st}\right) \cdot AI^{cp} \cdot (1 + LR) \qquad (2)$$

In which AI is the irrigated area. LR is the salt leaching factor, which is characterized by soil salinity and irrigation water salinity. Total irrigation water demand represented in water depletion (IRWD) is calculated as:

$$IRWD = NIRWD/BE \qquad (3)$$

In which *BE* is defined as basin efficiency. The concept of basin efficiency was discussed, and various definitions were provided by Molden and Habib[9]. The basin efficiency used in this study measures the ratio of beneficial water depletion (crop evapotranspiration and salt leaching) to the total irrigation water depletion at the river basin scale. Basin efficiency in the base year[10] is calculated as the ratio of the net irrigation water demand (NIRWD, Equation 2) to the total irrigation water depletion estimated from records. Basin efficiency in future years is assumed to increase at a prescribed rate in a basin, depending on water infrastructure investment and water management improvement in the basin. The projection of irrigation water demand depends on the changes of irrigated area and cropping patterns, water use efficiency, and rainfall harvest technology. Global climate change can also affect future irrigation water demand through temperature and precipitation change, but is not considered in the current modeling framework.

Autocorrelation function

The autocorrelation function r_k of the variable Y_t is obtained, Y_{t+k} and taking expectation term by term. The relationship proposed by Kottegoda and Horder[6] for the computation of autocorrelation function of lag K was used which is expressed as:

$$r_k = \frac{\sum_{t=1}^{N-K}(Y_t - \overline{Y})(Y_{t+k} - \overline{Y})}{\sum_{t=1}^{N}(Y_t - \overline{Y})^2}$$

Where,

r_k = Autocorrelation function of time series Y_t at lag k

Y_t = Rainfall and runoff (measured data)

$\overline{Y}$ = Mean of time series Y_t

k = Lag of K time unit

N = Total number of discrete values of time series Y_t

The autocorrelation or serial correlation is a graphical relationship of autocorrelation function r_k with lag k. The autocorrelogram was used for identifying the order of the model for given time series as well as for comparing the sample correlogram with model correlogram. For an independent time series the population correlogram is equal to zero for $K \neq 1$. However, sample of independent time series due to sampling variability have r_k fluctuating around zero but they are not necessarily equal to zero.

Therefore probability limits for the correlogram of an independent series is determined. The following equation was used to determine the 95 per cent probability levels[1].

$$r_k\,(95\%) = \frac{-1 \pm 1.96\sqrt{N-K-1}}{N-K}$$

Where, N = Sample size

Mean Forecast Error

Mean forecast error was calculated to evaluate the performance of auto regressive models fitted to time series of rainfall, runoff. The mean forecast error (MFE) was computed for the annual rainfall and runoff by the following equation.

$$\text{MFE} = \frac{\sum_{i=1}^{n}\chi_c(t) - \sum_{i=1}^{n}\chi_0(t)}{\eta}$$

where,

$\chi_c(t)$ = Computed rainfall and runoff value

$\chi_0(t)$ = Observed rainfall and runoff value

η = Number of observations

Goodness of fit of autoregressive (AR) models

The goodness of fit tests of AR models fitted to annual hydrologic series were accomplished by testing whether the residuals of a dependence model for correlation and whether the order of the fitted model is adequate compared with the order of the dependence model and whether the main statistical characteristics of measured series one preserved. The following tests were performed to test the goodness of fit of autoregressive (AR) models.

RESULT AND DISCUSSION

The WSM calculates effective irrigation water supply in each basin by crop and by period (NIWi, t), over a 30-year time horizon. The results from the WSM are then incorporated into IMPACT for simulating food production, demand, and trade. The autoregressive models up to order 2 were tried in this study. The parameters of AR models up to order 2 were determined through equation. Presented fig: 2.

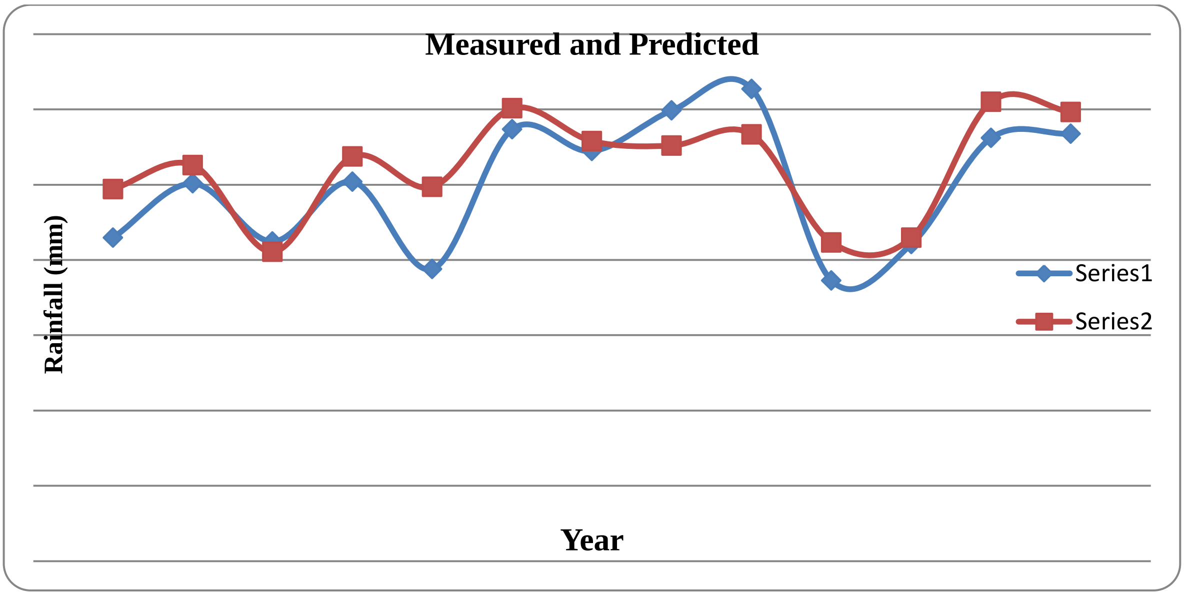

Fig. 2: Comparison of correlogram of measured and predicted series for rainfall

The annual series Y_t for rainfall, runoff and sediment yield was modelled through the autoregressive model. The various steps involved in are identification, estimation of parameters and verification of the model type, order and parameters. The general shape of the auto correlogram and partial auto correlogram are used as a basis for identification. The auto correlogram is a plot of autocorrelation function against lag K and partial autocorrelation is a plot of partial autocorrelation function against lag K. Shows in fig: 3.

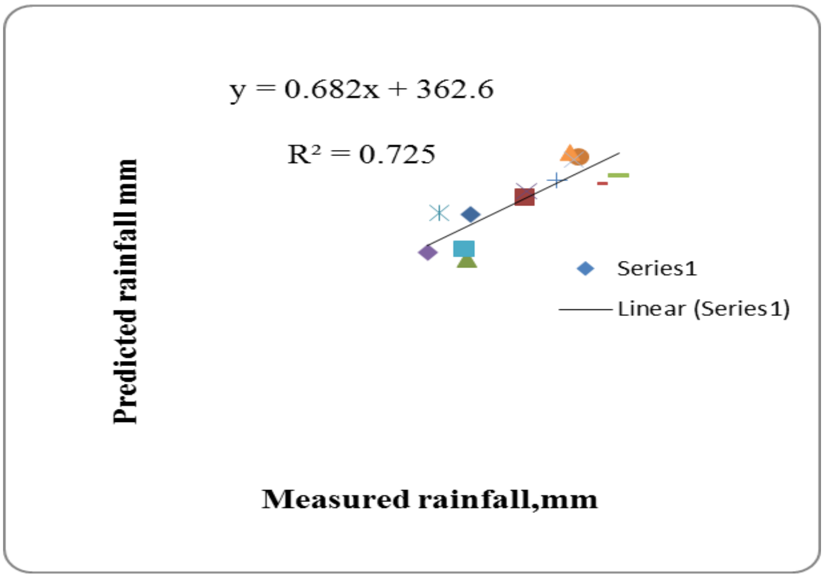

Fig: 3: Comparison of correlogram of measured series for rainfall

CONCLUSION

The purpose of this modeling exercise is to develop a tool for policy analysis in regional and global water resources development and management. As stated, many policy-related water variables are involved in this modeling framework including potential irrigated area and cropping patterns, for both surface and groundwater, water use efficiency, water storage and inter basin transfer facility, rainfall harvest technology (that is, to increase effective rainfall for crops), allocation of water to agricultural and non-agricultural uses, and committed in stream flow requirements. In particular, water supply in irrigated agriculture is integrated with irrigation infrastructure, which permits the estimation of the impact of investment on expansion of potential crop area and improvement of irrigation systems.

Acknowledgement

I wish to place on record my sincere thanks and whole hearted thanks to my guide Dr. Santosh Kumar Srivastava, Associate Professor, Department of Soil Water Land Engineering & Management, Sam Higginbottom Institute of Agriculture, Technology and Sciences, Allahabad under whose supervision this work has been carried out.

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