SPACE TECHNOLOGY BASED STUDY OF CLIMATE CHANGE IMPACTS ON AGRICULTURAL WATER FOOTPRINTS IN A HYDROLOGICAL BASIN

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ABSTRACT:

Crops consume water through the process of evapotranspiration and water consumption varies from crop to crop that is also influenced by climate of a region. The agricultural water consumption pattern varies spatially as well as temporally across the regions depending on cropping systems that characterize them. This variation can be classified and grouped in terms of agricultural water footprints of the region. In the present study, Tungabhadra reservoir catchment of Tungabhadra sub basin in Karnataka has been considered to identify and characterise different crop regions using satellite derived data, and evaluate geographically varying agricultural water footprints under existing climatic conditions. Crops in Tungabhadra catchment are grouped primarily into, rain fed and irrigated. Crop water requirements are computed for these major crop regions through FAO's Penman-Monteith equation using basin scale climatological data. Regions of water abundance and water deficit are identified based on rainfall pattern and surface water storages. Point observations of weather data made through Automatic Weather Stations (AWS), installed within and around the basin by ISRO are processed to obtain spatially varying monthly climatic patterns, which are representative of three crop seasons of the current year. For these climatic patterns, estimates of evaporating power of atmosphere and crop water requirements are obtained. Based on this, five water footprints in the catchment are identified and regions of water abundance and crop stress are highlighted. In order to draw up adaptation strategies for vagaries due to climate change, crop water requirements in the zones of agricultural water footprints are simulated for an assumed climate change scenario of temperature increase. Impacts on water footprints vis a vis climate change condition are studied further, and appropriate adaptive strategies and water management aspects, are discussed.

1. INTRODUCTION

Any change in climate is likely to impact agriculture. The change could be in terms of temperature, precipitation, or any other climatic parameters. Considerable study has gone in to question of just how farming might be affected in different regions, and how much. Researchers have come out with different climate projections, of which some relating to the degree of temperature and its geographic distribution, and some others pertaining to the concomitant changes likely to occur in the precipitation patterns that determine the water availability to crops, and to the evaporative demand imposed on crops by the warmer climate. However, it may be noted that there exist several uncertainties that limit the accuracy of these projections. Further, the problem of predicting the future course of agriculture in a changing environment is compounded by the fundamental complexity of natural agricultural systems. The problem can be well addressed by means of identifying and defining various agricultural water footprints that characterize a region. Obtaining information on different crop systems and quantifying the water requirements through space based technological inputs such as remotely sensed data and data from Automatic weather Stations (AWS) will make it possible to achieve. Hoekstra and Chapagain (2008) define the water footprint as the total volume of water that is used to produce the goods and services consumed by an individual or community. As per this definition, the agricultural water footprint is indicative of the amount of water used to produce agricultural products consumed by an individual or community. We in this paper, define the agricultural water footprint as the crop water requirement in an unique cropping system environment because, it provides an appropriate framework to find potential solutions and contribute to a better management of water resources, particularly at changing scenarios of climate. The objectives of the paper include, identification and delineation of various agricultural crop systems in a hydrological terrain unit, assess the crop evaporative potential of the atmosphere during the current year's crop mid season climatic condition and for a hypothetical changed climate scenario of increased temperature, analyze the crop water requirements, vis a vis, the rainfall pattern and suggest potential adaptation measures.

2. STUDY AREA

Tungabhadra reservoir catchment located in Karnataka state of India is considered for the study. Tungabhadra river is a tributary of Krishna river that flows towards east and joins Bay of Bengal. Tunga and Bhadra are the two important tributaries of Tungabhadra river and they originate from eastern parts of Western ghats region. The geographical area of Tungabhadra reservoir catchment is about 28860 sq.km. This catchment area is divided into four watersheds. The study area map depicting drainage systems and watershed boundaries is shown in Figure 1. The upstream portion of the study area is located in hilly terrain while the downstream portion consists of undulating terrain and plains. In hilly terrains of the study area, density of vegetation consisting of forests and agricultural plantations is high. In plains and undulating terrains two contrasting vegetation cover conditions are observed.

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One is the dense vegetation cover in canal commands and the other is the sparse and poor vegetation cover in rain fed areas. Major principal crops in the catchment include, paddy, ragi, jowar, bajra, maize, sugarcane, groundnut and cotton. Major non-food crops seen in the study area are coffee, tea and tobacco.

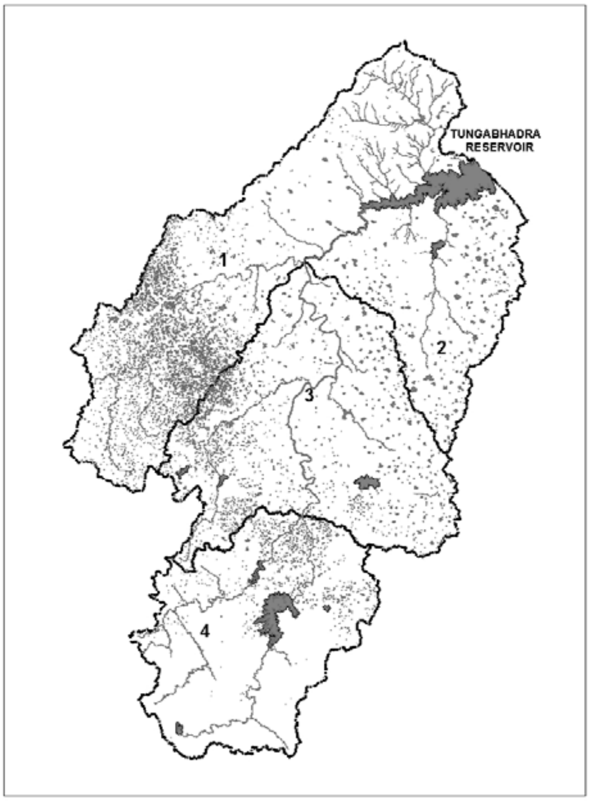

Figure 1. Study Area Map Showing Watersheds (Numbered) and Surface Water Bodies

3. SATELLITE DATA DERIVED CROPPING SYSTEMS MAP

State wise landuse/landcover map on 1:50000 scales prepared for Karnataka using satellite data of IRS LISS III under National (Natural) Resources Information System (NRIS) program of the Department of Space, Government of India, are used to identify and demarcate various cropping systems in the study area. Four major distinct crop regions of kharif and rabi crops, kharif crops, rabi crops and agricultural plantations are defined as basic units for agricultural water footprint characterisation (Fig. 2). The basis for such a grouping is that the physiological condition of all the crops in a particular group is likely to be more or less similar and their water consumption rates are expected to be almost the same. 'Kharif-only' crops are grown with source of rainwater mainly from southwest monsoon supported by tank and or well irrigation. 'Rabi only' crops are grown mostly in black soil regions of the catchment with the support of northeast monsoon rains and other supplementary sources of water. Regions of both kharif and rabi seasons are mainly the canal command areas wherein water intensive crops such as paddy are grown. The agricultural plantation regions are found predominantly in the hilly district of Chikkmagalur with non-food crops such as coffee and tea.

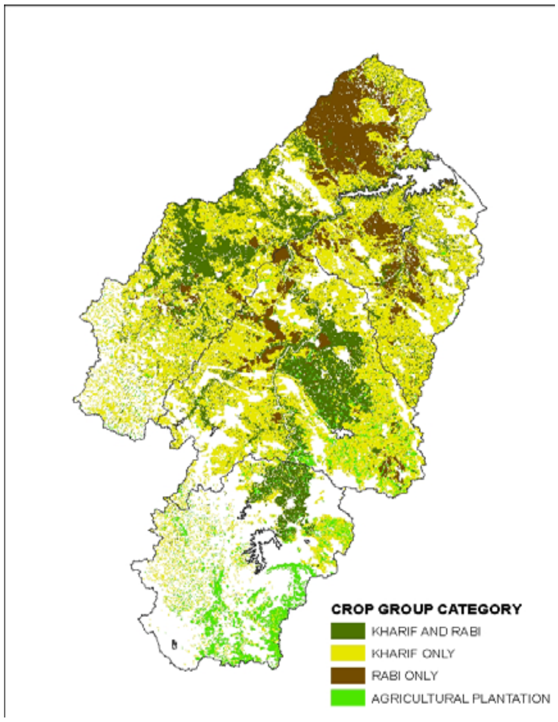

Figure 2. Distinct Cropping Systems of the Catchment

4. AGRICULTURAL WATER FOOTPRINTS IDENTIFICATION

4.1 Evaporative Power of Atmosphere

We have identified four different crop regions and each of them is considered to be one of the agricultural water footprints of the catchment. The most important component of water requirement in these regions is crop water consumptions through the process of evapotranspiration. Evapotranspiration is crop specific and is also controlled by the climate of the region. Climate dictates the evaporative power of atmosphere. The climatic parameters influencing evapotranspiration include surface air temperature, humidity, wind speed and radiation. The FAO suggests reference crop evapotranspiration (ET_0) as a measure of evaporative power of atmosphere (Allen et al., 1998). From the original Penman-Monteith equation and the equations of the aerodynamic and canopy resistance, the FAO Penman-Monteith equation has been derived and is given as,

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

Where ET_0 reference evapotranspiration [mm day^{-1}],

Rn net radiation at crop surface [MJ m^{-2} day^{-1}],

G soil heat flux density [MJ m^{-2} day^{-1}],

T air temperature at 2 m height [^{0}C],

u_2 wind speed at 2 m height [m s^{-1}],

e_s saturation vapour pressure [kPa],

e_a actual vapour pressure [kPa],

(e_s - ea) saturation vapour pressure deficit [kPa],

Δ slope vapour pressure curve [kPa $^0C^{-1}$],

y psychrometric constant [kPa $^0C^{-1}$].

The FAO Penman-Monteith equation determines evapotranspiration from a hypothetical grass reference surface and provides a standard to which evapotranspiration in different periods of the year or in other regions can be compared and to which evapotranspiration from other crop groups can be related.

4.2 Time Step

Evaluation of water footprints across the study catchment has been done at monthly time steps. Notwithstanding the non-linearity in the Penman-Monteith equation and some weather parameter methods, mean monthly weather data can be used to compute the mean monthly values for the reference evapotranspiration. Mid season months of each of the three crop seasons of 2008-2009, viz., December 2008 for rabi, April 2009 for summer, and August 2009 for kharif are considered for the study.

4.3 Climatic Data

Climatic data required for mid season months of 2008-2009 are synthesized from weather data recorded by Automatic Weather Stations (AWS) installed in and around the study catchment. As many as 33 AWS locations are chosen and spatial distribution of them is depicted in Figure 3.

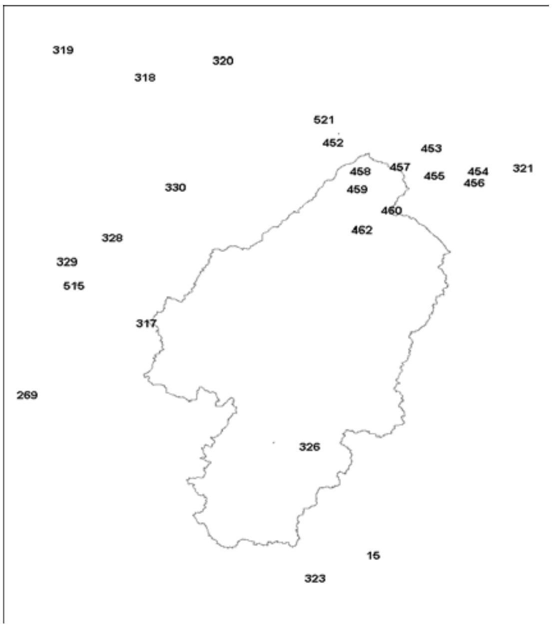

Figure 3. Location of Automatic Weather Stations (Each Station is Numbered)

For each location, ET_0 estimations are made from monthly data of minimum and maximum of temperature and relative humidity, and daily mean of temperature and wind speed. Radiation calculations are made using monthly average daily sunshine duration.

4.4 Agricultural Water Footprints

ET_0 values in mm/day obtained for every point location are used to generate interpolated raster data in GIS environment. Contours at 1 mm/day interval are then derived for all the three months and are depicted in figure 4. These ET_0 contours clearly bring out the evaporative power of the atmosphere that prevailed over the catchment during mid crop season months of 2008-2009. However, these estimates are made for the terrain covered uniformly with the reference crop, which is defined as a hypothetical crop with an assumed height of 0.12 m, with a surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evaporation from an extensive surface of green grass of uniform height, actively growing and adequately watered. To obtain actual crop evapotranspiration, we need to use appropriate crop coefficient (Kc) that in some way explains the crop's biophysical ability to transpire relative to reference grass surface. Also, these coefficients may have to be adjusted for variation in agronomic and field conditions to account for differences in evaporation from soil surface. The FAO's guidelines in this regard has been considered and the following Kc values are assigned for the four crop regions:

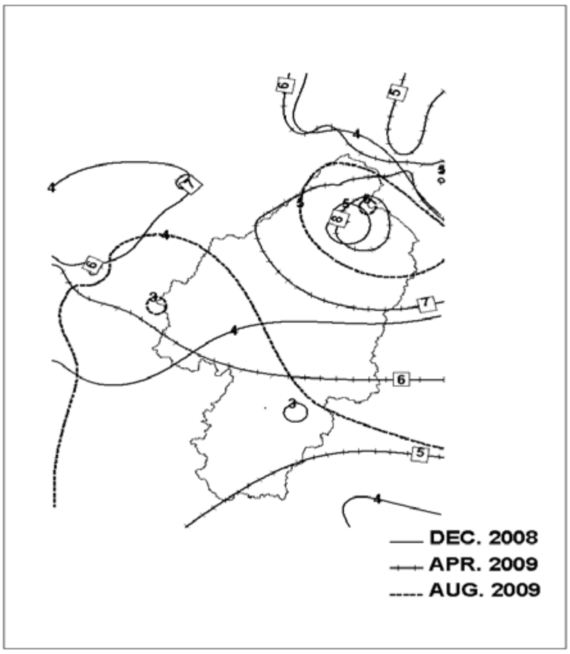

Figure 4. Contours of Evaporative Power of Atmosphere for the Current Year in mm Day^{-1}

- Kc = 1.20 for kharif and rabi crop groups,
- Kc = 1.10 for kharif crops group,
- Kc = 1.05 for rabi crops group, and
- Kc = 1.25 for agricultural plantations group.

The actual crop evapotranspiration 'ET_a' is then obtained by multiplying ET_0 with Kc. It may be observed from figure 4 that there is a gradual decrease of evaporative power of atmosphere from lower catchment to upper catchment areas. Based on the above, the study catchment may be divided into two ET_0 zones; one in north and the other in south. It is further noticed that the crops group regions, except kharif crops group region, are confined more or less with in one of the two ET_0 zones. These observations suggest that the kharif crops group region can be split in to two to form two different agricultural water footprints. And thus now, there are five distinct agricultural water footprints on the study catchment and they are indicated in figure 5, with some generalization of the boundaries. Of the many, AWS point-data, some are identified as representing a particular zone of water footprints. Table 1 provides computed ET_0 values at these AWS locations. Footprint wise values of ET_a and the corresponding daily average rainfall are provided in Table 2.

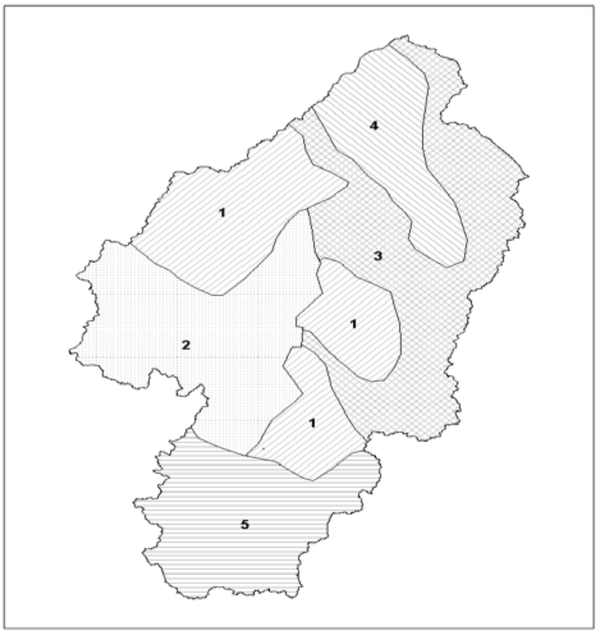

Figure 5. Agricultural Water Footprints of the Catchment (Boundaries Generalized)

S. No.	AWS No.	Footprint zone	ET_0 mm/day		
			Dec.	Apr.	Aug.
1	326	1	2.8	4.2	3.9
2	317	2	2.5	4.0	2.7
3	457	3	6.6	-	-
4	460	3	-	8.6	6.4
5	462	4	5.8	9.3	5.6
6	458	4	-	-	-
7	459	4	-	7.0	5.3
8	15	5	4.1	4.0	3.7
9	323	5	3.6	4.6	-

Table 1: Reference Crop Evapotranspiration at AWS Locations Representing Agricultural Water Footprint Zones

FP No	ET_amm/day			Rainfall (Total) mm/day		
	Dec.	Apr.	Aug.	Dec.	Apr	Aug.
1	3.4	5.0	4.7	0	-	5.3
2	2.8	4.4	3.0	0	0.3	4.4
3	7.3	9.5	7.0	-	0.3	4.5
4	6.1	8.6	5.8	0	0.4	4.7
5	4.9	5.4	4.6	0	2.0	-

Table 2: Crop Water Requirements and Rainfall Depths of the Current Year

5. CLIMATE CHANGE SCEANARIO

According to the Intergovernmental Panel on Climate Change (IPCC) panel's report of 1996, an increase in atmospheric concentrations of greenhouse gases equivalent to a doubling of carbon dioxide (CO_2) will force a rise in global average surface temperature of 1.0 to 3.5 degrees Celsius by 2100 (Pierre Crosson, 1997). In the present study, uniform temperature increase of 2°C is assumed to visualize the emerging scenario of changing evaporative power of atmosphere and the possible implications on agriculture in the catchment. ET_0 computations are made again using the FAO Penman-Monteith equation for mid crop season months for 2°C temperature increase. ET_0 contours are generated and are presented in figure 6.

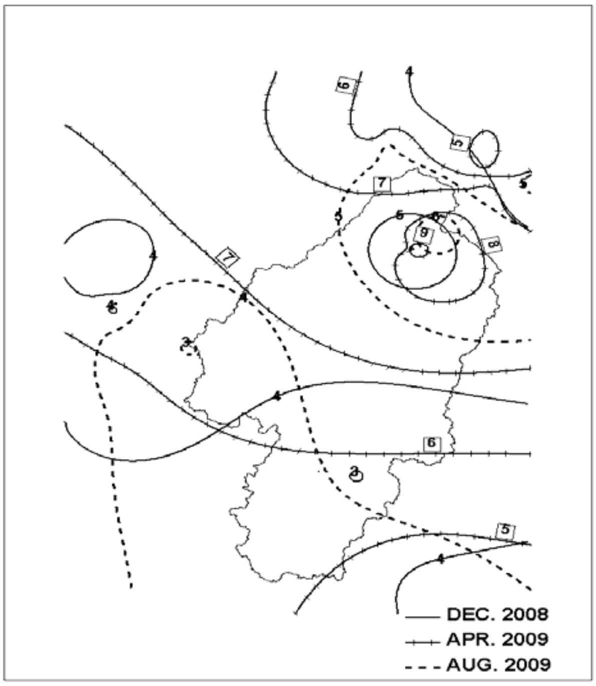

Figure 4. Contours of Evaporative Power of Atmosphere for Temperature Increase of 2°C in mm day^{-1}

It is seen that the evaporative power of atmosphere has been increased, though in a varying degree across the water footprint regions. With increasing temperature, average precipitation may also rise as much as 10 to 15 percent, as a warmer atmosphere can hold more water. Considering the same cropping system in the catchment, the ET_a values are computed for the nine AWS points and the computed values are given along with 10 percent increased rainfall values, in Table 3.

FP No	ET_a mm/day			Rainfall (Total) mm/day		
	Dec.	Apr.	Aug.	Dec.	Apr	Aug.
1	3.5	5.2	4.9	0.1	-	5.8
2	3.0	4.6	3.1	0.1	0.3	4.8
3	7.6	9.8	7.4	-	0.3	5.0
4	6.4	8.9	6.0	0	0.4	5.2
5	5.0	5.5	4.8	0	2.2	-

Table 3: Crop Water Requirements and Rainfall Depths of the Current Year

6. WATER MANAGEMENT ISSUES

From Table 2 it is found that actual evapotranspiration is higher than the average daily rainfall amount in all the water footprint zones and in many of the corresponding months. When only effective rainfall, which is available for crops at root zones, is considered, the deficits become more. Table 3 indicates that the rise in surface temperature has increased water requirement further. Though, there may an increase in rainfall as a result of rise in temperature, it is not certain that all will be available for crops at root depths. In such a scenario, crops region supported with other sources of irrigation will be able to make up the deficits through storage control and management. Thus, water management in water footprints representing 'kharif and rabi' and 'kharif only' crop regions, by storage control measures will be effective towards adapting the temperature increase situation. On contrary, rainfed areas with no supplementary irrigation will experience stress and as a result crop yield will reduce. However by employing appropriate soil moisture conservation practices, such as mulching and rainwater harvesting, crop water requirement may be met. Water footprints representing 'rabi only' and 'agricultural plantations' come under this category.

7. SUMMARY AND CONCLUSION

Four distinct crops group regions are delineated in the Tungabhadra reservoir catchment using satellite data derived landuse/landcover layer. The evaporative power of atmosphere during crop midseason months of 2008-2009, viz., December 2008, April 2009 and August 2009 representing rabi, summer and kharif seasons, respectively has been obtained by processing weather data from Automatic Weather Stations.

Crop coefficients are used to estimate crop water requirements during corresponding monthly periods. Five agricultural water footprint regions are then identified as having varying crop water requirements. Rainfall data analysis revealed that the effective rainfall amount is lesser than the crop water requirement in all the footprint zones. For a climate change scenario of 2°C temperature rise, the crop water requirement in each footprint zone is computed. It is noticed that the crop water deficits increased further. However, there is scope for adapting such a climate change situation in water footprint regions, where in surface storages such as tanks and reservoirs are present, by storage control measures. In other footprint regions, it is suggested that the adaptation measures would be based on soil moisture conservation practices.

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