Fair and equitable approach using GIS for solving the Krishna River Conflict, India

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Abstract

Conflict occurs between people in all kinds of human relationships and in all social settings. Because of the wide range of potential differences among people, the absence of conflict usually signals the absence of meaningful interaction. Since water is one of the most precious and indispensable resource of human kind, it is hence also a source of problems and tensions. Many methods and doctrines have evolved over the years in order to address the different situations. Out of all the methods, the method of fairness and equity (F&E) using GIS is undoubtedly, the best one as it let the different parties address the issue themselves on the basis of procedural and distributive justice. The present paper deals with the conflict resolution of the Krishna water conflict between the riparian states of Maharashtra, Karnataka, Telangana and Andhra Pradesh. Four factors have been identified on the basis of geography and hydrology of the basin which includes Drainage Area, Virgin runoff contribution, Cultivable area and the water quality. Simulated discharge for different gauging sites have been and been calculated using SWAT which is a public domain software which is freely available. Datasets used in this study are freely available like digital elevation model (DEM), soil map and land use land cover (LULC). Water quality has been addressed separately as unlike other factors it may lead to deduction of the area on the penalty basis (because of degradation). The cooperated negotiation method has been used to allocate the share amongst the states based on fairness and equity. The allocation should serve the purpose as it has been reached by the states themselves. The analysis has been performed for the annual average flow category only.

Keywords: Fair and equitable, Conflict, SWAT, Virgin Runoff.

1. Introduction

Conflict occurs between people in all kinds of human relationships and in all social settings. Because of the wide range of potential differences among people, the absence of conflict usually signals the absence of meaningful interaction. Conflicts have existed in all cultures, religions, and societies since time immemorial. Conflicts can develop in any situation where people interact - in every situation where two or more persons, or groups of people, perceive that their interests are opposing and that these interests cannot be met to the satisfaction of all the parties involved (Nandalal and Simonovic 2003).

Water is one of the most basic and essential needs of people and other species that share life on earth with humanity. Since the beginning of time, water has been shaping the face of Earth, not only as a geologic agent cutting valleys and canyons and sculpting rock formations, but also as a major factor in the rise and fall of great civilizations (on the banks of the Nile in Egypt, the Tigris-Euphrates of Mesopotamia, the Indus in present day Pakistan, and Hwang Ho of China).

All of these civilizations experienced tribulations of varying degrees of severity, with some of these even collapsing, when water supplies failed (water scarcity) and/or were improperly managed. The decline of the Sumerian civilization of Mesopotamia, for example, is believed to be due to prolonged droughts and poor irrigation practices resulting in salt build-up in the soil (Ashry 1998). A distinctive feature of these conflicts, as past experience seems to suggest, is that contenders overestimate their respective positive characteristics and contributions, while underestimating the negative ones (Cohen 1982; Taylor and Hastie 1991), suggesting a planned and deliberate strategy, pursued by various players in the dispute, to find justice based on favorable distribution rules.

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1.1 Issues to be addressed in the proposed methodology

In the first part of the study an attempt has been made to address the issue of a 'Fair and Equitable' sharing of a common resource and develop a quantitative basis for deriving such appropriations. This component of the study explores the seemingly obdurate and, equally obtuse, concepts of ''Equity' and 'Fairness' in water allocations in order to derive appropriations that may be deemed to possess such an attribute. It may be pertinent to note that these concepts of 'Equity' and 'Fairness' are as esoteric as they seem to be desirable and developing a practical and implementable framework is, therefore, a formidable task as it depends on perceptions and notions that are subjective and self-serving.

In the second part, Metagame Analysis (Fraser and Hipel, 1984), as part of the Game Theory based Conflict Analysis methodology, has been used to incorporate realistic, but almost exclusively qualitative, political and social factors in the Krishna conflict model. Specifically, Metagame Analysis has been used to organize information pertaining to the political aspects of the Krishna conflict and, following this, to derive feasible equilibrium solutions to the conflict by stability analysis.

2. Study Area Description

River basins form the basic hydrological units for water resources planning. The basin has been recognized as a practical hydrological unit for water resources management. Figure 1 shows the distribution of basin area over the three states. Krishna Basin is having a total area of 258948 sq. km which is nearly 8% of the total geographical area of the country. The basin has a maximum length and width of about 701 km and 672 km and lies between 73°17' to 81°9' east longitudes and 13°10' to 19°22' north latitudes. The basin is roughly triangular in shape and is bounded by Balaghat range on the north, by the Eastern Ghats on the south and the east and by the Western Ghats on the west. The Western Ghats form the main watershed in the Region between the ... aphical setting ... sin falls under ... of Bengal and ... gal, delineated ... s to outlet.

Fig. 1 Krishna Basin Shape File

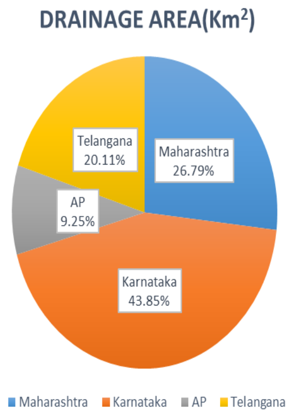

Fig. 2 Drainage Area Contribution

3. Methods and Materials

3. 1 Model used for the study –SWAT

SWAT (Soil and Water Assessment Tool) is a continuous-time, spatially distributed simulator that helps model a river basin and also predict the impacts of land management practices on water, sediment, and nutrient concentrations (Neitsch et al.,2001).It was developed by Dr. Jeff Arnold for the USDA. SWAT makes use of watershed information to simulate surface runoff and sub-surface flow. The model operates on a daily or sub daily time scale.

The hydrologic cycle is simulated in SWAT based on the water balance equation:

$$SWt = SWo + \sum_{i=1}^{t} (Rday - Qsurf - Ea - Wseep - Qgw)$$

Where SWt is the final soil water content (mm of H2O),SWo is the initial soil water content on day i (mm of H2O),t is the number of days, Rday is the precipitation in day i (mm of H2O), Ea is the amount of evapotranspiration on day i (mm of H2O), Wseep is the amount of water entering the vadose zone from the soil profile on day i (mm of H2O), Qgw is the amount of return flow on day i (mm of H2O).

3.2 Methodology

A model of the basin is set up in Soil and Water Assessment Tool (Version 2012).The anthropogenic activities in the basin are also incorporated in the basin by including the water resources projects in the model, so that the model set up would be a surrogate of the actual basin.

Data of reservoir releases inside the basin, outside the basin, power generation, industry requirement, domestic requirement, spillway releases, and evaporation losses are available. The flows were simulated and compared with the observed flows at specific gauging stations. The model is calibrated for the period of 1985-1991 and validated for the period 1992-1995 for a monthly time scale.

3.3 Data used for the study

Spatial data: DEM-Digital elevation Model is obtained from Shuttle Radar Topography Mission (SRTM) 90m x 90 m resolution digital elevation available from http://srtm.csi.cgiar.org

Soil Cover data: Digital soil map is obtained from FAO Geo network.

Land cover layer: Land cover data is obtained from the database Global Land Cover Facility.

Climatic data required: Rainfall and temperature data are obtained from IMD gridded data. Solar radiation, wind speed and humidity data were simulated by the model.

Flow data of gauged stations: Flow data of gauged stations maintained by Central Water Commission (CWC) are available from http://www.india-wris.nrsc.gov.in/,water resources information system of CWC.

Watershed delineation tool

SWAT 2012 has a watershed delineator tool that helps delineate the basin from the processing the DEM input. A threshold of 50,000 hectares is provided for stream delineation. The gauged sites and reservoir sites were identified and outlets were created at those locations. By choosing the outlet of the basin, the entire watershed is delineated. Reservoir are added manually at the reservoir sites where outlets have already been defined. A total of 325 sub basins were formed.

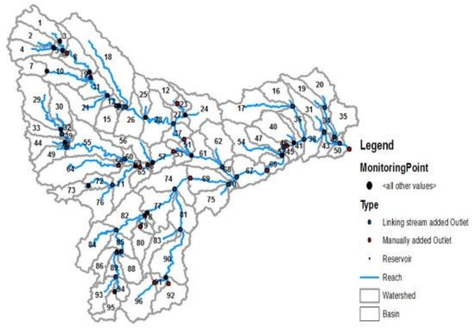

Fig. 3 SWAT Model of the Basin

4. Results at Gauging Sites

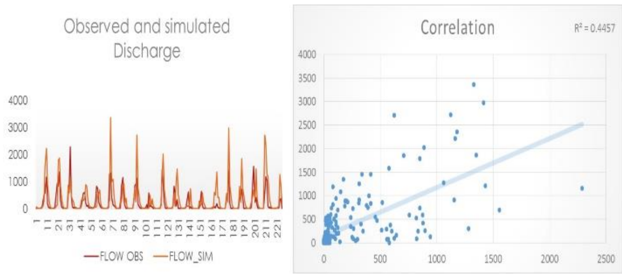

Fig. 4 Observed and Simulated discharge at Takkli basin

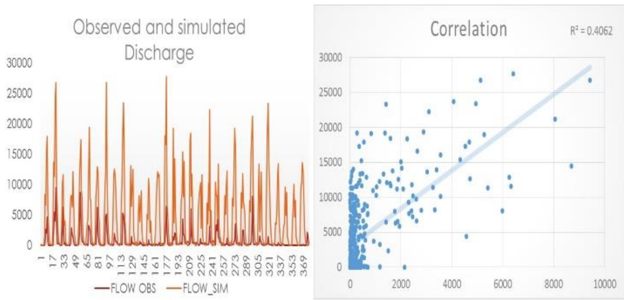

Fig. 5 Observed and Simulated discharge at Vijaywada basin

4. 1 Calibration of the model

In the process of manual calibration, parameters have to be changed with judgment to arrive at good results, basically a trial and error procedure. Automatic calibration is also possible but it is not an integral part of SWAT 2012 unlike SWAT 2009.

Parameters that are mostly altered in the process of calibration are:

CN2: Moisture condition II curve number, governs the infiltration rate and is a function of soil's permeability, land use and antecedent soil water conditions. This parameter can be changed in the .mgt file. While calibrating, the CN2 values are not changed by replacing value in order to preserve the heterogeneity of the model.

GWQMN: Threshold depth in the shallow aquifer required for return flow to occur (mm of H2O).

GW_REVAP: Groundwater "revap" coefficient.

REVAPMN: Threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur.

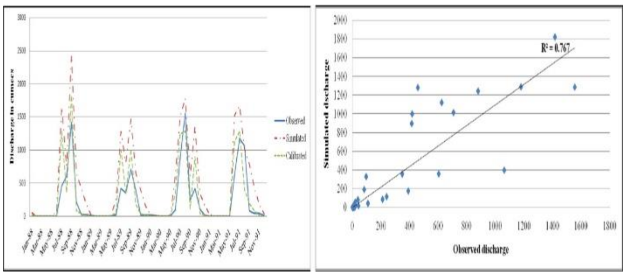

Fig. 6 Calibration at Takkli site

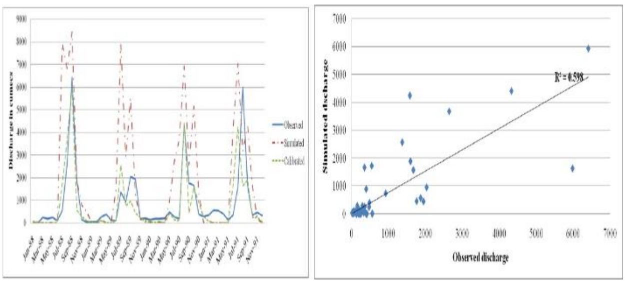

Fig. 7 Calibration at Vijayawada site

5. FAIR AND EQUITABLE ALLOCATIONS

5.1 Framework for procedural justice in negotiations

To determine apportionment, proportional entitlements may be based on a selection of factors as proposed by UNCIW (1997). For fairness, each contending state may be allowed to propose distinct, but quantifiable, factors on the basis of which respective proportional entitlements may be sought. It is reasonable to assume that the size of proportional entitlements, corresponding to any given factor, would be distinctly different for each of the contending states. Therefore, in keeping with requirements of procedural fairness and transparency, each contending state may independently identify the factor that maximize its entitlement and seek a share computed based on the chosen factor.

In the event of cumulative claims exceeding availability of the resource, a spirit of compromise is invoked requiring each claimant to put forth another factor that is ranked next in its respective order of preference for the second stage of negotiations. The process continues in this manner till the cumulative claims match availability of the sought resource thus yielding a point of equilibrium. An important attribute of this point of equilibrium being that each contender would be smug in the knowledge that a better respective allocation, than that obtained corresponding to this equilibrium point, is simply neither possible not fair.

The cooperative framework for negotiations presented in the ensuing discussion and the resulting ‘fair and equitable’ apportionment of Krishna waters is based on the following assumptions.

5.2 Assumptions

1. For simplicity, available water that is to be apportioned is assumed to equal one hundred volumetric units of water.
2. A cooperative, consensual solution to the problem of sharing of Krishna waters exists and the contending states recognize that such a solution is the most desirable and has the best chance of success.
3. Availability of water resources in Krishna River Basin is limited and the contending states recognize the need for voluntary compromise.
4. Contending states recognize that for any apportionment to be equitable and fair, the dialogue process needs to be transparent.
5. Litigant states, even within the cooperative mode, have a right to seek apportionment based on factors that maximize their respective share.
6. The states are able to rank their respective factors in order of decreasing preferences.
7. Entitlement for a given contending state, based on a combination of proportionality factors, assumes equal weights for all factors.

5.3 Factors for apportionment

According to UNCIW (1997), allocation of a shared water resource amongst its competing users may be based on the features that include Geography, hydrology and Climate.

Factors considered for fair and equitable distribution in present study:

1. Drainage area contributed by each state to the basin
2. Gross cropped area (GCA)
3. Virgin Runoff contribution by each state
4. Water Quality

5.4 Explanation for the factors used:

1. <u>Drainage area</u>: Since the genesis of the Krishna water dispute lies in the fact that each state is a

riparian to the basin, this automatically includes the drainage area as an important factor for the analysis.

2. <u>GCA</u>: The main use of the Krishna water is primarily agriculture. All the riparian states use water mainly for irrigation and all the major projects are for irrigation purposes as shown by the table earlier shown. Hence GCA is also a very important factor as the major use of the resource i.e. water is being used primarily for agriculture by all the riparian states and hence proportional division can be done keeping in view the distributional justice principle.
3. <u>Virgin Runoff contribution</u>: It is also a very important factor for the appropriation. Different basins contribute differently and thus will have different claims for share. The major intra-basin transfers occur from the Upper Krishna, where ~50 percent of the basin's discharge originates, to the Middle and Lower Krishna. Allocation to the Lower Krishna exceeds the volume of water generated in the sub-catchment by ~13 km^3, while the Upper Krishna is allocated 6 km3 but generates ~18 km^3. Most other sub-basins have a balance between water availability and water allocation, and therefore would contribute only marginally to flow downstream if all allocation were used. Hence this factor is a very important one as it is the basis of definite proportionality. The choice of virgin runoff strictly mandates the procedural justice as developed states have made various projects within their part of the basin and hence it will not be a level playing field for the poor state and especially Telangana which cannot claim any prescriptive as it is the latest which has come into the existence after the Reorganisation of the erstwhile Andhra Pradesh.
4. <u>Water Quality</u>: A downstream state helps the upstream states by providing passage to the Sea for its flood water and also exporting the salts and other dissolved pollutants carried from its river basin. It is also avoiding the potential submergence of upstream state area and possible ecological damage by the presence of a saline water lake in its territory. It also has to bear the major consequences of various forms of agricultural pollution and the water pollution caused by upper riparian. Each state thus should be penalised for polluting the resource which is shared. Now since we are adopting fair and equitable distribution in our analysis then we should also consider this factor. As no state is willing to provide free services to any other state in this conflict, so this becomes a point worth considering.

5.5 Cooperated Negotiations

Table 1: Contribution Table

State	Drainage Area F1	Cultivable Area F2	Virgin Runoff F3
MAH	26.79%	21%	33%
KAR	43.85%	48%	39%
AP	20.11%	12%	11%
TEL	9.25%	19%	17%

Table 2: Preference Vector

State	RANK 1 FACTOR/ PERCENT	RANK 2 FACTOR/ PERCENT	RANK 3 FACTOR/ PERCENT
MAH	F3/33	F1/26.79	F2/21
KAR	F2/48	F1/43.85	F3/39
AP	F1/20.11	F2/12	F3/11
TEL	F2/19	F3/17	F1/9.25

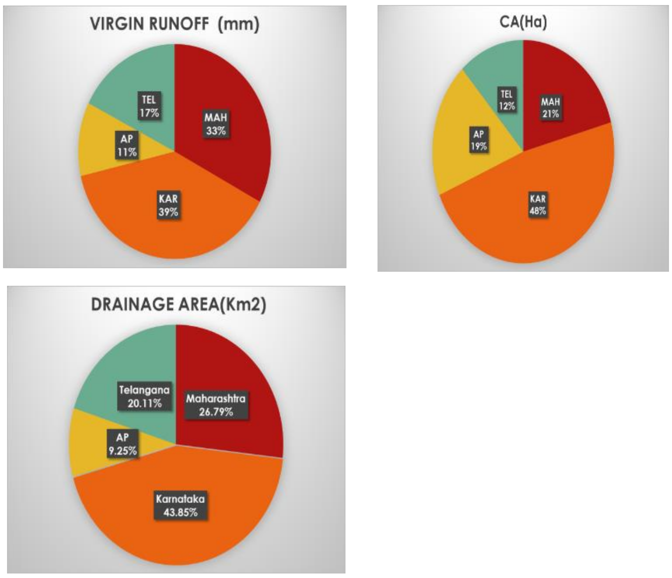

Fig. 8 Quantification of factors drainage area cultivated area and virgin runoff

Following the procedure outlined in Ravikumar and Khosa (2005), if all the states were to insist on allocations in proportion to the respective highest ranked factor, a total water requirement equal to

(33+48+20.11+20)=120.11% is implied. This, of course, is untenable and the need for a compromise is recognized as such by each of the contending states. Thus, they will then consider their second ranked

Rank 1 Sum	**(33+48+20.11+20)=120.11**	**>100%**	**Infeasible**
1st Compromise (Rank1; Rank2)	**(26.79+43.85+17)=109.87**	**>100%**	**Infeasible**
2nd Compromise (Rank1;Rank2;Rank3)	**(21+39+11+9.25)=100**	**=100%**	**Feasible Solution**

factor. This will continue when the allocated resource is within 100%.Here the process seeking fair share allocation in respect of Maharashtra, Karnataka, Telangana and Andhra Pradesh converges to a point of agreement with allocations of total availability respectively.

Table 3: Cooperative Negotiations Analysis

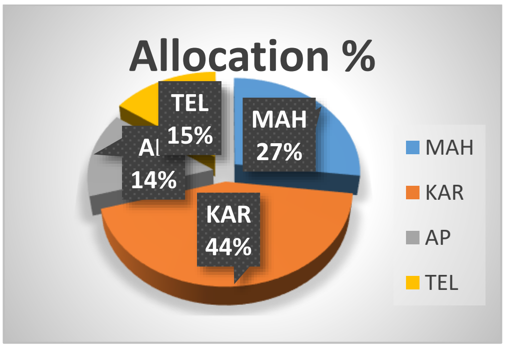

Fig. 9 Cooperative Negotiation Allocation

5.5 Temporal Non-Homogeneity and Spatial Homogeneity in Runoff Yield:

In order to incorporate the effect of inter-annual variability in monsoon rainfall over the study basin and its impact on sustainable region, virgin runoff potential of four levels of dependability is obtained in order to quantify the dynamic factor F3 in respect of each of co-riparian state. The flow categories are:

1. Max. flow (MAX)
2. Upper Quartile Flow (UQ)
3. Median flow (MED)
4. Lower Quartile Flow (LQ)

Similar analysis has been carried out and applied for the above listed categories. The results are as follows:

State/Flow Category	**KAR**	**MAH**	**TEL**	**AP**
MAX	**40%**	**26%**	**19%**	**15%**
UQ	**42%**	**33%**	**12%**	**13%**
MED	**43%**	**25%**	**17%**	**15%**
LQ	**44%**	**25%**	**16%**	**15%**

Water Quality Issues

Water quality is an important aspect in water use and hence in any water allocation problem it plays a crucial role. Since impaired quality water will unlikely be the choice of any state so it needs to be accounted in any water allocation problem. But the unavailability of the data and the reluctance of the states to share them is the major hurdle in accounting of this parameter as unlike the other factors like drainage area, runoff contribution, etc. which will contribute positively to the total share, this factor if found in excess contribute negatively. Merely following the permissible limits is not going to serve the purpose in the allocation problem as it will cause additional burden on the downstream riparian. The percentage of water quality degraded under a particular parameter chosen is more important because the downstream riparian will want the water allocated to them at the same parameters as used by an upstream riparian. For e.g. if permissible limit of COD is 25 units and the change in COD in its drainage area is from 10 to 20. The downstream state cannot increase the COD more than 5 units. Hence the percentage of water quality degraded is more important here. The water quality change discussed here is strictly due to **ANTHROPOGENIC** factors not by natural one as the state cannot be held liable for the natural causes of the water pollution.

Important water quality parameters in the Krishna Basin: P_H, BOD, Total coliform, Fecal Coliform and D.O. In a regional survey by the Central Pollution Control Board, the majority of streams were critical in terms of biochemical oxygen demand (BOD) and Fecal Coliforms during 2002 and 2003 (Central Pollution Control Board 2002). The factors considered above are the most critical ones regarding all the three states.

First and the last gauging sites on the same reach in a particular riparian state has been used for the calculation of % deterioration of BOD (the most critical parameter in the Krishna Basin). Almost all the gauging sites in every riparian state exceed the permissible limit for BOD.

Maharashtra

Site	Max	Avg.	Min
Phulgaon	3.5	1.64	0.1
Takli	3.7	1.65	0.3

% Deterioration in the Max. Value of BOD = $\frac{(3.7-3.5)}{3.5} * 100 = 5.714\ \%$

Karnataka

Site	Max	Avg.	Min
Halia	5.5	1.5	0.2
Vijayawada	6	1.1	0.1

% Deterioration in the Max. Value of BOD = $\frac{(6-5.5-3.5)}{6} * 100 = 9.091\ \%$

Andhra Pradesh

Site	Max	Avg.	Min
Yadgir	6.4	1.4	0.1
Bawapuram	4.5	1.5	0.1

% Deterioration in the Max. Value of BOD = $\frac{(4.5-6.4)}{6.4} * 100 = -29.6875\%$

6. Results and Discussion

6.1 Issue of Reorganisation of Andhra Pradesh and Telangana

The erstwhile Andhra Pradesh reorganised into new Andhra Pradesh and Telangana on June 2014. This has led to the emergence of a new player in this conflict and various scenarios considered also includes Telangana and its possible choices. What has not been included is those projects which were earlier the part of both states and now which has are entirely in one of the states (almost all in A.P.). This has raised further contentions in this matter. As the claim and allegations of Telangana is that A.P. intentionally devoid Telangana of various projects which were meant for irrigation in their area and there was always less allocation in the budget for them also (The Telangana Freedom Movement was going for many decades). So obviously these projects need to be appropriated as well between these two states. But unlike any automobile plant, these projects are various dams, canals and barrages which cannot be transferred.

The possible solution is the compensation in monetary terms (or perhaps in fixed amount of agricultural yield as agricultural resource is limited in Telangana). This will benefit both the states as AP have quite productive delta area which has high yield and hence high revenues. So AP can give the compensation in kind.

6.2 Fair and equitable Allocations

F&E allocation has been successfully derived and the share according to it has been allocated. In F&E allocations, each state is free to bring its own set of factors which maximises its share. As discussed in chapter 1 that all the techniques and methods which involves the parties themselves as solver of the conflict, have greater chances of being successful It is averred that the proposed methodology addresses the issues of equity and fairness through proportional allocations for distributive fairness and a cooperative, equal opportunity, model for negotiations for the important but perception based notion of procedural justice.

These allocations, labelled as 'F&E' and short for Fair and Equitable, allocations are derived for each of the contending co-basin states of Karnataka, Maharashtra, Andhra Pradesh and Telangana for five categories of flows ranging from MAX (maximum), UQ (upper quartile or 25% dependability), MED (median flows or 50% dependable flows), LQ (lower quartile or 75% dependability) and MIN (minimum) flows. To infuse a measure of realism, possibility of non-homogeneity in runoff availability across the river basin has also been considered and, accordingly, these 'F&E' allocations have been derived for the situation when runoff contribution in all states falls in the same flow category as well as the situation where runoff availability in these states falls in different flow categories.

6.3 Scope for Future Work

1. The present work makes a foundation for proving the efficacy of F & E allocations in the conflict resolutions by using Metagame and the Hypergame analysis.
2. The operating reservoir policy for each reservoir can be made so that the time and the quantity of water to be released can be found out.

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