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POTENTIAL EVALUATION OF WATER RESOURCE IN KRISHNA BASIN IN MAHARASHTRA

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Abstract

In this study surface water and ground water resource potential and demand was evaluated at sub catchment level. Hydrologic Modelling was done using HEC-HMS software taking dynamic canopy for evapotranspiration, SCS curve number for surface loss, constant monthly for base flow and storage-discharge for reservoir consideration. Basin model and curve numbers were generated using ArcGIS. Ground water fluctuation study of 10 years water level data along with remote sensing was used to evaluate ground water potential. Resource potential maps were generated using ArcGIS. Nonagricultural water demand was figured out using projected population of 2030 to generate nonagricultural demand. For finding agricultural demand three zones delineated considering area equipped for irrigation for no/one/two times a year. Annual demand using standard delta for these zones considering different cropping pattern was figured out. Demand maps were prepared using ArcGIS for agricultural and nonagricultural demands. Integrated demand-potential analysis was carried out to figure out deficit at sub catchment level and deficit maps were generated. Scenario analysis by upgrading or down grading cropping pattern (i.e. changing current cropping pattern) was also carried out analyze deficit/surplus of sub catchments and consequently basins. Deficit maps for all case scenarios were generated.

Keywords: ArcGIS, HMS, Scenario analysis, Potential-Demand, Deficit.

Introduction

Krishna basin of Maharashtra is always considered as most water rich basin in state. And because of that perception there are many schemes planned by Maharashtra state for interbasin transfers to move surplus water from this basin. But for staying these schemes operative for long term with climate changes challenges there is need to analyze water resource in basin and evaluate its potential for possible scenarios of future demands. With current practice we generally calculate potential of whole basin at some outlet where discharge is measured. But calculating resource potential at the end of entire basin spread over thousands of km^2 won't do. We have to go the catchment level for resource evaluation and need find the ways to utilize it in catchment itself. Because, basin itself may contain large amount of disparities in its subbasin in amount of potential. So it's high time to go to catchment level. Now as solution, it is always said that there is need of management of this resource. But any analysis or management of any resource is easier said than done, because it involves large number of factors taking care of. As it involves large number of factors, its management without any computer program is clearly impossible (11). So for management a GIS program is only best solution. Geographic Information System (GIS) help to integrate large information using large volume of spatial data derived from different sources (1).

Objectives

The ultimate objective was to calculate the water resource at catchment level using ArcGIS and HEC-HMS taking SCS-CN Method for simulation in surface water modeling and water level fluctuation method for ground water. In this study following objectives were achieved

a) To create a Data Bank/ inventory of Resources.
b) To create hydrologic model.
c) To figure out Potential of surface water from model.
d) To find safe ground water potential.
e) To estimate demand on resources for projected population and ultimate cultivable irrigation area.
f) To estimate the current deficit and different scenario deficit.
g) To prepare resource Potential Maps, resource Utilization Maps, resource Deficit Maps
h) To carry out Integrated Analysis.

Use of study

Calculating resource at catchment level would answer the question arising at the time of planning. Like

- Which are the natural high priority catchments for water resource development?
- What is the current resource deficit of particular basin?
- What should be the cropping pattern to control the deficit?
- How much water need to be stored in catchment with tanks, dams etc.?
- How much water is available for transfer to other basin?
- Is there imbalance of consumptive use of water?
- Which are the catchments with resource surpluses?
- & many more………

Study Area

Study area as shown in Figure 1 comprises the region of Krishna river basin which is covered by Maharashtra, Extending between latitude of 16 to 18 and 73.30 to 74.35 (Decimal degrees) with total area of 14516 km^2. Several tributaries having their origin in Western Ghats or in its offshoots form *Krishna* basin. Sahyadri ranges in the west have large impact on hydro-climate of study area. Black cotton soils, regur, vertisols or gurmosols soils cover major portion of the region. These soils are very fertile and occupy large area of the study region in Satara, Sangli and Kolhapur district.

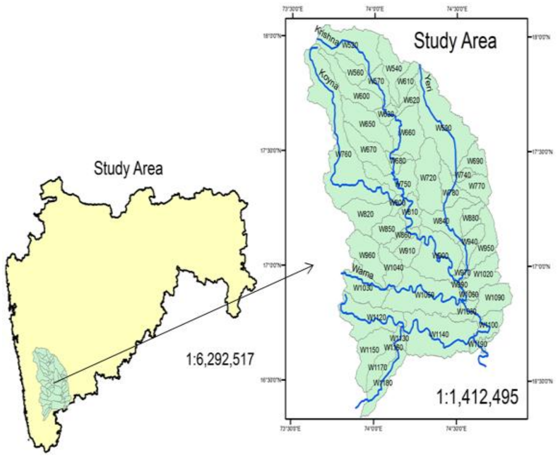

Figure 1 Study area

Materials and methods

Data collection

This first objective forms a very important part of this study and once it is achieved other things set in motion. For data collection source of data depends on type of data. There is no one stop shop for such data. Data sources are as given in table 1. Preparation of inventory includes three steps namely collection of data, validifying data for accuracy and data void, process it for analysis.

Table 1 Data types and their sources

Type of Data	Source of Data
Base maps	Survey of India
DEM	BHUVAN, SRTM, ASTER
Rainfall data	Department of agriculture, Maharashtra state.
Ground water level data	Central ground water board, India.
Water body information	Water resource information system.
Land use and land cover imagery	GLCC (USGS) BHUVAN / WRIS
Census data	Census of India
Flow data	Pune flood control division, CWC,RTDS (Water resource department)
Cropping Frequency/Pattern	BHUVAN NDVI&VF, FAO

Processes carried in ArcGIS before hydrologic modeling.

Processes carried in ArcGIS with GeoHMS tools are terrain processing, project generation, basin processing, stream and sub basin characteristic extraction, hydrologic parameter estimation, preparing model for export. These processes are necessary to generate basin model and meteorological model in ArcGIS.

Surface water modeling

There are two approaches being followed for assessing the average annual potential (runoff in the rivers). One is by adopting Dr. Khosla's formula which works out the natural runoff as the difference between the rainfall and the estimated evapotranspiration. This approach is suitable wherever observed river flow data are not available. The second approach is by using the observed flow data. In this approach the observed flows are corrected for the abstractions at upstream of the point of flow measurement, assumed return flows and evaporation from reservoirs to get the natural flows (5). The second approach based on the actual observed flows is obviously expected to give more realistic estimates. But for precision and in order to go to catchment level parameters like flow, stage, velocity, and timing must be predicted to provide the required information. This can be achieved with a mathematical model of watershed and channel behavior.

HEC-HMS is a numerical model (computer program) that includes a large set of methods to simulate watershed, channel, and water-control structure behavior, thus predicting flow, stage, and timing. It is a set of equations that relate something unknown of interest (the model’s output) to something known (the model’s input). In hydrologic engineering studies, the known input is precipitation or upstream flow and the unknown output is stage, flow, and velocity at a point of interest in the watershed (3). In the context of present study modeling was used to quantify the water resource per subbasin wise and overall volume of resource in basin.

Meteorological model with Thiessen polygon

This is an area-based weighting scheme, based upon an assumption that the precipitation depth at any point within a watershed is the same as the precipitation depth at the nearest gage in or near the watershed. Thus, it assigns a weight to each gage in proportion to the area of the watershed that is covered by that gage polygon. The gage nearest to each point in the watershed may be found graphically by connecting the gage, and constructing perpendicular bisecting lines; these form the boundaries of polygons surrounding each gage. So the weight assigned to the gage is the fraction of the total catchment area that gage polygon represents. Near about 170 rain gages were used for preparing Thiessen polygon. Thiessen polygon-sub basin intersection layer prepared for gage weight. Weight to the particular during gage weight processing is assigned according to the spatial coverage of that gage polygon in that basin. Metrologic model and gage file are automatically gets exported along with gage weight processing. For giving rainfall input, daily rainfall data from govt. of Maharashtra for june-sept was used.

Canopy Method

The canopy is one of the components that can be included in the sub basin elements. It is intended to represent the presence of plant in the land scape. Plant intercepts some precipitation, reducing amount of precipitation that arrives at the ground surface. The intercepted precipitation evaporates between storm events. Plants also extract water from the soil in a process called transpiration. For present study dynamic canopy method was adopted. This method includes an interception storage capacity and a crop coefficient that changes in time. The storage capacity specifies the amount of water (in mm) that can be held in the canopy before precipitation begins to falling on through to the ground surface.

Loss and Transform method

SCS Curve Number Loss Model for surface loss

The Natural Resources Conservation Service (NRCS) CN developed by the U.S. Department of Agriculture and NRCS, formerly known as the SCS, are used to estimate the runoff of an area or sub-area with a given type of cover, over a given soil, for a given depth of precipitation. A higher CN means more runoff where a CN of 100 means that all the rain will flow as runoff. CN's are no greater than 98, even for conventional pavements, since some small amount of rainfall will be held by the surface. The CN method provides a more flexible and site specific method for selecting appropriate design values for estimating runoff **(9).**

$$Q = \left[\frac{(P-0.2\,S)^2}{P+0.8\,S}\right] \qquad I_a = 0.2\,S$$

$$S = \left[\frac{1000}{CN}\right] - 10$$

Where, Q = runoff (in) P = rainfall (in) S = potential maximum retention Ia = initial abstraction (in) CN = runoff Curve Number value.

SCS Unit Hydrograph method for transform

Basin lag time parameter values were computed during data processing using the HEC GeoHMS application in ArcGIS environment and stored in the attributes table of sub-basin data layer. Basin Lag time in hours for each sub basin was computed using equation (USACE, 2000)

$$\text{Lag} = \frac{L^{0.8}(S+1)^{0.7}}{1900 \times Y^{0.5}}$$

Where S= Maximum Retention Lag= Basin lag time (hours) L= Hydraulic length of the watershed (Longest Flow Path) (feet) Y= Basin Slope (%).

Processes for Curve Number Generation

Land Cover/Soil Classification

For the purpose of preparation of CN grid soil cover was classified as given in following table 2. Their general rates of infiltration are also given in table. Soil classification is very important as it is key factor in determination of CN number. Soil with high infiltration rate was put in class A and soil with less infiltration was put in class D. For present study area most of the soil falls in class C & D as seen from figure 2. For preparing land cover polygon, GLCC (global land cover classification) data from USGS was taken and processed in ArcGIS. After processing the raster data, polygon feature generated was checked for validation with available soil maps. There wasn't any considerable difference between soil maps and polygon layer. But the classes of soils were more than four and they needed to be merged together to reduce them too four. So, the soils generally having nearly similar infiltration rate were brought to one class. Reclassified soil classification is listed in Table 2, and reclassification map of study area can be seen from Figure2.

Table 2 soil reclassification

Soil Group	Description	Ranges of loss rates (mm/hr.)
A	Deep sand, deep loss, aggregated silts	7.62-11.43
B	Shallow loess, sandy loam	3.81-7.62
C	Clay loams, shallow sandy, soils low in organic content, and soils usually high in clay	1.27-3.81
D	Soil that swell significantly when wet, heavy plastic clays, and certain saline soil.	0-1.27

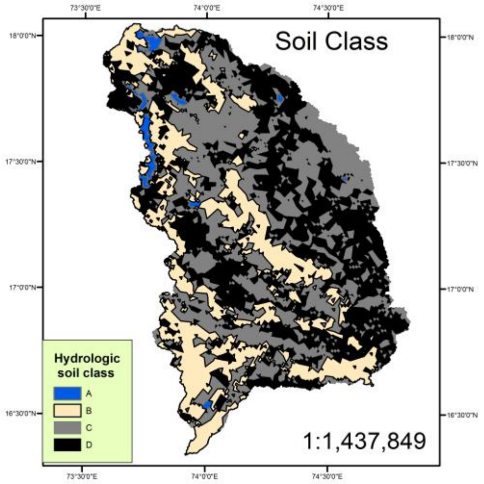

Figure 2 Soil classification

Land Use:

Nature of land use also plays important role in determination of CN number for describing infiltration properties. For preparation of land use poly-gon also, GLCC data was used. Raw GLCC rasters were image processed and polygons were generated. These polygons were checked for validation with Bhuvan (Thematic Data). Classification of NLCD (National land classification data) was reclassified as shown in following table 4. For land use data also, classes generated were more than four and they reduced to four by merging similar classes as listed in Table 3. Land uses like water bodies, wetlands etc. were given LU value 1 and uses like grass land; grounds, barren land etc. were given LU value 4. Land use map of study area can be seen from Figure 3.

Table 3 Land use reclassification

Original NLCD classification		**Revised classification (reclassification)**	
Number	*Description*	*LU Value*	
11	Open water	1	Water
90	Woody wetlands		
95	Emergent herbaceous wetlands		
21	Developed, open space	2	Residential
22	Developed, low intensity		
23	Developed, medium intensity		
24	Developed, high intensity		
41	Deciduous forest	3	Forest
42	Evergreen forest		
43	Mixed forest		
31	Barren land	4	Agriculture
52	Shrub/scrub		
71	Grass-land/herbaceous		
81	Pasture/hay		
82	Cultivated crops		

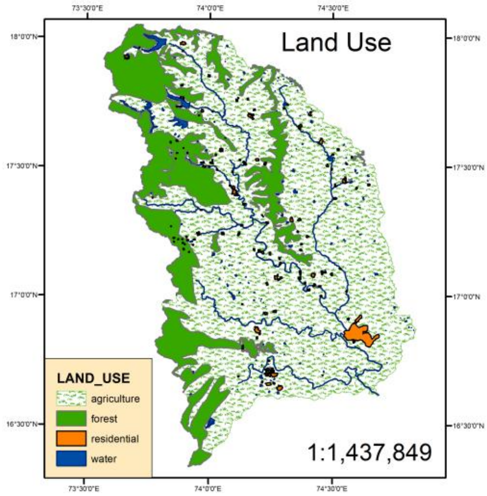

Figure 3 Land use classification

CN Look Up table:

It is a table needed for CN grid generation, which relates LUValue and Soil class to a particular CN number. Numbers for this relation were taken from Soil Conservation Services' (SCS) TR-55 report (9). On the basis of this Table 4 composite CN number was derived for different catchments of different soil class and different land use. CN raster generated through these processes is shown in Figure 4

Table 4 CN look up table

LUValue	Description	Soil Classification			
		A	B	C	D
1	WATER	100	100	100	100
2	RESIDENTIAL	81	88	91	93
3	FOREST	57	73	82	86
4	AGRICULTURE	65	73	79	81

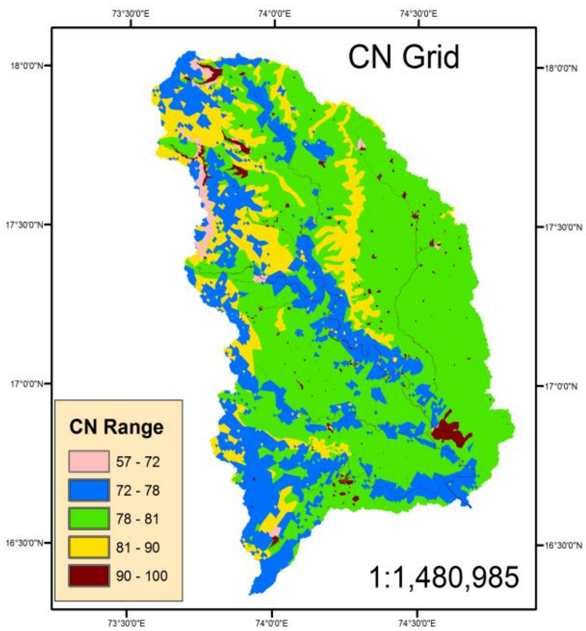

Figure 4 Curve number raster

Base flow

Base flow is the sustained or "fair-weather" runoff of prior precipitation that was stored temporarily in the watershed, plus delayed subsurface runoff from the current storm. Some of conceptual models of watershed processes account explicitly for this storage and for subsurface movement. Base flow model used for this study was "constant, monthly varying value method. These values were taken according to assumption of Krishna Water Disputes Tribunal in report 2010 (5). In this report KWDT have taken 5% of irrigational water use as return flow. Though Govt. Of Maharashtra argued to tribunal with experimental proofs to take it as 20-25%, but KWDT adopted it as 5%. Values adopted for study were 1 m^3/s for January-June and 3m^3/s July-December.

Reservoirs

A reservoir is an element with one or more inflow and one computed or specified. Inflow comes from other elements in the basin model. If there is more than one inflow, all inflow is added together before computing outflow. These elements can be used to model reservoirs, lakes, and ponds. Different types of routing methods are Outflow routing, Specified release routing, Outflow structure routing. Two important parameters needed for above first two routing methods are Elevation –Storage and Storage - Discharge data. For present study specified release routing method was used for routing with paired data of Elevation – Storage and time series data of discharges.

So, the surface water potential resulted out of surface water modeling is shown in Figure5

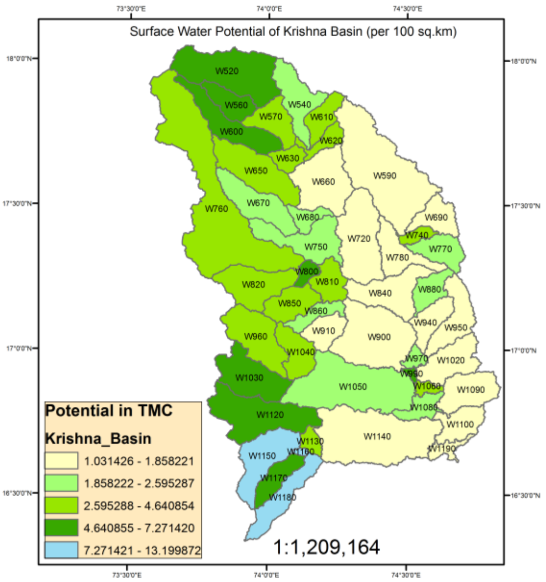

Figure 5 Surface water potential

Ground Water Potential

The characteristic of groundwater gets reflected on the soil and vegetation of the ground. Hence, the characteristics of the groundwater at a particular area can be determined to a particular extent, by its surface manifestation in terms of the land use/ land cover pattern (Mukherjee S. et.al 2008). For the present investigation satellite data Resourcesat, OCM NDVI and Vegetation Fraction (VF) and Landsat were used. Ground water level data of 280 well for 10 years was brought to GIS format in form of shape files (point data with readings for 4 months of all 10years). With the help of geoprocessing tools these data was normalized to prepare minimum, mean and maximum ground use depth rasters. All these rasters of different years were averaged together to get 10 year averaged maximum, mean and minimum depth of utilization. Fluctuation beyond 2 m was taken as over extraction. But some of the regions did have the mean use beyond 2 m. So, while calculating potential even though utilization goes beyond 2 m it is considered as potential. To prepare safe potential raster mean utilization depth raster was used. Each cell carrying a cell value and this value was multiplied by area of cell giving volume at that cell. Sinchan report of government of Maharashtra (xv) shows that out of total irrigated area 25-30% area is being irrigated with ground water. Therefore while calculating ground water potential 25% cells in subbasin (i.e.25% area of subbasin) in each basin were used for volume calculation. Ground water potential of study area is shown in Figure 6.

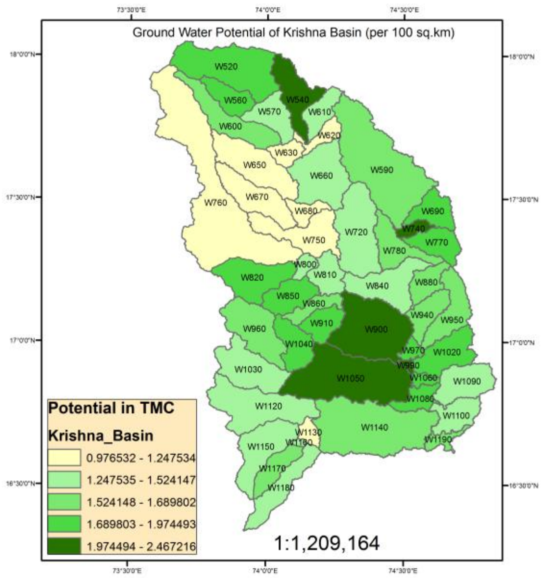

Figure 6 Ground water potential

Demand analysis

Non Agricultural water demand

- For the purpose of calculating non Agricultural water demand population of census of 2011 was projected for 2021 and 2030.
- Drinking water demand is calculated at the rate of 135 LPCD.
- Drinking water demand for projected population of 2030 is considered for analysis.
- In addition with drinking water demand, to account for all other demands (except agriculture water demand)

factor of 1.25 is used. As it is well known fact that industrial or commercial or any other kinds of demands increases in proportion of population.

- Analysis of water supplied to different cities like *pune, Solapur, Sangli, Satara* etc. has shown that industrial and other water demand never exceeds 25% of drinking water demand.

Agricultural Demand Analysis

- Agricultural demand is calculated on annual basis considering three zones of agriculture listed in Table 6.
- Area equipped for irrigation with surface water supply or ground water supply for two/one/no times a year is derived from satellite imagery of NDVI and VF.
- In context of annual demand calculation, a type of crop doesn't affect much in case of single grain crop demand.
- But area under two crops could be under water intensive crops like sugarcane or it may be under two grain crops.
- So, analysis must be carried considering both cases as annual delta of one case is completely different from other.
- In case of rainfed agriculture, area may be under single grain crop but it is not equipped for irrigation.
- Considering LULC and figures given by department of agriculture area under each zone in following is reduced to find gross sowable area,

Table 6 Cropping zones

Zone	Area	Type of cropping
Area equipped for irrigation for two crops per year.	26237 km^2	Sugarcane/Two grain crops (TGC)
Area equipped for irrigation for one crop per year	27022 km^2	Two grain crops (TGC)
Area under rainfed agriculture	16230 Km^2	Mostly a grain crop

Current cropping pattern of study area is shown in Figure7

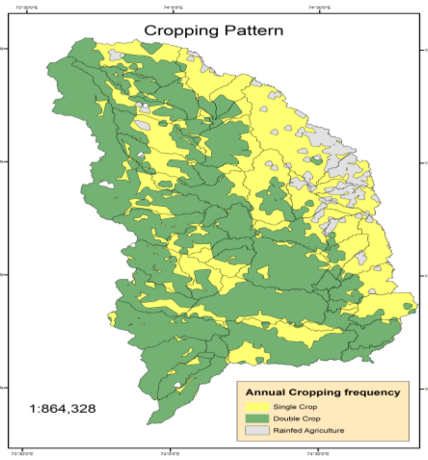

Figure 7 cropping zones

Crop Water Requirement

- Annual water demand of crops was calculated considering three classes of crop as shown in table 7.
- In case of water intensive crops like sugarcane rice, banana and other similar crops area considered in a class. Similarly for area under one/two grain crops.
- Annual theoretical delta and base period of crop was taken from FAO publications **(2).**

- Gross number waterings for sugarcane/two grain crops were reduced to account for watering those were covered in mansoon rainfall.

- For single crop it was not reduced because single crop is supposed to be taken in non mansoon period and needs to be supplied with all waterings. So, volume of water required per sq.km. Of crop concerned was calculated in TMC in Table 7.

Table 7 Delta calculations

Crop Nature	**Supply for Sugarcane& Other Water Intensive**	**Supply for Single Grain Crop**	**Supply for Two Grain Crops**
Theoretical Delta (mm)	2500	500	1200
Base Period (In Months)	12	6	6+4
Gross Watering	30	6	12
Net Waterings(Reducing for Mansoon Cover up)	22	6	10
Practical Delta (mm)	1625	500	1000
Volume Supplied(In TMC/Sq.Km)	0.0574148	0.0176579	0.038858

Demand Analysis for Different Agricultural Pattern

- As mentioned earlier study area was divided in three zones namely two crop zone, one crop zone and rainfed based on being equipped for irrigation. So, based on that each catchment was going to have maximum three different croppings in itself.
- For current pattern of cropping (prefixed "CP") two cases were considered, one with considering two crop area under sugarcane (CP_Sugarcane) and other with two grain crop (CP_TGC)
- In scenario analysis, changes in these cropping patterns have been made and respective demand for that changed pattern (prefixed "NP") was derived. For example what would be the demand of catchment if area under rainfed agriculture is brought under irrigation for single crop or sugarcane?
- Total four cases of scenario were studied listed in table 8

Table 8 Scenario case

Case	Description	Code used
Case_1 (Sugarcane)	Two crop area is considered under sugarcane	CP (Sugarcane)
Case_2 (Two grain crops)	Two crop area is considered under two grain crops	CP (TGC)
Case_3 (TGC1_RF1)	Two grain crop area is brought down two one crop supply and rainfed agriculture supplied for one crop	NP (TGC1_RF1)
Case_4 (CPRF1)	Current pattern is kept unchanged and in addition rainfed agriculture is supplied for one crop	NP (CPRF1)

Results and discussions

- While calculating potential of both surface water and ground water, conditions, parameters were so taken that minimum available potential of a unit was figured out.
- In integrated analysis, combined potential of surface and ground water was analyzed with different patterns and scenarios of demand. For integrated analysis non Agricultural demand of year 2030 at the rate of 170LPCD was used. Maps of deficits showing deficit in TMC for per sq.km. Areas were generated. More negative deficit beyond 3 TMC shows that subbasin is self-sufficient for that cropping pattern from its natural supplies.
- If a subbasin shown in yellow color in map for particular scenario then it indicates than it will be in water stress condition for that pattern. If a subbasin shown is red color in map for particular scenario then it indicates than it is incapable to support that pattern with its natural supplies.
- As speculated earlier, there's going to be deficit in some of sub basins in krishna basin with current cropping pattern, along with it there are some sub basin which are going to have surpluses as seen in Figure 8

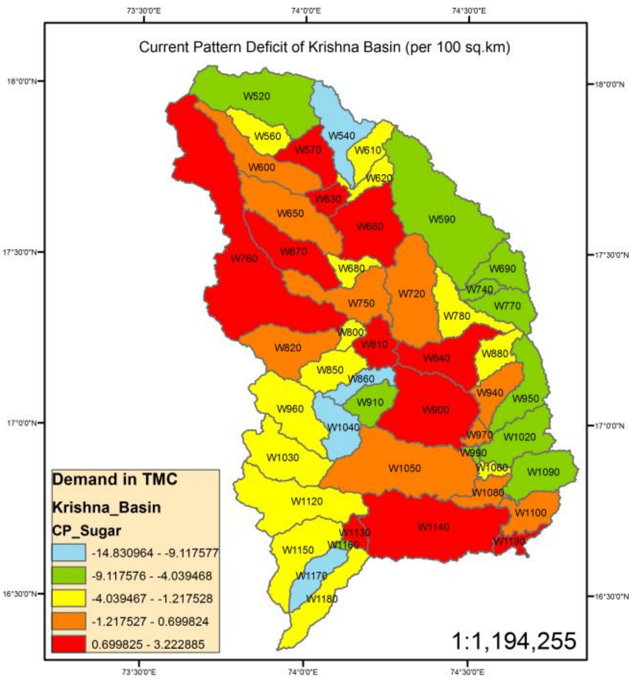

Figure 8 Current pattern (Sugarcane) deficit map

- The case scenario named CP_TGC is going to give quite surpluses but the pattern meant to reduce sugarcane field which is highly unlikely to happen. Instead it is better to bring down water consumption in those fields with micro irrigation. The deficit for CP_TGC is shown in Figure 9

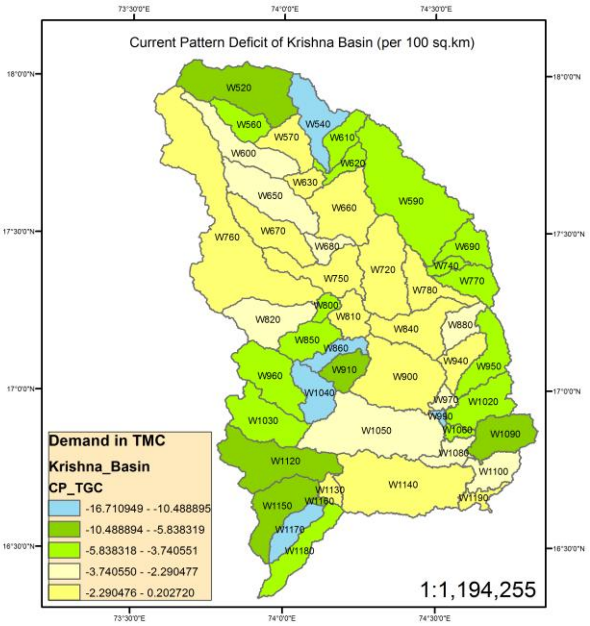

Figure 9 Current pattern (TGC) deficit

- To have surpluses which can provide interbasin transfer link enough water, pattern named NP_TGC1_RF1 is quite ideal one. This pattern supplies region under two season cropping for one season only and for other season the region will have to rely on ground water. This pattern is so suitable for the Krishna basin because it does have spare ground water resource.
- This pattern promotes consumptive use of ground water, where Krishna basin is lagging and also provides for rainfed agriculture one season supply. This could stop over extraction of ground water in those regions. Deficit (negative or positive) for this pattern can be seen from Figure 10

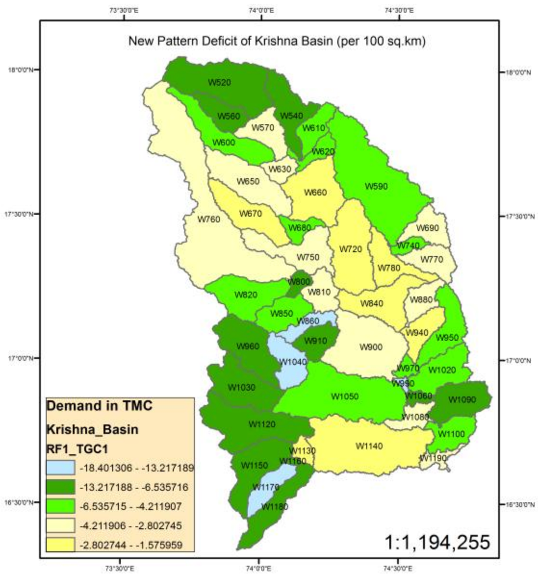

Figure 10 New pattern (TGC1_RF1) deficit map

- The last pattern named CPRF1 is quite water intensive which provides for keeping current pattern same but supply rainfed regions with one season supply, as can been seen from Figure 11 even most of the sub basin in Krishna basin is not capable to support that pattern

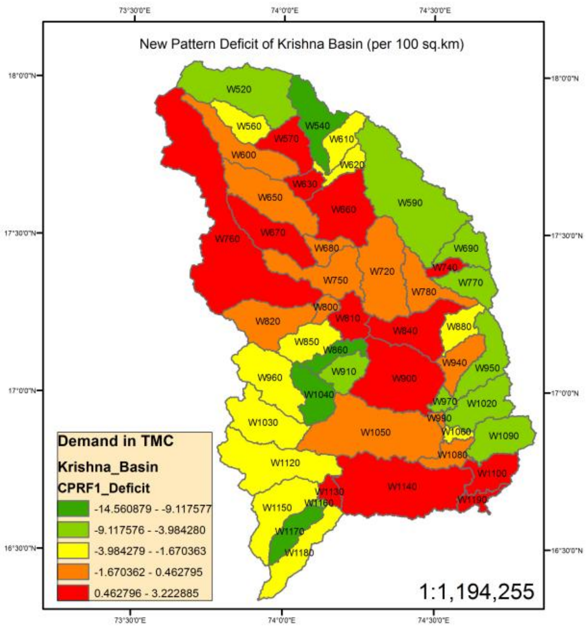

Figure 11 New pattern (CPRF1) deficit map

Conclusions

1. In order to have more realistic and void free data, data from more than one source/agency need to be processed.
2. Creating basin and meteorological model in Arc-GeoHMS was easier than in Arc Hydro tools.
3. SCS CN method was giving more realistic losses and hence, more realistic surface runoff results. Losses came out from Initial & constant and Deficit & constant method were way too high than reality.
4. Ground water potential figured out with water level fluctuation method correctly balances the equation *Current cropping pattern demand + nonagricultural demand + release to lower riparian state = Surface water potential + Ground water potential.*
5. Analysis of different case scenario shown that changing pattern of cropping have very high effect on demand and consequently on deficit. So along with potential creation, sustainable cropping pattern changes are also important.

6. The cropping pattern named TGC1_RF1 (which brings down two season supply to one and supplies water to rain fed area for a season) turns out quite suitable for all basins, because it promotes conjunctive use of ground water in the regions under two season supply and also brings rain fed area under one season supply.
7. So, it can be safe to conclude that for long term working of interbasin transfers, it is necessary to change cropping pattern or bring down demand by micro irrigation.
8.

Acknowledgements

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