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Assessing water security across the Krishna River Basin

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Abstract: The Krishna River Basin covers an area of 258,000 km^2 (nearly 8% of India) in three large states—Karnataka, Maharashtra, Andhra Pradesh—with a combined basin population of 70 million. Water extractions for agriculture, industrial, and domestic uses continue to grow to support one of the fastest developing regions of peninsular India. The basin is facing acute water shortages which are leading to interstate conflicts on the allocation and use of the resource. Intense competition for water between urban, industry and agriculture is going to aggravate due to rapid economic growth of the region.

This research attempts to capture the current trends of key drivers of water demand and assess their implications on future water demand. The assessment uses the PODIUMSIM model for projecting basin's water future. The PODIUMSIM, the Policy Dialogue Model, is a tool for simulating the alternative scenarios of water future with respect to the variation of food and water demand drivers. The model integrates both "Water demand and supply" and "food demand and supply" and hence provides a framework for addressing water and food security issues. This model was used to simulate future water demand for 12 sub-basins of Krishna Basin in India to look at the level at which future demand can be met using different levels of the security of water supply. The approach taken was a sub-basin approach to try to capture spatial variations within the basin.

Results from the projections show that there is a huge discrepancy between the water supply and demand of different sub-basins in Krishna. The water demand for irrigation will increase from 34 km^3 in 2001 to 43 km^3 and that Krishna will be highly dependent for outside food by 2031. Population growth was found to be the main drivers of domestic water demand. At a basin level, the deficit in water supply for Lower Krishna and the high surplus volume in Upper Krishna would have been masked by averages. Change in consumption pattern will lead to an increasing deficit for non-grain crops whereas increasing water productivity is very much essential to meet the needs in the future. Most sub-basins are unable to meet environmental flow requirements and climate change will increase water demands significantly in future, mainly through the agriculture sector. From this research, it was concluded that Krishna's water future requires dramatic policy changes to ensure that the people continue to have sufficient amount of water for their daily needs

Keywords: *Water demand, water supply, River Basin, PODIUMSIM*

1. INTRODUCTION

Traversing the states of Karnataka (KT), Andhra Pradesh (AP) and Maharashtra (MH) is India's fourth largest river basin, the Krishna River. Since the 1960s, discharge at the Vijayawada gauging station, downstream from the diversion to the Krishna Delta has reduced from a pre-irrigation average of 56 km^3 (1901-1960) to 17 km^3 (1994-2003) due to rapid expansion of irrigation projects (Biggs et al. 2007). This shows that the basin is closing which leads to scarcity and more frequent water crises due to over-commitment of water resources. However, to curtail water shortage, the three states continue to promote more development projects, and compete for water rights (Biggs et al, 2007).

In 1969, the Krishna Dispute Tribunal (KWDT) was made responsible for the allocation of water among the three states sharing the Krishna Basin. In 1979, KWDT issued its final award based on evaluation of the status of water resources and uses at that time as well as on the expected future use, mainly through irrigation project development. According to the decision, 15.8 km^3/yr was allocated to MH, 19.8 km^3/yr to KT and 22.6 km^3/yr to AP. The new KWDT formed in April 2004 is expected to report on revised allocations between 2008 and 2010. This however, has not resolved the conflict. Instead, it has encouraged the three states to further develop irrigation and agriculture despite the limited resources.

Mahmood and Kundu (2006) forecasted that the population in all three states will increase from 225.9 million in 2001 to 268 million in 2051. Economic growth is causing eating habits to depict that of Western cultures. As fast food chains begin to penetrate the Indian market and as convenience and time gain importance, more water will be needed to meet their needs. Furthermore, factories and industries are popping up as international companies tries to take advantage of skilled labor and resources and environmental demands are also gaining attention. Not to forget is the looming threat of climate change. The aggregated effect of all these future scenarios will increase the pressure on this already water-stressed basin, intensifying already existing inter and intra-state conflicts over water allocation.

Krishna Basin varies spatially in terms of precipitation, evapotranspiration, water availability, cropping regions or population density (Biggs, 2007). As the three states in Krishna becomes more assimilated into the rest of the world, environmental demands, change in lifestyles and government policies are beginning to deviate from the trends observed before the 21st century. Projections that have been done do not seem to take into consideration the leaps and bounds Krishna is capable of in the light of globalization. Therefore, there is a need to incorporate the influence of globalization on Krishna's food and water demand.

A complex system such as a basin needs to be managed systematically through the assistance of tools to model separate components in river basin systems. Although some details may not be captured, it is the correlation between components and trends that needs to be captured (Mc Kinney et al., 1999). Hydrological modelling and population projections have been done to assess the future water demand but many fail to consider the reality of globalization and climate change in their scenario testing. Also, spatial variation is something that requires more attention especially nowadays with increasingly advance instruments and equipments for measuring variations across sub-basin.

Figure 1. Schematic of Krishna River Basin

The objective of this paper is to analyze water supply and demand of 12 sub-basins in Krishna Basin (Figure 1) with respect to changes in key drivers such as population, consumption pattern, crop area, crop yield and irrigation efficiency, industrial growth, environmental flow requirements and climate change, using PODIUMSIM. PODIUMSIM has been used for projections at country levels and basin levels (Amarasinghe et al., 2007; Amarasinghe et al., 2005). The sub-basin approach in this paper attempts to capture not only the essence of the relationships between water demand driver and water supply, but also variations within the sub-basin. One baseline scenario, coined as the Business as Usual (BAU) scenario was projected followed by a number of alternative scenarios to test the sensitivity of water supply and demand towards different key drivers.

The results can then be used to assist policy makers in understanding the quantitative aspects of food and water demand in each sub-basin and in turn help form the basis of policy formulation and resolve water disputes.

2. PODIUMSIM MODEL

The PODIUMSIM, the Policy Dialogue Model, is an interactive policy planning and scenario analysis tool (developed by International Water Management Institute). This tool can simulate the alternative scenarios of water future with respect to the variation of food and water demand drivers (Yakubov and Mathrithilake, 2008). The model integrates both ‘Water demand and supply’ and ‘Food demand and supply’ and hence provides a framework for addressing water and food security issues. The tool consisted of four modules: food demand, crop production, water demand and water balance. The food demand component estimates the future food demand at the sub basin level and the major drivers are rural and urban population and per capita dietary consumption. The crop production component assesses the outputs of irrigated and rainfed crops and the main drivers are area cultivated and crop yield. The water demand component estimates the water requirement for irrigation, domestic, industrial, livestock and environmental demand. The irrigation requirement is estimated using crop area, crop coefficient, potential evapotranspiration and effective rainfall. The domestic water demand was estimated using current population, growth rate and per capita water use. The water balance components accounts all the demand and supply in the sub-basin and estimates surplus or deficit.

3. DATA

The approach used in this research was at sub-basin scale to try to capture the essence of spatial variations and to show how these variations will accentuate with time. To incorporate the spatial variation factor, data used for assessing demand and supply was by sub-basin. However, as most information, except water supply, is collected and compiled according to administrative boundaries, most information was available at district level (Table 1). Therefore, estimates were made according to the percentage of area of the district within the sub-basin.

For projecting future demand, year 2001 was used as the reference year. The daily calorie supply per capita for the base year was assumed as 2495 kcal and will reach 2800 kcal by 2035. In south India, grains provide 74% of the total calorie supply, Non-grain food crops represent 27%, and animal products 9%. The main food grain in the south is rice followed by coarse cereals. The nutritional intake is changing very fast in India. The consumption of food grain is decreasing and consumption of non-food grains and animal products are increasing. The increased consumption of animal products will have a significant impact on water demand. To produce one kilogram of rice 1900 liters of water is required where as to produce 1 kg of beef 43000 liters is needed.

Agriculture is the biggest water user in the Krishna catchment. Sub-basin data of net and gross irrigated area were obtained by aggregating district level data from the Department of Agriculture. To divide between season 1 and season 2, the area sown more than once was calculated by finding the difference between total gross and net sown area. Then, the area sown more than once was divided among crops with a second season according to the proportion of area covered in season one. The expected yields for each of these crops were estimated from total production in each sub-basin and cultivated area of each crop. Yields for season one and two were assumed to be similar.

Table **1.** Details of sub basins in Krishna Basin

Sub-basin	Area (km^2)	Rainfall (km^3)	75% Depen-dable Runoff (km^3)	Total population (Million)
Upper Krishna	17,972	27.10	18.31	5.93
Middle Krishna	17,558	9.92	0.93	2.5
Ghataprabha	8,829	8.13	3.62	2.18
Malaprabha	11,549	31.14	1.6	2.25
Upper Bhima	46,066	16.23	10.30	13.46
Lower Bhima	24,548	26.05	2.41	4.82
Lower Krishna	36,125	42.28	3.57	10.87
Tungabhadra	47,827	13.40	12.17	7.17
Vedavathi	23,590	8.39	1.44	4.65
Musi	11,212	2.64	1.30	9.11
Palleru	3,263	9.93	0.45	0.55
Munneru	10,409	203	2.21	3.66
Total	268,334	214.1	58.3	67.15

The total water requirements for domestic use is estimated based on the population, percentage of rural and urban populations having access to water and per capita water consumption. The current population of Krishna basin is 6.8 million with two-third live in rural areas. Per capita water use varies with sub basin, with 200 liters/day for Upper Bhima and 120 liters/day for Musi. In rural areas, the per capita water use was estimated to be 40 lpcd. However, water supply is only available to 43.8% of the urban households in AP, 55.6% KT and 68.9% MH whilst in the rural area, 9.3%, 10.4% and 22.5% of households have access to piped water supply.

In a closing basin like Krishna, industrial demands for water can only be met by diverting allocation away from existing users, usually agricultural usage. It has been estimated that water demand for the industrial sector and energy generation will increase by 4.2% annually in a rapidly booming economy like India. Moreover, compared to developed countries, water productivity of the industrial sector is extremely low. In this research, industrial water usage is based on estimates found in Van Rooijen et al. (2009).

4. FOOD AND WATER IN THE FUTURE: 2035

4.1. Business as Usual Scenario

In the business as usual scenario (BAU), the directions of the key drivers used for projections were based on the recent growth trends of key drivers: population, percentage of urban population, crop area and crop yield. Other drivers such as consumption pattern, industrial usage and domestic per capita use were assumed to be the same as 2001 as described in the earlier section.

In the BAU scenario, a 1% growth of percentage of urban population for all sub-basins was used. It was assumed that there will be no change in consumption patterns, coverage of piping to households and consumption of water for domestic use per capita, industrial water demand and net sown area from the base year. However, due to expansion of irrigation, for instance the Telugu Ganga Project, irrigation coverage is expected to increase. In 2001, irrigated area is estimated to be half of the total net sown area. The growth rates of irrigated crop area used in the BAU scenario was based on projections done by Amarasinghe et al. (2007)

Having one of the lowest grain yields among the largest producers, there is still room for improvement in crop yields within the Krishna Basin. However, past trends has show that yields growth rates are decreasing; from an annual growth rate of 3.4% in the 1980s to 1.4% currently for grains. This trend is similar for all other crop types. Crop yields in the BAU scenario assumed this similar trend in growth of crop yields. Following projections made by Amarasinghe et al. (2007), it was assumed that irrigated yields will increase by 0.9%, 1.2%, 1.6%, 0.7%, 0.9% and 1% for rice, wheat, maize, other cereals, pulses and other crops respectively.

The analysis of the results shows that the total food grain consumption in the base year was 13.1 MT (Million Ton), 39% from rice, 32% from wheat and 15% from maize. However with the change in dietary habits, more maize will be consumed in the future as it is one of the major sources of feed. Krishna is already importing food from outside as the baseline production is 11.5 MT. The spatial patterns within Krishna shows that the only self-sustaining sub-basins are Paleru, Lower Krishna, Tungabhadra, Lower Bhima and Munneru in 2001. With the increase of population and change in dietary habits the total food requirement for 2035 is estimated as 24.3 MT (Figure 2). Production on the other hand only increased by one third to 18 MT. The amount of crops Krishna will have to source from other basins increased almost four-folds. By this time, only Lower Krishna and Paleru are able to support the requirements within their own sub-basins. Most of these deficits come from non-grain crops. The economic value of total grain deficit in year 2001 is US$ 0.8 billion and it will reach US$ 15 billion by 2035.

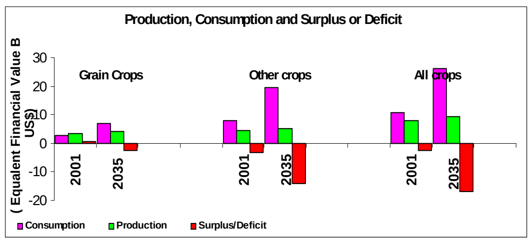

Figure 2. Equivalent financial value of consumption, crop production and surplus or deficit in 2001 and 2035

Krishna will be highly dependent for outside source of food. This shows that if the crop area and yields are grown at the rates projected in the BAU scenario, Krishna will not be able to sustain the increase in demand due to population growth alone. As water is already scarce, expanding agricultural area is not the answer to Krishna’s problems. These results seem to ring the alarm bells calling for a significant change in population policy and agricultural technology.

The estimated total irrigation requirements for 2001 are estimated to be 34 km^3 and this will reach 43 km^3 by 2035. The irrigation efficiency used for this estimate is 50% for surface water and 60% for groundwater. To meet the growing food demand more water will be required for irrigated agriculture even after improving irrigation efficiency.

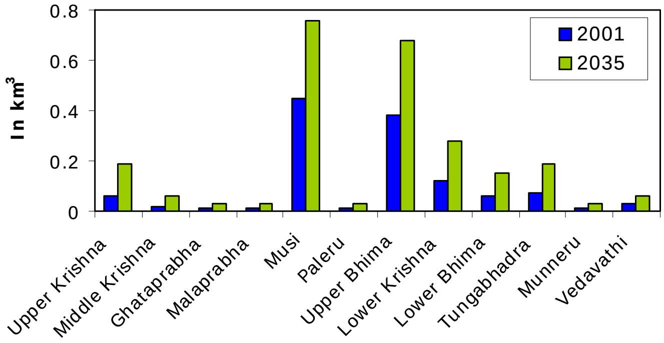

Figure 3. Domestic diversion in 2001 and 2005

Domestic demand is highest in Musi where urban population is highest and water supply accessibility is higher (Figure 3). However, the highest percentage increase of water demand was in Upper Krishna due to its high population growth rate in the BAU scenario. Total domestic water demand in the basin was estimated to be 1.4 km^3 based on population data from Census of 2001. This number is quite low with those estimated by Van Rooijen et al. (2009) because this study considered the percentage of households with pipe supply in urban and rural areas. Domestic water demand for the population without pipe supply is met from canal supply and groundwater. Domestic demand increased with population growth. In 2035 the total domestic demand will increased to 3.0 km^3. Upper Bhima and Musi, is going to withdraw more than 50% of the total domestic water demand.

Industrial demand is the highest in Tungabhadra followed by Upper Bhima and Musi. In terms of percentage of industrial demand over total water demand, it was the highest in Vedavathi, 1.69% followed by Upper Bhima, 1.55% and Tungabhadra, 1.50%. It was the lowest in Paleru, just 0.05%. Tungabhadra is home to Raichur City which has the biggest thermal plant in the Krishna Basin. Up to 0.92 km^3/yr of water is withdrawn for cooling. Industrial withdrawal is high in Upper Bhima due to the presence of Pune, the second largest urban and industrial centre of Krishna Basin. Likewise, Hyderabad, the largest urban agglomeration in Krishna Basin is located in Musi sub-basin. Generally, industrial demand correlates with population.

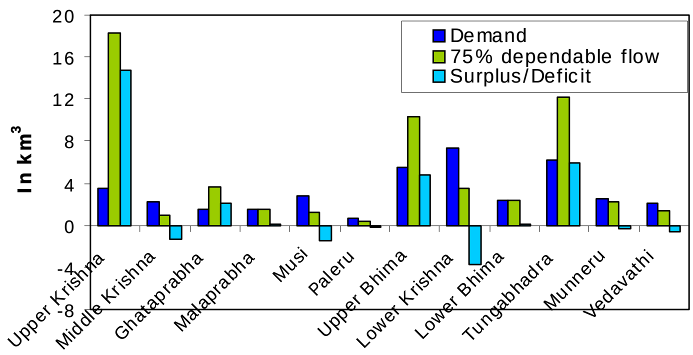

Figure 4. Comparison of total supply and demand in Krishna's sub basins

Water withdrawal for thermal power generation is often neglected in studies of water supply and demand. In Rooijen et al (2009), it was found that thermal power takes up to 87.8% of total industrial water demand. Assuming that thermal power consumption is still 87 % of total industrial withdrawals, total industrial withdrawals will be 8.5 km^3 by 2035.

As an aggregate, the Krishna Basin had surplus water supply in 2001 (75% dependable flow), but six sub-basins could not fulfill its water demands (Figure 4). Lower Krishna faced the biggest water scarcity problem with its water supply only providing 56 % of its total demand. Lower Bhima and Malaprabha were not far from joining the six deficit sub-basins. Upper Krishna was rich in water resources availability. Approximately one third of the basin's discharge originated from Upper Krishna. It used only about 20% of its available resource; yet, its total water demand is

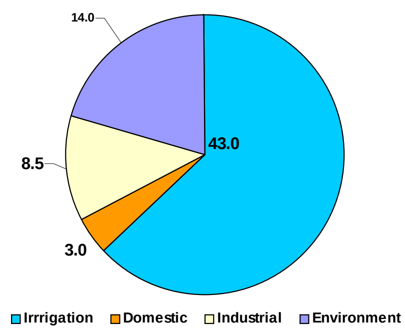

Figure 5. Total demand under future scenario

also of the lowest, giving an ample surplus of water supply.

In contrast, Lower Krishna has a sixth of Upper Krishna's runoff but uses two times more. It has the highest water deficit due to its high agricultural activities. According to this research half of all the sub-basins in Krishna face water scarcity. They all require more water than is available and need to acquire water from other sub-basin. By 2035, the total demand of the Krishna basin will reach 71.0 km^3 (Figure 5). This includes allocation of water for the environment. As a result of increasing economic activities, the quality of water is declining in most of the sub basins in the Krishna. Therefore the water demand for environment is increasing rapidly. Smakhtin and Anputhas (2006) estimated the environmental flows for Krishna as 14 km^3 using Flow Duration Curve shifting method.

4.2. Improving Irrigation Efficiency and Water Productivity to meet Future Food Security

The food security situation will become dreadful by 2035 due to population growth and stress on land and water availability. The most viable policy option for tackling future food insecurity is by increasing future production levels through technology innovations and diversifications. The analysis shows that the gross cropped area should be increased by 1.2 percent annually in order to stay food secure in 2035. But this policy option is infeasible as there is already stress on available land for agriculture.

Therefore the only options for attaining food security are increasing per ha yield and expanding irrigated area. Since the yields of irrigated crops are more than the rainfed and year to year fluctuation due to weather variability is smaller. Therefore bringing more area under irrigation is a viable option. But the total water available for irrigation is limited due to competition from urban, agriculture and environment. The current irrigation efficiency of surface water and groundwater systems is approximately 50 percent and 65 percent respectively. Significant water saving can be achieved if the irrigation efficiency can be increased by 10-15 percent. A 10 percent improvement in surface and groundwater system could save 6 km^3 of water and by using this water an additional 1 million ha can be brought under irrigation. This requires significant investment in physical infrastructure and institutions.

There is also a potential to increase the water productivity of different crops. The water productivity of crops grown in Krishna is very low (Figure 6). Current average water productivity of wheat and maize grown in Krishna is 0.18 and 0.79 kg/m^3. The water productivity of similar crop grown in China is as high as 0.76 and 1.31 kg/m^3 (Mu et al. 2008). Therefore better on farm water management practices and technological innovations are to be implemented to improve the water productivity of major irrigated crops. Further research is needed to identify regions with low and high crop yields and water productivity and also to study measures to improve both.

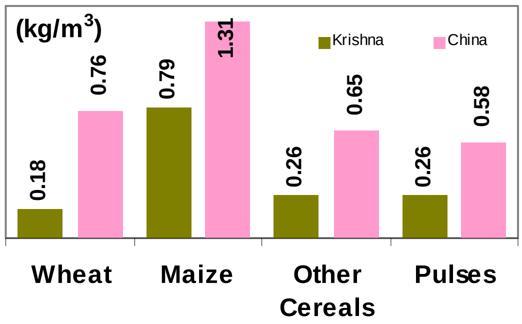

Figure 6. Water productivity of major crops in Krishna and China

The potential of water transfer to Krishna is an option being pursued in India to alleviate water scarcity. The option here is to transfer water from water surplus Godavari basin to water scarce Krishna. The link will bring 0.5 km^3 water to meet the drinking water demand in Hyderabad City. The water availability in Lower Krishna is to increase to 11 km^3 and therefore more area can be brought under irrigation in this area.

4.3. Climate Change

Few would argue with the proposition that global climate change is one of the most complex and important issues confronting the world today. The food security situation will become worst under a changing climate. It is believed that climate change will affect the timing of India's annual monsoon and result in increased intensity and frequency of storms, severe droughts, intense flooding and increased precipitation variability. It is predicted that on average, by the end of the century, India will experience a 3 to 5 ^oC temperature increase and a 20% increase in precipitation. Gossain et al. (2006) suggests that in the Krishna basin a decline in precipitation by 20% can be expected. A corresponding decrease in runoff is predicted to vary from 30 % to 50%. Therefore achieving food security will be challenging, especially given the impacts and consequences of on-going and future climate change. To estimate the implications of climate change on water demand, this alternative scenario assumed that average monthly temperature is increased by 1 ^oC and precipitation decreased 10%. From the projections, it can be seen that climate change will have a significant impact on water demand and supply. Water demand for irrigation is increased by 7% due to more evapotranspiration from increased temperature and decreased rainfall. Climate change may well lead to changes in cropping and land use patterns. Agricultural systems are very sensitive to extreme climatic events such as floods, wind storms and droughts and seasonal variability such as frost, cold temperature and change in rainfall patterns. Therefore farmers has to adopt adaptation strategies like changing planting and harvesting dates, selecting drought resistant varieties, rotating crops to cop up with changing situation.

5. DISCUSSION AND CONCLUSIONS

The Krishna River Basin of South India is the fourth largest river system in terms of annual discharge. Increasing water scarcity has resulted in water competition among states and sectors. Water demand is expected to increase, due to population growth, urbanization and economic growth. This research attempts to capture the trends of key drivers of water demand in the past to assess their implication on future water demand.

Two main factors driving increased food demand are population growth and dietary changes. As the standard of living improves a shift in consumption patterns is happening from cereals to live stock products, fish and high valued crops. The analysis of the results shows that the total food grain consumption in the base year was 13.1 million t, and is expected to reach 24.3 million t by 2035. Results from the projection of the BAU scenario showed that water demand will increase from 34 km^3 in 2001 to 43.82 km^3 and that Krishna will be highly dependent for outside food in 2035. The demand for water in industrial and domestic uses increases with urbanization. The estimates also show that the proportion of water diverted for non-agricultural sectors increases, agriculture remains the largest water user. The water withdrawals for domestic and industrial purposes were estimated as 3 km^3 and 8 km^3 by 2035. Among the sub basins, Lower Krishna is facing the biggest water scarcity problem with its water supply only providing 56% of its total demand.

Technology innovations and diversifications are very much essential for increasing future production and tackling future food insecurity. Increasing per ha yield and expanding irrigated area are the viable options. Improving water productivity offers good scope of saving significant quantity of water which can be used for bringing more area under irrigation. Scenario analysis also showed that climate change will have a significant impact on water demand and supply.

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