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Water Resource Model of Krishna River Basin

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ABSTRACT: The model considers the integral land phase of the hydrologic cycles. It is capable of representing anthropological impacts such as changes in land and water use, environmental flows, impacts of water storage and depletion through withdrawals for various water uses and addition through returns/ inter-basin water transfers. The Krishna analytical Water Resources Assessment model is used to analysis on strategic development and management of water resources in North Karnataka. It also analyze scenarios to evaluate various future policy options for development and management of water and related land resources.

Keywords: hydraulic cycles, anthropological, environmental, scenarios, policy, management.

I. INTRODUCTION

The river Krishna is an Inter-State river in Southern India. It is the second largest river in Peninsular India, rises in the Western Ghats at an altitude of 1337 m. near Mahabaleshwar in Maharashtra State. It flows across the whole width of the peninsula, from west to east, for a length of about 1400 km, through Maharashtra, Karnataka and Andhra Pradesh.

The entire catchment area of Krishna basin is 2,58,948 sq km. including the other basin states, and their catchment. The principal tributaries of Krishna in Karnataka are Ghataprabha, Malaprabha, Bhima and Tungabhadra. All these rivers except the Malaprabha River having their catchment area both in Karnataka and Maharastra.

II. OBJECTIVE OF MODEL

The basic objectives of the north KAWRA model for North Karnataka are:

1. To understand the water balance available at basin and sub-basin scale in the present scenario.
2. To consider the impact of changing land and water use on the resources, taking into account Inter-dependencies between different elements of the land phase of the hydrological cycle.
3. To quantify the water uses for agriculture, domestic, industry and environment and integrate sectoral water uses.
4. To maximize benefits by formulating various factual conditions at basin and sub-basin scale.
5. To analyze scenarios to evaluate various future policy options for development and management of water and related land resources. The secondary data collected from different government sources and research organizations in North Karnataka have been used for the analysis.

III. METHODOLOGY

The methodology has been evolved considering various existing methods with some modifications. Basin-wise Krishna Analytical Water Resources Assessment (KAWRA) model has been developed to provide an integrated computational framework for a basin and/ or sub-basin level assessment of water resources. The model considers the integral land phase of the hydrologic cycles. It is capable of representing anthropological impacts such as changes in land and water use, environmental flows, impacts of water storage and depletion through withdrawals for various water uses and addition through returns/ inter-basin water transfers.

This research is conducted by gathering data from various sources such as existing literature, various websites, interviews of relevant people & the case study. Data collected for this research, it sources and the method of data collection & the data sampling frame is as follows:

A. Primary Data

Data that has been collected from first-hand-experience is known as primary data. The primary data is initial level data are collected in this stage. Primary data has not been published yet and is more reliable, authentic and objective. Primary data has not been changed or altered by human beings; therefore its validity is greater than secondary data. The primary data is collected from following sources. The methods adopted to collect primary data are direct in depth interviews.

B. Secondary Data

The secondary data is collected from following sources. Various published & unpublished sources will be used for the data collection.

The Rainfall, discharge, evapo-transpitation, groundwater, population, irrigation and industrial data were collected from different sources for the years 1990-2015 for each sub-basin of the study area and then analysed using KAWRA. The sources of secondary data are used to find out the available water resources at basins and sub-basin scale in Krishna river system as shown in Table 1.

IV. FRAMEWORK OF KAWRA MODEL

The KAWRA Model as shown in Table 2 made up with following five Sub- Models MSF, MAS, MDS and MES.

Table 1: Source of Secondary Data.

Sr. No.	Data Types	Sources
1.	Rainfall	http://www.indiawaterportal.org http://www.imd.gov.in
2.	Ground water level	http://cgwb.gov.in
3.	Ground water Uses	http://karnatakahydrologyproject.org/ground_water/district_table.html http://wrdkarnataka.nic.in/ground_water_resources.html http://cgwrd.in/water-resource/ground-water-status.html
4.	Discharge	http://www.cwc.nic.in
5.	Population	http://censusindia.gov.in
6.	Meteorological data	http://www.indiawaterportal.org
7.	Daily TRMM Rainfall 3B42 (V7)	http://trmm.gsfc.nasa.gov
8.	Soil map & Land use land cover(2006-2014)	http://www.nrsc.gov.in
9.	Agriculture	http://www.karnataka.org
10.	Land use land cover	http://landcover.usgs.gov

Table 2: Kawra Model.

KAWRA MODEL	
Model for Supply and Demand (MSF) • Estimate of water resources at basin and sub-basin • Develop relationships among various demand and supply	**Model for Agricultural Sector (MAS)** • Water availability for agriculture • Water requirement for agriculture • Maximizing the benefit from agriculture
Model for Domestic Sector (MFS) • Water availability for domestic purpose • Water requirement for domestic purposes • Maximizing the benefit from domestic uses	**Model for Environmental Sector (MES)** • Water availability for Environment as E-flows • Maximizing the benefit from Environmental Sector
Model for Industrial Sector (MIS) • Water availability for Industries and Maximizing the benefit from industries	

The architecture and objects of these subs- modules are as following:

1. Model for Supply and demand (MSF). The model estimate and develop relationships among various demand and supply of water resources at basin and sub-basin scale. The available are rainfall, surface water and groundwater resources, various demands and their best management by maximizing the benefits in temporal and spatial domain. The objects of this sub- modules are:

a. To estimate of water resources at basin and sub-basin.

b. To develop relationships among various demand and supply.

2. Model for Agricultural Sector (MAS). The objectives of MAS are to:

a. Water availability for agriculture

b. Water requirement for agriculture

c. Maximizing the benefit from agriculture

3. Model for Domestic Sector (MFS). The objectives of MFS are to:

a. Water availability for domestic purpose

b. Water requirement for domestic purposes

c. Maximizing the benefit from domestic uses

4. Model for Environmental Sector (MES). The objectives of MES are to:

a. Water availability for Environment as E-flows

b. Maximizing the benefit from Environmental Sector

5. Model for Industrial Sector (MIS). The objectives of MIS are to:

a. Water availability for Industries

b. Maximizing the benefit from industries

V. MODEL FOR SUPPLY AND DEMAND (MSF)

This MSF includes the approaches used to estimate and develop relationships among various demand and supply of water resources at basin and sub-basin scale. In general, the inflow (supply) and outflow (demand) relationship can be understood by a very simple equation:

$$Inflow - Outflow = Supply - Demand = Storage \qquad (1)$$

Or

$$\frac{Inflow}{time} - \frac{Outflow}{time} = \frac{Supply}{time} - \frac{Demand}{time} = \frac{Storage}{time} \qquad (2)$$

For surface water and ground water balance analysis, the above relationships can be further elaborated by considering physical parameters and basin characteristics. The equation can be written as:

$$\sum_{t=1}^{n}[P_{basin} + Q_{in\_us} + Q_{nps\_ssf} + Q_{nps\_irf} + Q_{ps\_indf} + Q_{ps\_munf} + Q_{ab} + Q_{gw}]_t - \sum_{t-1}^{n}[I_{abs} + I_{fil} + E_{tp} + D_{ir} + D_{ur} + D_{rr} + D_{id} + D_{soil}]_t = \sum_{t=1}^{n}(Q_{out\_ds})_t + \frac{Q_s}{t} \qquad (3)$$

P_{basin} = Rainfall of the basin in m^3,

Q_{in_us} = Inflow discharge at upstream in m^3,

Q_{nps_ssf} = Inflow discharge from sub-surface flow in m^3,

Q_{nps_irf} = Inflow discharge as irrigation return flow in m^3,

Q_{ps_indf}= Inflow discharge from Industries in m^3,

Q_{ps_munf} = Inflow discharge from Municipality in m^3,

Q_{ab} = Inflow discharge from other basins in m^3,

Q_{gw} = Inflow discharge from groundwater in m^3,

Q_s= Storage of discharge in reservoir in m^3,

I_{abs} = Initial abstraction losses in m^3,

I_{fil} = Infiltration losses in m^3,

E_{tp} = Potential Evapo-transpiration losses in m^3,

D_{ir} = Demand for irrigation in m^3,

D_{ur} = Demand for population and livestock in urban area in m^3,

D_{rr} = Demand for population and livestock in Urban area in m^3,

D_{id} = Demand for industries in m^3,

D_{soil} = Demand for soil's field capacity in m^3,

Q_{out_ds} = Outflow discharge at downstream in m^3,

t = Time in days.

The equation (3) of MFS model shown above clearly states that the outflow discharge at any river system is the surplus water available in the river after satisfying all the demands of the basin area. The equation (3) can be successfully used in smaller basins for assessment of available rainfall, surface water and groundwater resources, various demands and their best management by maximizing the benefits in temporal and spatial domain. The ground water in conjunction with surface water and rainfall can be used at various places for effective integrated water resources management.

It is now essential to estimate the water demand and supply for different sectors, namely, agriculture, domestic, industry and environment. It is also important to maximize the benefit, by making optimum use of rainfall, surface runoff and groundwater at each basin and sub-basin and estimating their cost-benefit ratio.

VI. MODEL FOR AGRITURAL SECTOR

1. Water availability for agriculture. The gross availability for agricultural sector is estimated using the relationships for rain-fed based agriculture and for irrigation based agriculture.

For rain-fed based agriculture:

$$WA_{agrf} = \int_{t=1}^{n}(P_{basin} + C_1 * Q_{gw} + Q_{nps_{ssf}} + Q_{nps\_ssf} + Q_{nps\_irf})_t \qquad (4)$$

For irrigation based agriculture:

$$WA_{agir} = \int_{t=1}^{n}(P_{basin} + C_2 Q_{in_{us}} + C_3\, Q_{ob} + C_4 Q_{gw} + Q_s + Q_{nps\_ssf} + Q_{nps\_irf})_t \qquad (5)$$

WA_{agrf}= Water supply required for rain-fed regions for agriculture in m^3,

WA_{agir}= Water supply required for irrigation regions for agriculture in m^3,

t = Time in days,

C_1, C_2, C_3 ***and*** C_4 **=** Coefficients for different variables.

2. Water requirement for agriculture. It is to be noted that, for the supply of water in rain-fed or irrigation based agricultural areas we need to estimate the crop water requirement for different crops at different time periods. Crop water requirement depends on several factors, including cropping pattern, crop-growth periods, crop coefficients (Kc), potential evapotranspiration (Etp), effective rainfall and percolation in paddy areas. Crop water requirement (Cwr) of the paddy crop is estimated as (Amarsinghe *et al.*, 2004):

$$WR_{paddy} = A_p * [\sum_{i=1}^{m}\{\sum_{j=1}^{n}(K_{p(i,j)} * E_{tp(i,j)} - R_{e(i,j)} - \sum_{j}^{n} P_{p(i,j)}\}] \qquad (6)$$

And the crop water requirement of other crop is estimated as:

$$WR_{other} = A_p * [\sum_{i=1}^{m}\{\sum_{j=1}^{n}(K_{o(i,j)} * E_{to(i,j)} - \sum_{j}^{n} P_{o(i,j)}\}] \qquad (7)$$

WR_{paddy}= Crop water requirement for paddy in m^3 for i^{th} cell (plot area) and j^{th} time period (days),

WR_{other}=Crop water requirement for other crops in m^3 for i^{th} cell (plot area) and j^{th} time period (days),

$K_{p(i,j)}$= Crop coefficient for paddy for i^{th} cell (plot area) and j^{th} time period (days),

$K_{o(i,j)}$= Crop coefficient for other crops for i^{th} cell (plot area) and j^{th} time period (days),

$E_{tp(i,j)}$= Evapo-transpiration for paddy area in m^3 for i^{th} cell (plot area) and j^{th} time period (days),

$E_{to(i,j)}$= Evapo-transpiration for other cropped area in m^3 for i^{th} cell (plot area) and j^{th} time period (days),

$R_{e(i,j)}$= Rainfall excess in m^3 for i^{th} cell (plot area) and j^{th} time period (days),

$P_{p(i,j)}$= Percolation during paddy crop in m^3 for i^{th} cell (plot area) and j^{th} time period (days),

$P_{o(i,j)}$= Percolation during other crops in m^3 for i^{th} cell (plot area) and j^{th} time period (days).

In fact the efficiency of water supply from canal water and groundwater is required to be included in equations (4) and (5) to obtain the actual water withdrawal for irrigating the agricultural area. The equations (4), (5), (6) and (7) can be balanced and re-written as:

$$WA_{aagrf} = \int_{t=1}^{n}(P_{basin} + C_1 * Q_{gw} + Q_{nps\_ssf} + Q_{nps\_irf})_t * (Eff) = WR_{other} = A_p * [\sum_{i=1}^{m}\{\sum_{j}^{n}(K_{o(i,j)} * E_{to(i,j)}) - \sum_{j=1}^{n} P_{o(i,j)}\}] \qquad (8)$$

and

$$WA_{aagir} = \int_{t=1}^{n}(P_{basin} + C_2 Q_{in\_us} + C_3 Q_{ob} + C_4 Q_{gw} + Q_s + Q_{nps\_ssf} + Q_{nps\_irf})_t * Eff = WR_{paddy} = A_p * [\sum_{i=1}^{m}\{\sum_{j=1}^{n}(K_{p(i,j)} * E_{tp(i,j)} - R_{e(i,j)}) - \sum_{j}^{n} P_{p(i,j)}\}] \qquad (9)$$

WA_{aagir} = Absolute water supply required for rain-fed regions for agriculture in m^3,

WR_{paddy} = Absolute water supply required for irrigation regions for agriculture in m^3,

Eff = Summation of all efficiency for the water supply (rainfall + ground water pumping + irrigation efficiency+ flow from upstream as pumping + flow from other basins).

The Irrigation Efficiency at the basin level, Canal Conveyance Efficiency at the basin level, Watercourse Conveyance Efficiency at the basin level, Field Channel Efficiency at the basin level and Field Application Efficiency at the basin level are essentially required to be incorporated for estimation of the cost for transportation.

3. Maximizing the benefit from agriculture. To maximize the benefit (profit), it is essential to consider the following decision variables (a) allocations of water among water use sectors and crop areas, (b) ground water head (state variable), and (c) hydrological information (rainfall, discharge) of the current year and previous years. The following equations can be derived:

$$MaxAG = \sum_{j=1}^{n}\sum_{i=1}^{m}[(CY_{Kharif(i,j)} * A_{Kharif(i,j)} * INR_{Kharif(i,j)} + CY_{Rabi(i,j)} * A_{Rabi(i,j)} * INR_{Rabi(i,j)}) - (A_{Kharif(i,j)} * INRI_{Kharif(i,j)} + A_{Rabi(i,j)} * INRI_{Rabi(i,j)})] \qquad (10)$$

MaxAG**=** Maximized Agriculture profit (Rs.),

$CY_{kharif(i,j)}$=Crop yield during Kharif for i^{th} cell (plot area) and j^{th} time period (days) (tons/ha) ,

$A_{kharif(i,j)}$= Cropped area of Kharif for i^{th} cell (plot area) and j^{th} time period (days) (ha),

$INR_{kharif(i,j)}$= Cost of the produced crop in Kharif for i^{th} cell (plot area) and j^{th} time period (days) (Rs./tons),

$INRI_{kharif(i,j)}$ = Cost of the seed of the crop, transportation of surface water or pumping of groundwater and other expenses in Kharif for i^{th} cell (plot area) and j^{th} time period (days) (Rs./tons),

$CY_{Rabi(i,j)}$ = Crop yield during Rabi for i^{th} cell (plot area) and j^{th} time period (days) (tons/ha),

$A_{Rabi(i,j)}$ = Cropped area of Rabi for i^{th} cell (plot area) and j^{th} time period (days) (ha),

$INR_{Rabi(i,j)}$= Cost of the produced crop in Rabi for i^{th} cell (plot area) and j^{th} time period (days) (Rs.),

$INRI_{Rabi(i,j)}$= Cost of the seed of the crop, transportation of surface water or pumping of groundwater and other expenses in Rabi for i^{th} cell (plot area) *and* j^{th} time period (days) (Rs./tons).

All the equation used above can be transformed into simple mass balance equations, which have been used in previous studies. However, if the data sets are available in adequate amount, the above equations can be successfully used and different future scenarios can be generated.

VII. ANLYSIS AND DISSCUSSION

In the present work of integrated water resources management analysis has been done for the sub-basins Hiranyakeshi, Bennihalla, Hirehalla, Tas nadi, Combined waters of Mula & Mutha Ghod, Nira, Sina, Combined waters of Tunga & Bhadra, Varad, Hagari(vedavathy), Markandeya and the whole basin. The KAWRA model parameters have been estimated and the runoff at the outlet has been estimated using the equations derived in this chapter. The results obtained for all the sub-basins and for the Krishna basin as a whole are discussed below in chronological order.

Hiranyakeshi sub-basin

Earlier the Thiessen method has been used to obtain the mean rainfall over the Hiranyakeshi sub-basin. The basin receives more than 2000 MCM of rainfall per year (Fig. 1) and its monthly distribution is also very significant which may be used for different purposes (Fig. 1). The available ground water is 177 MCM and utilizable groundwater is 84.94 MCM by considering efficiency and correction coefficient values are 0.8 and 0.6, respectively.

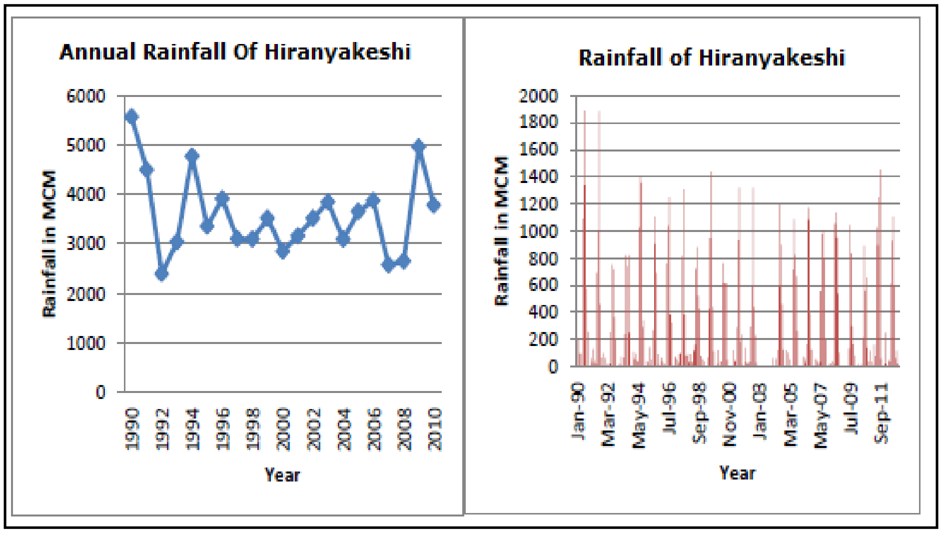

Fig. 1. Mean Annual and Monthly rainfall of Hiranyakeshi Sub-Basin.

The crop water requirement (CWR) is obtained using the equations (6) and (7) as suggested by Amarsinghe *et al*. (2004). The crop coefficient has been observed to vary between 0.4 -1.2 for different stages of the crops.

Fig. 2 illustrates the estimated total Evapo-transpiration and crop water requirement in Hiranyakeshi sub-basin, which is found to be lower than available rainfall.

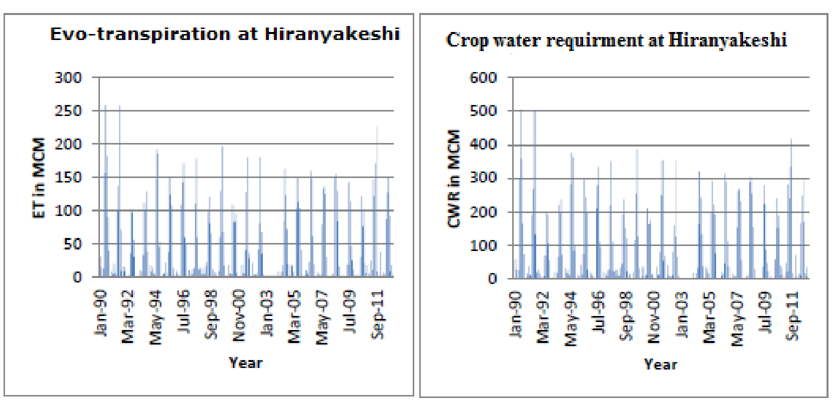

Fig. 2. Evapo-Transpiration and Crop Water Requirement at Hiranyakeshi.

The Evapo-transpiration has been obtained using the following Penman-Montieth equation:

$$ET = \frac{0.408\ast\Delta(R-G)+\gamma\frac{900}{T+273}u(e_s-e_a)}{\Delta+\gamma(1+0.34u)} \quad (11)$$

Where ET= Reference Evapo-transpiration (mm/day), R= net radiation at the crop surface (MJ/m^2/day), G = soil heat flux density (MJ/m^2/day), = slope vapour pressure curve (kPa/ oC), T= mean daily air temperature (oC), u = wind speed (m/sec), es = saturation vapour pressure (kPa), ea = actual vapour pressure (kPa), = psychometric constant (kPa/ oC). Now the KAWRA model parameters are calibrated and validated. The results are obtained for two situations. First only existing agricultural demand has been considered and the estimated outflow runoff at Hiranyakeshi has been compared with the observed runoff values (using equations 6 and 7). In the second step the other existing demands such as domestic, industrial and environmental (4%) have also been considered (using equations 6, 7, 8, 9, 10, and 11) and compared with observed values. The results obtained are given in Fig. 3 for both the conditions. It has been observed that the r^2 values are very high and the calibrated KAWRA model parameters are suitable for generating future scenarios. The values of coefficients c1 to c27 have been varying between 0.6 to 0.9, all the efficiency varies between 0.6 to o.8 and the crop coefficient varied between 0.4 -1.20 for different stages of the crops.

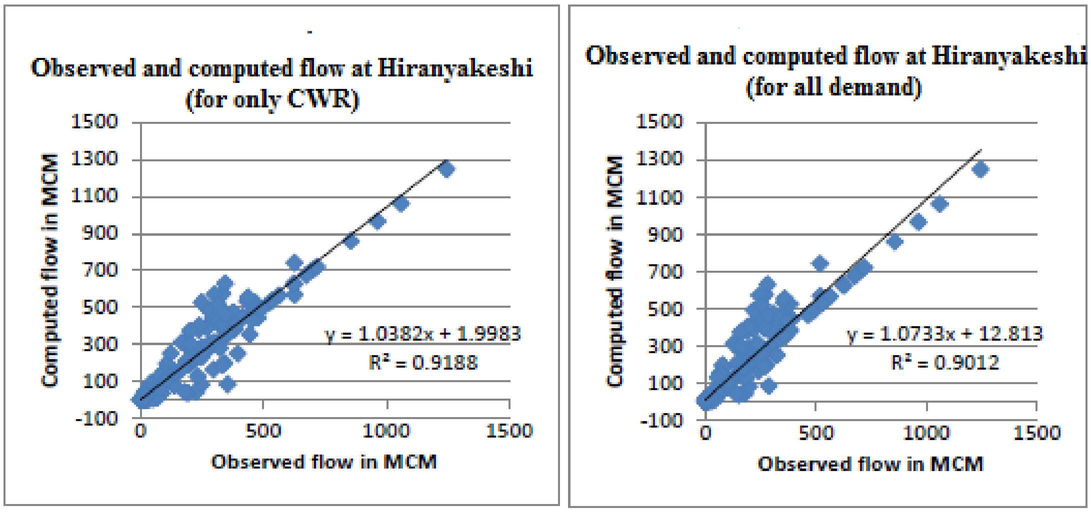

Fig. 3. Comparison of Discharges at the Outlet.

The results obtained clearly indicate that a large amount of water is available and ground use is less than 20% in most of the regions of the Hiranyakeshi sub-basin. It has been observed that the crop water requirement is much below the available rainfall. If the agricultural area is utilized fully, irrigation is done by storing the water and consumptive use is utilized, the crop production can be maximized and cost of production can be reduced. Moreover, the crop water requirement is required to be increased by increasing the crop production with multiple crops and by using more agricultural land for crop production. There is vast scope of having water resources project to store available water obtained from rainfall and use it for irrigation purposes. The profit of production comes out to be less 34 million Rupees from agriculture, livestock and fisheries which can be maximized by increasing production and reducing investment for production (equations 10, and 11).

Krishna Basin

Finally the analysis for the whole Krishna river basin has been done. As discussed earlier the basin lies in North Karnataka & Maharashtra States. The Thiessen method has been used to obtain the mean rainfall over the entire Krishna river basin. The basin receives more than 34000 MCM of rainfall per year (Fig. 4) and its monthly distribution is also high, which may be used for different purposes (Fig. 4). The available ground water is 1920 MCM and utilizable groundwater is 921.60 MCM by considering efficiency and correction coefficient values are 0.8 and 0.6, respectively. Significant amount of available groundwater may be used for irrigation, domestic and industrial purposes.

The crop water requirement has been obtained using the equations (6) and (7) as suggested by Amarsinghe *et al.* (2004). The crop coefficient has been observed to vary between 0.4-1.2 for different stages of the crop. Fig. 5 illustrates the estimated total Evapo-transpiration and crop water requirement in Krishna -basin. In this, the ET losses due to reservoir area have not been con side red, which comes out to be 600 MCM.

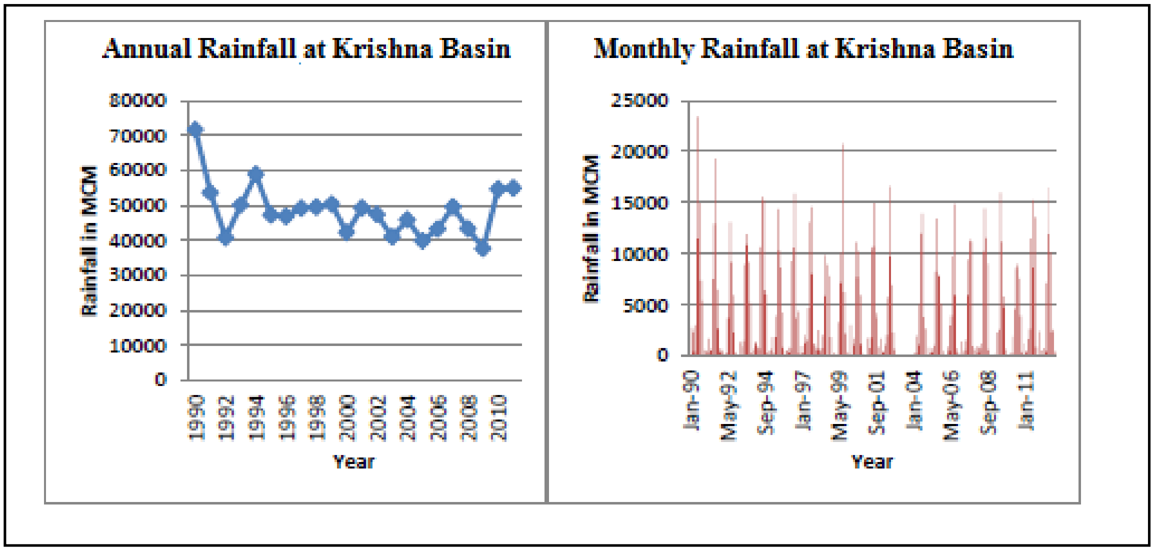

Fig. 4. Mean Annual and Monthly Rainfall of Krishna –Basin.

The Evapo-transpiration has been obtained using the following Penman-Montieth equation (1) discussed earlier.

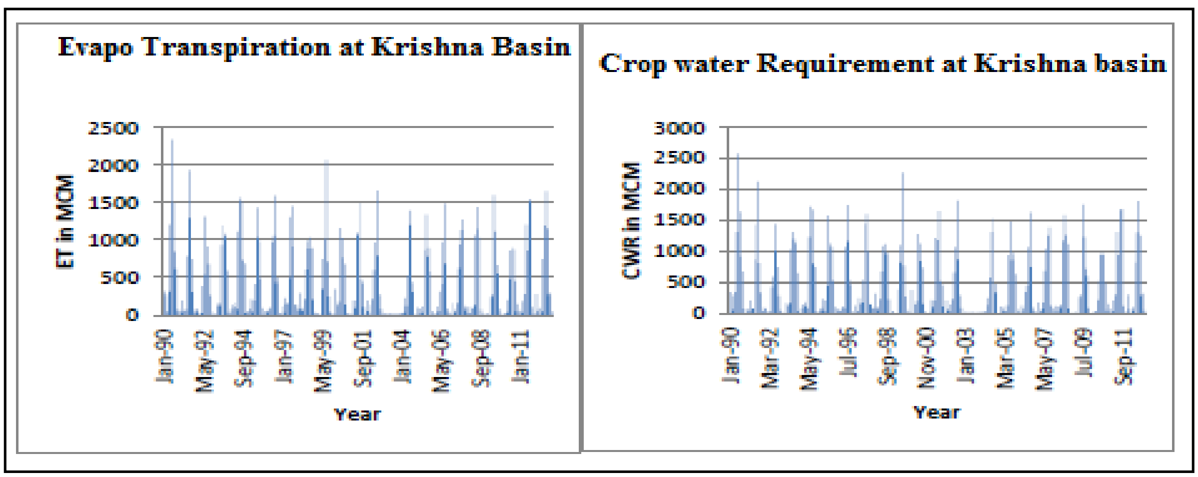

Fig. 5. Evapo-transpiration and Crop Water Requirement at Krishna –Basin.

Here the KAWRA model parameters are calibrated and validated for Krishna river basin. The results are obtained for two situations. First, only agricultural demand has been considered and the estimated outflow runoff has been compared with the observed runoff values (using equations 6 and 7). In the second step, the other demands such as domestic, industrial and environmental (4%) have also been considered (using equations 6, 7, 8, 9, 10 and 11) and compared with observed runoff values. The results obtained are given in Fig.6 for both the conditions. It has been observed that the r^2 values are high in case of Krishna -basin and the developed KAWRA model parameters are successfully used for generating future scenarios. The values of coefficients c1 to c27 have been varying between 0.6 to 0.9, all the efficiency varies between 0.6 to o.8 and the crop coefficient varied between 0.4 to 1.20 for different between stages of the crops.

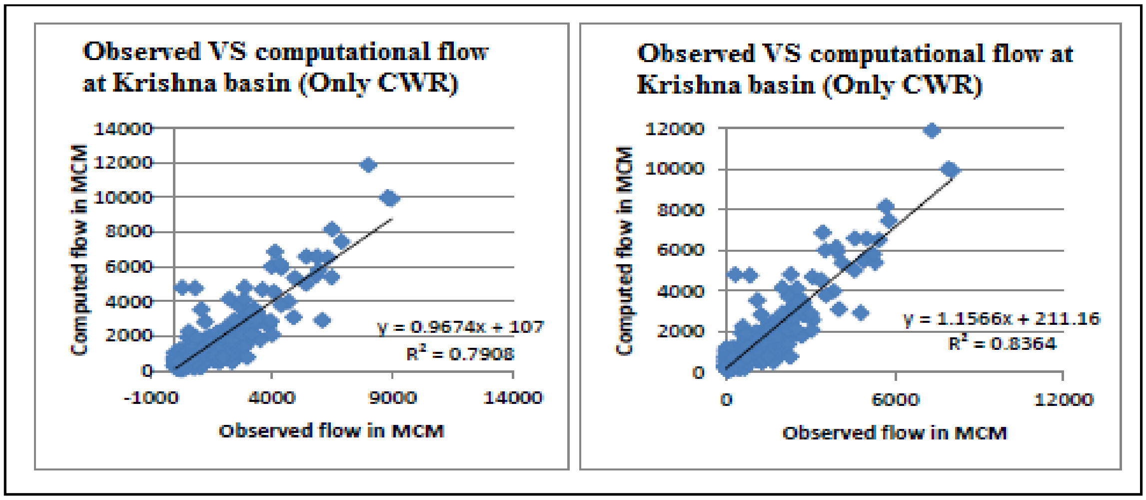

Fig. 6. Comparison of Discharges at the Outlet.

Again the results obtained clearly indicate that a large amount of water is available and ground use is less than 30% in most of the regions of the Krishna -basin. It has been observed that the crop water requirement is much below the available rainfall and even available groundwater at various locations of Krishna -basin. If the agricultural area is utilized fully, irrigation is done by storing the water and consumptive use is utilized, the crop production can be maximized and cost of production can be reduced. Moreover, the crop water requirement is required to be increased by increasing the crop production with multiple crops and by using more agricultural land for crop production. There is vast scope of having water resources project to store available water obtained from rainfall and use it for irrigation purposes. The optimum use of conjunctive use is also missing in the sub-basin. The profit of production comes out to be less 274 million Rupees from agriculture, livestock and fisheries, which can be maximized by increasing production and reducing investment for production (equations 10 and 11).

CONCLUSION

The following conclusions of sub-basins are drawn based on the analysis finding: The developed model KAWRA is a generic model and has been utilized to estimate the optimum integrated water resources management. The water resources management analysis has been done for the sub-basins Hiranyakeshi, Bennihalla, Hirehalla, Tas nadi, Combined waters of Mula & Mutha Ghod, Nira, Sina, Combined waters of Tunga & Bhadra, Varad, Hagari(vedavathy), Markandeya and the whole basin. The water is available (supply) at different basin as a whole including rain water, river water and the groundwater.

a. The model coefficients and efficiencies provide space to the user for considering conservative estimate of water availability (supply) and maximizing the use of water demand for different purposes. With the variation of coefficients, the model is suitable for use at different basin and can be transformed into simple model in the absence of some variables.

b. By increasing agricultural areas, industrial areas and domestic areas and their respective demands, different future scenarios can be generated.

c. The model has been successfully used to maximize the benefit and helped in understanding the variables involved in reducing the production cost and increasing the benefits.

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