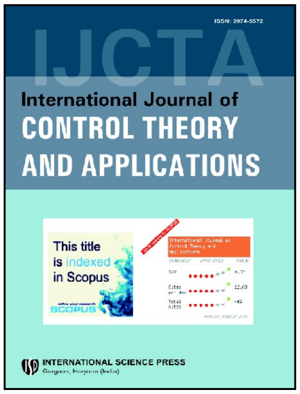

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Time Series Prediction for Water Resource Management in Semi Arid Zone

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Abstract: A proper requirement of the resources must be analyzed and proper measures must be adopted so that they can be availed in the coming future with least complexities. Water being one of the most vital resource has been considered in this paper. Water resources are getting extinct gradually due to excessive usage and limited replenishment generating worries for the future availability. System Approach is applied considering different possibilities incorporating time series analysis, Thornthwaite water balance model and Ingles and Desouza's rainfall runoff model. The variables considered include population, rainfall, evaporation, runoff and irrigation of crops. A comparative study of water usage with respect to groundwater recharge has been done. Efficient utilization of water for various purposes are suggested and benefits are evaluated to suggest the best solution for sustainable water resource management in the region. A case study for nine villages in Chirawa region of district Jhunjhunu in Rajasthan state of India validates the model.

Keywords: Time series analysis, groundwater management, benefit assessment

I. INTRODUCTION

A challenging role has been played by scenario development in identifying the possible circumstances and their impact in future instances [1]. Although future cannot be predicted yet it is required to manage the potential requirements and their fulfillment. This generates the need of scenario development. Scenario forces organizational planners to consider paradigms that challenge their current thinking focusing on long term and short term stories about the future [2]. Its wide application in different areas of research estimates the outcomes of the systems in different conditions. Various methodologies and models have been developed for different areas of research incorporating different sets of parameters or factors which are able to generate the scenarios along with their possible prospects efficiently.

As water resources are getting exploited more in comparison to their replenishment due to various factors around the system, water management is required to be done for the future generations. Rapid economic development coupled with other human activities cause this transition of water resources [3]. Therefore water resource planning can be described as a guiding resource for water management to achieve special goals [4].

Sustainable water resource management requires ideally accurate estimations on per capita consumption and a good understanding of the factors influencing the consumption [5]. Insufficient water resources with respect to demands from different agents may cause water conflicts [6]. Balancing human demands for water with environmental requirements to maintain functioning ecosystems requires the quantification of ecological water requirements [7]. Various applications of scenario planning with respect to three modes of water, i.e. precipitation, surface and groundwater have been incorporated. A watershed, a groundwater or a river basin can be focused for development planning and management [8]. Water resource planners have learned to plan, design, build and operate structures that increase the benefits people can obtain from the water resources [9]. This paper is focused on the Business As Usual (BAU) scenario development with respect to the water management considering different sets of parameters like precipitation, population, irrigation etc.

1.1. Water Management

Preserving water as one of the most important resources is required for the future generations for a sustainable life on the planet. Underground aquifers (groundwater), meteorological rainfall (precipitation) and river flows (surface water) provide water for various purposes of mankind which are getting scarce in their potential due to their excessive usage and limited replenishment, climate change, increasing demands and changing land use scenarios [10]. The pavement of the land by urban infrastructures generates more run off instead of storage due to percolation inside the soil. Urban planning and development is suggested based upon the microclimatic conditions which is used to plan the further development [11]. Increase in temperature is causing rise in evaporation. This may evolve the condition of drought due to multiple climatological and hydrological parameters [12, 13]. Parameters and their effects on the water resources which are causing its extinction are required to be identified.

II. METHODOLOGY

Data related to various factors like social, environmental, technical, economic etc. for the previous years is collected. Future year values of such data are predicted using time series analysis defined by equation (1) [14].

$$Y_t = S_t * I_t * T_t$$

where S, I and T are seasonality, irregularity and trend respectively, being the inherent property of any sequence of historical data, tends to predict the future values Y after time t of various factors, in order to find the severity of the situation so as to suggest alternatives to deal with the problems that may arise. Here the time horizon up to year 2025 has been considered for prediction. All data used for prediction ranges from year 2007 to 2014. Predicted values are validated with data of 2015 to judge the accuracy of prediction.

A comparative study between demand and groundwater recharge is conducted using the predicted data for year 2025 to derive the scarcity of water. Total water demand is evaluated based upon the population and crop water requirement. Groundwater recharge is evaluated as the difference between total inflow and sum of total evaporation and total runoff, although it may also happen due to the region outside the boundaries. Total inflow, total evaporation and total runoff is the product of catchment area into rainfall, potential evapotranspiration (PET) and runoff respectively. PET has been evaluated using Thornthwaite model presented by Equation (2) [11].

$$P_e = 1.6d\left(\frac{10T}{I}\right)^a \tag{2}$$

where, T is the monthly average temperature, d is a correction factor that accounts for the length of each month obtained by dividing the number of days in a month by 30, I is the total heating index in a year such that $I = \Sigma_{i=1}^{12} i$ and i is the monthly average heating index such that $i = (T_m / 5)^{1.514}$, the value of a corresponds to the expression

$a = 0.49239 + 1.792 * 10^{-2} I - 7.71 * 10^{-5} I^2 + 6.75 * 10^{-7} I^3$. Runoff is calculated using the Inglis and De Souza's method [15] presented by Equation (3) and Equation (4).

$$\text{For hilly area, } R = 0.85 \ P - 30.5 \tag{3}$$

$$\text{For plains, } R = (P - 17.8)\, P / 254 \tag{4}$$

where R and P are runoff and precipitation respectively, both expressed in cm. Later scarcity of water is evaluated as the difference between total demand and total recharge which is required to be compensated by certain water conservation methods.

Various alternatives comprising of water conservation methods and replenishment of the ground water table are suggested. The best solution among the suggested solutions is evaluated in terms of benefits obtained. This required the combination of various alternatives in terms of water saving. The alternative having relatively higher benefits is selected as the optimized solution to deal with the problem of water scarcity.

III. CASE STUDY

A region comprising of nine villages in Chirawa tehsil of Jhunjhunu district in the state of Rajasthan in India has been considered to plan the BAU scenario in future with respect to the ground water utilization and replenishment. Name of the villages are Narhar, Ardawata, Gidaniya, Swamisei, Lakhu, Gothri Lamba, Gothri, Kidwana and Nuniya Gothra. These villages fall under the semi-arid zone of the region. The situation of project area in Chirawa Block has been declared as 'DARK ZONE" due to over exploitation of ground water and restricted for new irrigation wells and increasing depth of existing wells. The cause of ground water depletion and pollution are rooted in population growth, economic expansion, and decline in ground water recharge and over abstraction caused by the rapid increase in the number of wells, tube wells and progress in pumping technology.

Data related to population, rainfall, temperature and crops have been collected from the region. Total catchment area of the region is 5086629 square meters, obtained using hydrology tool of ArcGIS 10.1 applied under its boundary. The Digital elevation model (DEM) data for the region has been taken from USGS Earth Explorer. Fill, flow direction, flow accumulation, pour point selection and watershed area identification are the successive steps followed in ArcGIS 10.1 to obtain catchment area. The boundary of the villages are obtained from village boundary database provided by Survey of India. Varying statistics of rainfall, temperature and population are shown from Table 1 and Table 2.

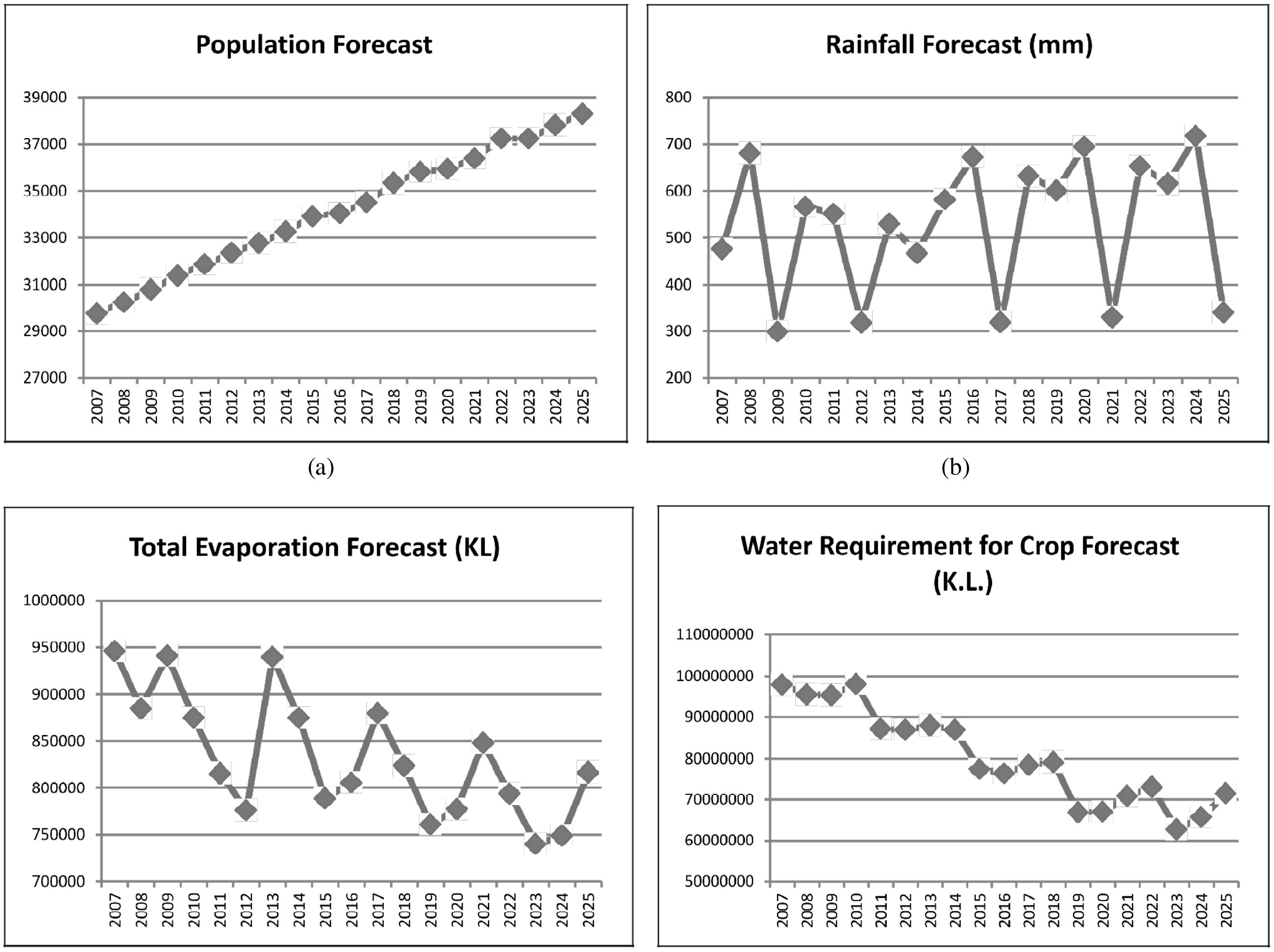
Table 1
Rainfall and average temperature in the region from year 2007 to 2014

	Rainfall (mm)								*Average Temperature (R °C)*							
Month/Year	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*
January	0	0	0	4	0	0	19	0	13.54	13.61	14.62	11.90	11.40	12.50	12.50	13.00
February	74	0	1	10	42	0	29	34	17.96	17.59	17.95	15.95	16.75	14.80	16.40	15.80
March	33	0	15	4	6	0	0	40	20.91	27.62	23.55	22.10	22.80	22.35	23.15	21.25
April	20	31	0	0	0	16	10	10	30.78	30.32	28.08	29.20	27.90	27.95	28.30	27.65
May	43	78	25	0	45	11	16	21	32.98	30.39	33.57	32.50	34.20	32.70	33.90	31.35
June	68	114	41	21	48	3	39	81	34.14	30.86	33.00	34.20	28.80	23.15	34.55	33.95
July	62	87	136	84	45	68	138	67	31.76	31.23	31.68	31.10	31.10	33.00	32.10	32.65
August	26	233	35	203	182	177	134	155	30.55	29.27	31.30	29.85	29.40	29.40	29.55	30.75
September	150	138	44	186	183	39	117	33	29.13	28.26	28.97	29.65	28.35	30.60	29.70	29.65
October	0	0	0	10	0	0	15	26	26.06	28.23	25.92	26.05	25.90	25.65	26.90	25.40
November	0	0	2	20	0	0	12	0	22.56	21.87	21.50	19.84	22.10	20.20	19.75	21.25
December	0	0	0	24	0	4	0	0	14.47	15.36	18.46	13.30	14.75	15.05	15.95	14.45

Table 2
Population in the region from year 2007 to 2014

2007	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*
29751	30241	30788	31387	31859	32346	32766	33253

Later the prediction of data has been carried out using time series analyses involving moving average method of extrapolation defined by Equation (1). Results of predictions for population, rainfall, evaporation and water requirements for irrigating crops are presented in Figure 1(a-d) over y-axis with respect to years over x-axis.


Population Forecast

(a)

Rainfall Forecast (mm)

(b)

Total Evaporation Forecast (KL)

(c)

Water Requirement for Crop Forecast (K.L.)

(d)

Figure 1: (a) Forecast graph for population (b) Forecast graph for rainfall (c) Forecast graph for evaporation (d) Forecast graph for crop water requirement

Water requirement for population is estimated by an average value of 40 liters per day per head given by IS code, for communities with population up to 20000. It has been assumed that for sustainable system an average water requirement for crops and maximum water requirement for human use must be fulfilled. Recharge of groundwater is declining which must compensate the total water usage to make the system sustainable. Average water requirement of 83327128 KL for any year is not balanced by recharge of 801668 KL in year 2025. 82525460 KL of water must be reimbursed by certain water conservation methods.

Certain water conservation methods are suggested like reduction of evaporation losses using continuous floating covers, modular systems, shade structures and chemical covers. Recharge of water table using rain water harvesting such as creating percolation wells for surface runoff and village tanks for roof top runoff. Alternative crops can be produced which requires lesser water as compared to the other crops being practiced. Production of cash crops which gives better return and efficient methods of irrigation like sprinkler and drip irrigation. Benefits with respect to various alternatives have been analyzed to obtain the best set of alternatives to be adopted.

It has been identified that evaporation can be reduced by 90%, 90%, 75% and 30% by using continuous floating covers, modular systems, shade structures and chemical covers respectively [16]. Rain water harvesting can save about 30% of drinking and cooking water [17] which is about 8 liters per day per head [18]. Alternative food crops can save about 30% of water in our study region. Sprinkler [19] and drip irrigation [20] can save about 40% and 70% of water respectively. Therefore the benefit of any system can be generalized as:

Water saved from evaporation + water saved using rain water harvesting + water saved using efficient irrigation

Considering the year 2025 benefits evaluated are presented in Table 3. Twelve possible combinations of the solutions with their net benefits are presented in Table 4.

Table 3
Expected saving of water using different measures in year 2025

Water saved from evaporation (K.L.)	*Continuous Floating Covers*	*Modular Systems*	*Shade Structures*	*Chemical Covers*
	735033	735033	612527	245010
Water saved using rain water harvesting(K.L.)		33972		
Water saved using efficient irrigation (K.L.)	Alternate food crop **24828280**	Sprinkle Irrigation **33104373**	Drip Irrigation **57932652**	

Table 4
Total water which can be saved using the twelve possible combinations in year 2025

S. No.	*Combinations of Alternatives*	*Water saved (KL)*
1	Continuous floating covers, Rain water harvesting, Alternate food crop	25597285
2	Continuous floating covers, Rain water harvesting, Sprinkle irrigation	33873378
3	Continuous floating covers, Rain water harvesting, Drip irrigation	58701657
4	Modular systems, Rain water harvesting, Alternate food crop	25597285
5	Modular systems, Rain water harvesting, Sprinkle irrigation	33873378
6	Modular systems, Rain water harvesting, Drip irrigation	58701657
7	Shade structures, Rain water harvesting, Alternate food crop	25474779
8	Shade structures, Rain water harvesting, Sprinkle irrigation	33750872
9	Shade structures, Rain water harvesting, Drip irrigation	58579151
10	Chemical covers, Rain water harvesting, Alternate food crop	25107262
11	Chemical covers, Rain water harvesting, Sprinkle irrigation	33383355
12	**Chemical covers, Rain water harvesting, Drip irrigation**	**58211634**

IV. RESULTS AND DISCUSSION

Forecasts evaluated with respect to various variables like population, rainfall, potential evaporation and water requirement for crops are validated with their actual data obtained for year 2015. Errors of 1.3 %, 5%, 13% and 22% are found in the predicted data with respect to actual data for population, water requirement for crops, evaporation and rainfall respectively. Error occurred is directly proportional to the degree of uncertainty of the type of data. Population and water requirement for the crops are more or less in control of the human beings while evaporation and rainfall are the natural processes. Based upon these forecasts water requirement in the region for year 2025 can be made sustainable using the best alternative of implementing continuous floating covers or modular systems to reduce evaporation, rainwater harvesting for household purposes and drip method of irrigation for cultivating crops.

V. CONCLUSION

Prediction of the water accessibility for year 2025 in the semi-arid region of selected villages in Chirawa block reflects downfall in groundwater recharge and rise in demand. To make the system sustainable in the region, it is required to adopt efficient methods for crop production and water conservation. The benefit in terms of total water saved suggests implementing continuous floating covers or modular systems to save water from evaporation, to create rain water harvesting structures at homes for household purposes and to apply drip method of irrigation in crops. About half of the water requirement can be compensated by implementing the solution identified.

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