# Prospect of River Basin Authorities in Nepal and Example of Knowledge Base Tool Application in Bagmati Basin

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***Abstract* - We propose Integrated and Participatory River Basin Management (IPRBM) approach for water resources management in Nepal under the institutional basis of strong River Basin Authorities (RBA). Such governance model could be very appropriate considering the infant federal system in Nepal to minimize complications in planning, development and management of river basins and infrastructures. This would also be effective given the scope of multiple utilization of water resources in the country. This is thought to be inevitable to achieve the goal of safe and sustainable operation, management and governance of water resources as well as water infrastructures like dams, barrages, irrigation canals located in the basin. A basin planning tool, coupled with various models to simulate (and forecast) all relevant physical processes in a basin scale such as surface and ground water hydrology, water resources (demand and distribution) including water infrastructures (in a simplified manner), water quality and ecology. Such system serves as a "macro-brain" of the RBA for basin studies, monitoring and data management, impact analysis as well as policy- and decision-making processes. We develop a first version of basin planning tool for Bagmati basin using SimBasin as an example. The tool is also coupled with gaming tool that helps to grasp the complex processes and ease the dialog between science, planners, executers and communities.**

***Keywords – Water Resources, IPRBM, SimBasin, WEAP, Federal System***

## I. Introduction

Across the globe since many decades most of the countries are concerning and focusing for the security of water through the approach of integrated water resources management (IWRM) within the river basins. IWRM means basically to work under the holistic approach with coordination among all water users within the basin. Integration, decentralisation, participation and management of water resources within the basin are major principle of IWRM (GWP, 2000). In Nepal, IWRM concept has been introduced in government document- Water Resource Strategy (WRS), 2002 and National Water Plan (NWP) 2005 by Water and Energy Commission Secretariat (WECS). However, till now there is a lack of official integrated water resources policy to apply IWRM approach. Donor agency such as World Bank (WB), Japan International Cooperation Agency (JICA), Asian Development Bank (ADB), INGOs have implemented IWRM at national and local level but through particular ministry and department. Inappropriate sectoral management of water resources has led to slow development of river basin in Nepal. Recently federalisation has been established in Nepal. Under this federal system of country water resources related administrative boundary and water security is major concerns which may affect the utilization of water resources in different sectors such as irrigation, hydropower, domestic water supply and sanitation.

As an example, we present here a case of Bagmati basin. Federal system in the country has divided particularly Bagmati basin into two states nearly around State-3 (85%) and State-2 (15%) hence equitable access for utilization and sharing of benefits in these states is quite difficult. Management of water resources is multi dimension dynamic process interconnected with different sectors and parameters. Optimisation of available water resources in the basin and balancing between multi stakeholders via the approach of Scenario analysis can help to model many practical problems. Scenario analysis offers new paradigm of understanding hard and complex situations through approaches oriented to problem with different alternatives in sustainable manner (Swart et al., 2004). We use SimBasin, which incorporates hydrological and water resources model (Water evaluation and planning - WEAP model) coupled with a Serious Gaming tool. The Serious Gaming has added a valuable contribution in the field of water resources management as discussion support tool by providing perceptive knowledge and awareness to various stakeholders in managing complex river basin. With the application of Serious Gaming coupled with process-based models (science as the brain behind gaming) policy- and decision-makers, and other stakeholders can easily perceive and understand all facets and concerns of water resources system, assess the impacts and risks of interventions and measures as well as understand reasons of conflicts. Through the optimization and trade-off between different water users such as hydropower, irrigation, water supply, environmental flow through WEAP model under different Scenarios and integration of output from WEAP model to SimBasin as tool for the decision making process of Bagmati basin in an integrated approach considering all water users under one umbrella.

## II. RBAs for IPRBM: First Proposition

### A. *River Basin Management (RBM)*

There are two focal footings of River Basin Management (RBM), namely (i) INTEGRATED that implies integration of multiple use of water as well as related themes and disciplines for process understanding, optimal planning, monitoring and adaptation; and (ii) PARTICIPATORY that implies participation of all water users, communities and stakeholders for close cooperation, conflict resolution and optimal utilization (Giri, 2018). The consideration shall be not only in a basin scale but also in the reach scale given many important problems such as river bed, bank and land erosion, river habitat and ecology, impacts, safety and optimal operation of water infrastructures as well as other reach scale social and environmental problems.

### B. *First Proposition for RBAs in Federal Nepal*

For integrated and participatory management of water resources under federal system of governance in Nepal, we have proposed to establish RBAs. There are some good practices in the World (one of the noticeable is the longstanding experience of Spain as presented by Giri (Giri 2018, 2019a). Following are the rationale of such proposition (Giri, 2019b):

(i) Providing effective water governance particularly under federal and decentralized system where political boundaries do not match with river basin boundaries.

(ii) Facilitating cooperation and coordination between federal and state authorities, public and private developers and water users, communities, technical support departments, knowledge institutions, think-tanks and other relevant stakeholders.

(iii) Enabling proper planning, centralized water use regulation, infrastructure building and management as well as for establishing a unified and efficient monitoring and controlling mechanism from reach to basin scales.

(iv) Enhancing safety and sustainability of water infrastructures such as dams, weirs, barrages, canals etc.

Five major River Basin Authorities have been proposed (Giri, 2019b) as follows:

(i) Koshi RBA (shared by States 1, 2 and 3)

(ii) Gandak RBA (shared by States 3, 4 and 5)

(iii) Karnali RBA (shared by States 5, 6 and 7)

(iv) Mahakali RBA (shared by State 7)

(v) Rapti-Babai RBA (shared by State 5)

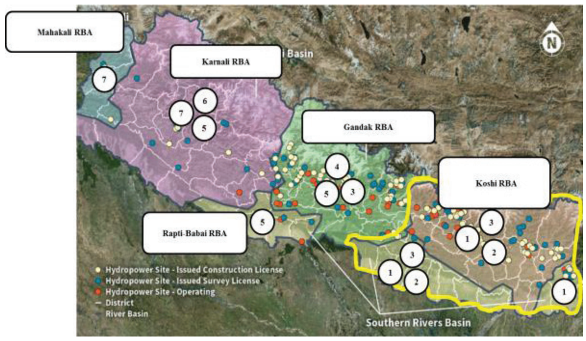


Fig. 1. Five major River Basin Authorities have been proposed (Giri, 2019b; image: Hatch, 2017)

Existing federal, regional and local organizations, bodies, departments, authorities, commissions, committees, user associations could effectively be reorganized for institutional set-up of the RBAs. Similarly, there are already some existing knowledge and research institutions in the country that shall be enhanced, strengthened and adapted for technical support to the RBAs. Federal and regional support and investment in favor of innovative technologies as well as dedicated Research & Development centers, think-tanks, specialized educational institutions and capacity building centers (such as RBM research centers, centers for geomorphological studies, water information and monitoring centers within the RBA, physical and computational modelling centers and laboratories etc.) should be in all levels. In the course of time the changes could be expected in regard to political, economic and social status of the country that might lead to changes in balance between federal and state authorities, capacity and impacts (administrative, financial and technical). There could also be increasing or decreasing influence of the private sector's engagement, roles and impacts. Preparedness and adaptation to such changes are necessary criteria. Regular and close coordination and cooperation between all the concerned bodies (federal, regional and local), departments, committees, user associations and other stakeholders are very important for an effective function of the RBAs (Giri, 2019b).

## III. Development of WEAP Model For Bagmati Basin

WEAP software integrate hydrological and management model to facilitate for the study of integrated water resources management of single and transboundary river basin. Mainly WEAP is based on water balance approach and is convenient to use by balancing water demand and supply. WEAP can be coupled with wide range of both engineering as well as management possibilities for example reservoir operation, flood control, water demand and supply analysis, water allocation, water quality and natural components like baseflow, groundwater, surface water within the river basin. (SEI, 2015). Demand sites are based on the different water user sector as irrigation, hydropower, domestic water supply, environmental flow, industry etc. and water allocation for demand sites in WEAP is established on priority and supply preferences (Yates, et al., 2005). Furthermore in WEAP demand site priority starts from number 1 to 99 with 1 as the highest and 99 as lowest demand priority.

### A. Catchment Delineation

Catchment and streams of Bagmati basin was delineated using Quantum Geographic Information System (QGIS) from catchment delineation method. Two digital elevation model (DEM) tiles of Bagmati basin was downloaded from SRTM 1 Arc-Second Global by means of USGS Earth Explorer through earthexplorer.ugs.gov. Mosaic (merge) of two multiple DEM tiles of study area was done in QGIS from build virtual raster tool to generate single raster layer. The downloaded DEM tile was in geographic coordinate system WGS 84 (EPSG: 4326) and for the further process of DEM raster layer it was re-projected into global projection for Nepal: WGS 84/ UTM zone 45N. DEM raster layer was clipped by using clip raster by extent tool to minimise the algorithms calculation time. For delineation of stream and catchment in QGIS, unprocessed DEM raster layer peaks and depressions was removed by using algorithm and tool fill sinks developed by (Liu, 2006). In order to derive the streams of study area from DEM, Strahler order tool was used. The Strahler order 7 of higher order i.e. bigger streams was used to derive the streams through raster calculator tool. The coordinate of outlet point at the southern border of Nepal near Gaur, Rautahat district was captured and used to delineate catchment of study area via unslope area tool in QGIS. The raster layer of catchment boundary was converted from raster to vector layer using polygonize (raster to vector) tool (Kwast, 2018).

### B. WEAP Model Set-up

The vector layer of basin boundary and river was projected into geographic coordinate system EPSG: 4326 – WGS 84 in QGIS before added in WEAP. The current (base line) scenario was developed for period 2001 to 2017 for the study area. River, demand sites, catchments, reservoirs, run of river hydro, diversion, other supply, flow requirement, stream flow gauge was added. Connection of demand with supply was done through transmission link. Furthermore, return of flow from demand sites to river was done via return flow link. Priorities and supply preferences for demand sites of study area was assigned according to Water Resources Act, 2049 (1992), Nepal (Ministry of Water Resource, 1992).

Runoff (simplified coefficient method) was selected and used for modelling catchment of study area. Rainfall runoff method is simple and convenient method in terms of data requirement which calculate runoff through difference between precipitation and evapotranspiration. The certain percentage of precipitation go into runoff as baseflow i.e. parameter such as effective precipitation. Simulation time period for current (base line) Scenarios starts from 2001 to 2017.

### C. Adaptation of SimBasin and Game Application

The game SimBasin developed by Craven, et al. (Craven, et al., 2017) was modified and applied for Bagmati basin to use as an interactive tool. Simple adaptation of application SimBasin was done for this research. Some modifications were carried out on WEAP model and configuration sheet of game. Then WEAP model of Bagmati basin was coupled with the game model. For this research, the game start year and end year was taken as 2019 and 2039.The base map of study area (Bagmati basin) prepared in QGIS was inserted in the game. On narrative sheet of game, the decisions was amended in Visual Basic for Application (VBA) modules (Indicators, SimCuenca, Strategies respectively) in Microsoft Excel according to interventions (existing and future) already developed in WEAP model. Irrigation, hydropower, domestic water supply are major sectors as well as stakeholders in the study area and these sectors were also used in WEAP for the development of model, hence on that basis these three sectors were selected for adaptation of SimBasin for Bagmati basin. Demand of these sectors was also extracted from WEAP and applied in the game. Furthermore, study area contains three watersheds and the modification of SimBasin was carried out for watershed that holds maximum deficit of water for particular indicator such as domestic water supply – upper watershed and irrigation – lower watershed (Rautahat district).

WEAP water resource model, indicator routine library to calculate indicators built on results of model, decision routine library which execute decisions in model, game manager who accomplish the interaction of all these components, game narrative, graphical user interface (GUI) which convey the communication with players and also the players are the major components of the game. Game manager, indicator routine library and decision routine library are based on visual graphic application, Microsoft Excel Worksheet work as game narrative and GUI includes Worksheet of Microsoft Excel as well as excel user forms.

## IV. Results

### A. Model Calibration and Validation

Calibration of base model i.e. observed and simulated discharge was done for monthly time series from year 1992 to1994 at downstream gauging station Khokana (Department of Hydrology and Meteorology, N.D.). The model calibration between observed discharge at Khokana gauging station and simulated discharge was done manually over the period of 1992-1994 through trial and error to maximize the coefficient of determination ($R^2$) and Nash-Sutcliffe Efficiency (NSE). Calibration was performed by the adjustment of land use input parameter effective precipitation and also changing crop coefficient (Kc) by changing cropping pattern practices used in Bagmati basin. The Kc also followed the value recommended by the Design Manuals for Irrigation Projects in Nepal (M.3 Hydrology and Agro-meteorology Manual – 1990) (Sir M MacDonald & Partners Ltd, et al., 1990). After calibration of discharge between observed and simulated, the calibrated value was used to validate the next nine years i.e. 1995 to 2003 of historical measurement data of streamflow observed in Khokana gauging station located in Bagmati river. The validation result is not good for year 1995 to 1997 however, result for the period of 1998-2003 illustrates fair agreement between observed and simulated discharge and has quite good validation result. $R^2$ and NSE for calibrated years (1992-1994) is 0.853 and 0.713 respectively. While these indicators are different for different period of validated period (1995-2003). The average $R^2$ and NSE for the validated period are 0.803 and 0.714 respectively.

### B. *WEAP Study Scenarios*

For the explorative study of the area (Bagmati basin) with WEAP model, different scenarios including a reference scenario were developed for year 2018 to 2050 in WEAP to evaluate the changes in unmet demand for all demand sites i.e. domestic water supply, irrigation and environmental flow as well as generation of electricity from existing and planned projects. Here are the scenarios:

1) Reference Scenario: The scenario was developed for year 2018 to 2050 and the input parameter such as population and irrigated area was considered same as baseline (present) condition. The objective of this scenario was to visualize the changes in unmet demand of demand sites for coming future years under the present situation (no changes).

2) Scenario 1: Scenario with change in population growth

3) Scenario 2: Scenario with change in population growth and growth in irrigation demand

4) Scenario 3: Scenario with change in population growth, growth in irrigation demand and consideration of planned projects

### C. *Analysis of Current (Baseline) Scenario*

Result of baseline scenario clearly reflects that mainly during dry period Bagmati basin has unmet demand for all sectors i.e. domestic water supply, irrigation and environmental flow. Upper watershed has maximum shortfall of 90% in domestic water supply nearly in November and December. The continuous increase in population inside Kathmandu valley and rapid unplanned urbanization has successively escalated the water demand in upper watershed. Rautahat and Sarlahi districts have high shortage of water for irrigation during entire dry season (October – May) of about monthly average flow 17 $m^3/s$ to 22 $m^3/s$ respectively which is nearly 98% of unmet demand for each month. This clearly shows lower watershed irrigation is totally dependent on monsoon rainfall. However, lower watershed has tremendous potential for groundwater and aquifers which are highly productive in lower watershed. Groundwater is important and supplementary source for irrigation in lower watershed particularly in dry period and around 40% of irrigation is being performed through groundwater (JWA Japan Water Agency, et al., 2018). Despite being very an important source for irrigation, due to lack of data, groundwater was not considered in this research. Therefore, the reason for such huge water stress in supply and massive gap between supply and demand for irrigation in Rautahat and Sarlahi district is also because of not considering groundwater in this research.

A noticeable huge unmet in-stream flow requirement (environmental flow) was observed in lower watershed mainly during pre and post-monsoon period. The deficit of flow for environmental purpose is more than 95% in lower watershed which reflects lower watershed of Bagmati basin is highly water deficit watershed relative to other two watersheds. Every sector of all watersheds has high monthly average unmet demand on November which is likely due to less rainfall during post-monsoon period and Bagmati basin holds the same rainfall pattern throughout the basin. Monthly electricity generation in Bagmati basin is found to be maximum during monsoon season (June - September) that exhibits electricity production is mainly depended on monsoon flow of the river. Moreover, in base line scenario all hydropower projects in Bagmati basin except Kulekhani dam are runoff river hydropower. However, major operation of Kulekhani dam is only for electricity production. Therefore, that leads to high monthly electricity generation during monsoon season.

### D. *Analysis of Scenarios*

Comparison between all scenarios for all sectors (monthly average and yearly) are depicted in Figure 1 to Figure 6. In every watershed Reference scenario and Scenario 1 has same monthly average and yearly unmet demand due to same growth rate of irrigated area. While Scenario 3 holds less shortage of water for irrigation this underlines that after the development of reservoirs and inter basin transfer of water will help to address the water deficit for irrigation in study area. Due to growth in irrigated area Scenario 3 has high yearly unmet demand compare to Scenario 1 and 2. From 2018-2029 yearly unmet demand is similar in both districts i.e. Rautahat and Sarlahi of lower watershed because of same irrigated area for all Scenarios. However, in 2030 there is drastic decline in unmet demand for both districts due to development of inter basin of water from another basin. Because of increment in irrigated area from 2031 there is again increase on unmet demand at Rautahat and Sarlahi district. It is also noted from result that Scenario 2 has highest shortfall of water in all watersheds because this scenario is developed with probable growth rate of population and irrigated area without any future interventions that can support to reduce the deficit of demand. Though after inter basin of water from another basin, Sarlahi district still holds the great shortage of water which likely due to highly growth in irrigated area. Furthermore, groundwater has not consider for study of future period (2018-2050), hence the result of all scenarios is presenting the situation of huge unmet demand in Bagmati basin.

Monthly average unmet environmental flow (Instream Flow Requirement) at each watershed is seen quite low in Scenario 3 after development of reservoir and inter basin transfer. Scenario 1 and 2 hold equal unmet flow rate for environmental purpose due to equal priority is assigned for domestic water supply and Instream Flow Requirement, additional same population growth rate is also used for both scenarios. In all three watersheds Reference scenario has slightly less unmet environmental flow compare to Scenario 1 and 2 due to low population growth rate (5.30%, 0.38% and 2.33%). In Scenario 3 after the construction of Kokhjor-1 Hydropower Project and Sunkoshi Marin Diversion Project annual electricity generation has sharply increased to very high from 2030 (667 Million- Kwh) with maximum of 858 Million-Kwh on 2047.

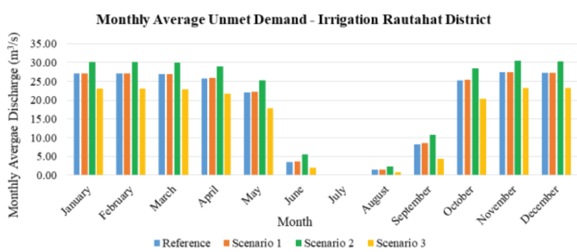


Fig. 2. Monthly Average Unmet Demand - Irrigation Rautahat district (Lower watershed)

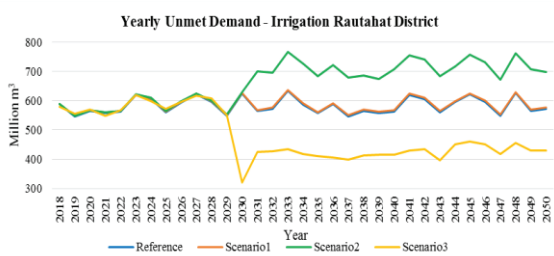


Fig. 3. Yearly Unmet Demand - Irrigation Rautahat District (Lower watershed)

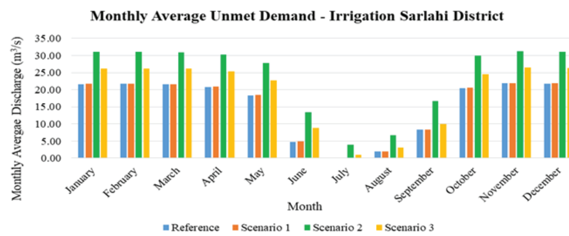


Fig. 4. Monthly Average Unmet Demand - Irrigation Sarlahi district (Lower watershed)

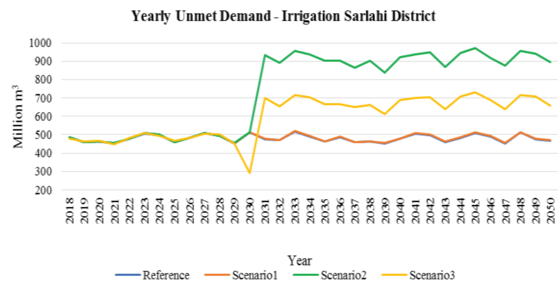


Fig. 5. Yearly Unmet Demand - Irrigation Sarlahi District (Lower watershed)

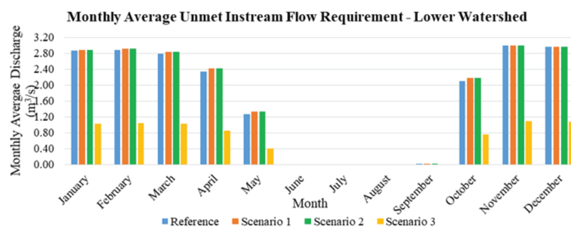


Fig. 6. Monthly Average Unmet Instream Flow Requirement - Lower Watershed

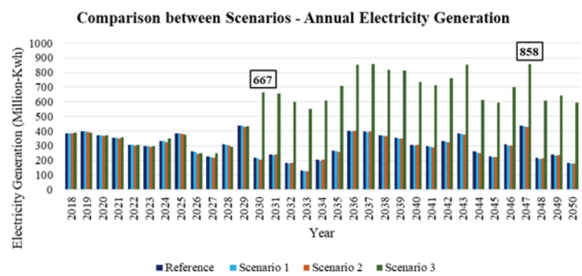


Fig. 7. Comparison between Scenarios - Annual Electricity Generation

## *E. SimBasin Gaming Result*

Result of game SimBasin shows that among all indicators irrigation has the highest total penalty points of 20 which indicates that supply does not satisfy the demand during the entire game year (2019-2039) i.e. grey - possible range zone and red - failure zone both overlaps with each other as shown in Figure 7 that cause indicator value to drop inside the failure zone and penalty point has occurred. The strategies such as improvement of irrigation system and inter basin transfer from Sunkoshi Marin Diversion Project was also adopted but the demand for irrigation is huge hence unmet demand is still quite high. Domestic water supply has zero penalty point that illustrates supply has totally satisfied the demand and decreased the unmet demand to zero. Similarly, hydropower holds penalty points of 10 that reflects electricity demand is satisfied after application of strategies for electricity production. Furthermore, for hydropower during baseline and 1 round (2019 – 2023 and 2024 – 2028 respectively) the value drop into the red zone as shown in Figure 8 because supply does not satisfy the demand as a result penalty points appear.

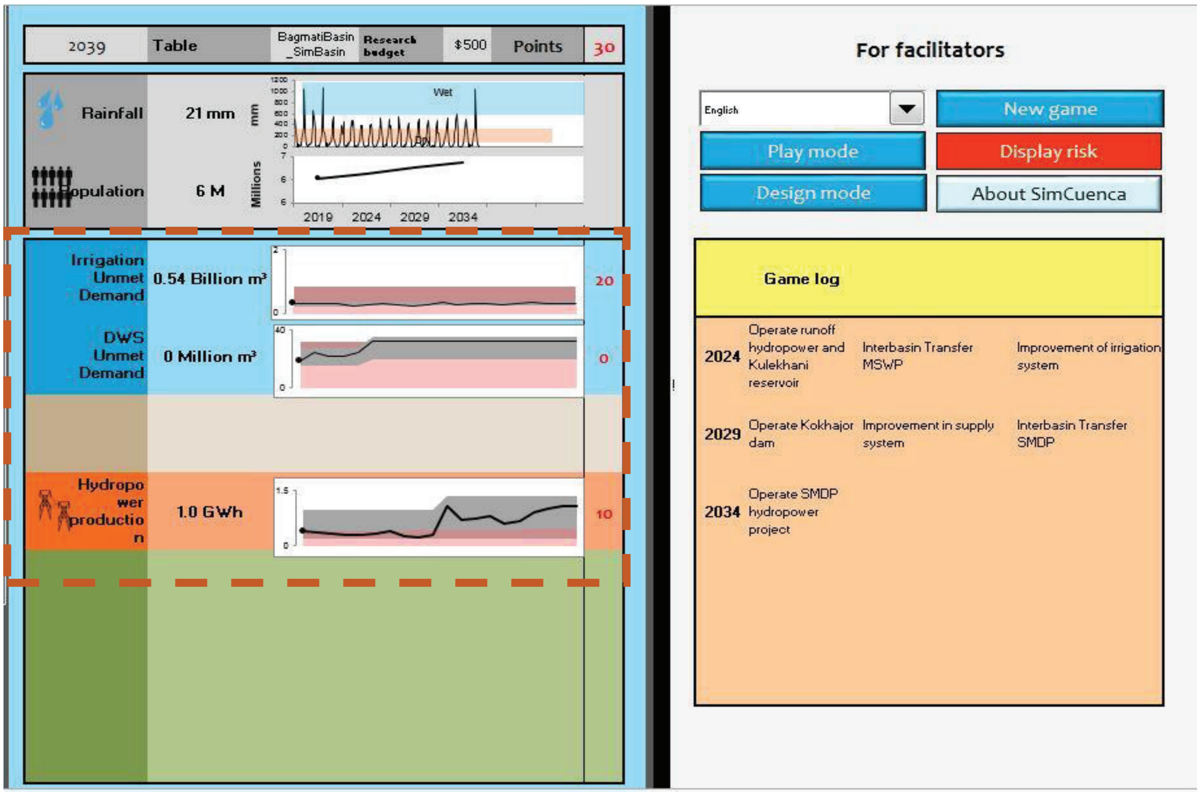


Fig. 8. Game Result Sheet with strategies adopted for study area

## V. Conclusion and Recommendation

We proposed Integrated and Participatory approach under the institutional basis of strong River Basin Authorities that could be very appropriate considering the infant federal system in Nepal and multiple use of water resources. This is thought to be inevitable to achieve the goal of safe and sustainable operation, management and governance of water resources and infrastructures.

Furthermore, we demonstrated how knowledge base tool can be applied as a basin planning tool to support the activities of RBAs in an example of Bagmati basin. The study analysed and evaluated the present and future unmet demand for different sectors such as domestic water supply, irrigation, hydropower and environmental flow in Bagmati basin using scenario analysis in WEAP model, integrated in SimBasin with a gaming tool.

### *A. Current quantitative situation of water resources in Bagmati basin:*

- The results from this research presents that on baseline scenario (2001-2017) the study area has quite high unmet demand mainly during dry season. Upper watershed has the highest monthly average unmet demand (0.79 $m^3/s$, around 90%) on November for domestic water supply.
- In lower watersheds Rautahat and Sarlahi districts have high unmet demand for irrigation throughout dry season (October to May) that is nearly about 98% (average) for each month. Maximum highest monthly average unmet flow for Rautahat and Sarlahi districts are 22 $m^3/s$ and 17 $m^3/s$ respectively.
- Environmental flow is relatively quite high during dry period (November to April) throughout the basin. Upper and middle watersheds have comparatively lower unmet instream flow requirement compared with lower watershed. Among three watersheds, lower watershed has high deficit of water for environmental flow mainly during November and December of about 3 $m^3/s$.
- Monthly generation of electricity in study area (Bagmati basin) is maximum during rainy season (June - September) which demonstrates that electricity production in runoff river hydropower is predominantly governed by monsoon flow.

- Therefore, this illustrates that Bagmati basin is fully dependent on monsoon rainfall. In spite of huge potential of groundwater as supplementary source for irrigation as well as domestic purpose mainly in lower watershed, due to lack of data, the research conducted only considered the surface water as supply source for all sectors. Thus, consideration of only surface water points out more unmet demand for all sectors in Bagmati basin. Moreover, conflict between major and minor stakeholders on water demand and supply are major setback of sectoral decision making practices in study area. Recent transformation of country into federal states has added additional complications in planning, development and management of river basins.

*B. Future scenarios considering future interventions (measures):*

- Monthly average unmet environmental flow in overall watershed is seen to be quite low after development of reservoir and inter basin transfer. The annual electricity generation is very high after construction of Kokhjor-1 Hydropower Project and Sunkoshi Marin Diversion Project.
- In 2030, yearly unmet demand in Rautahat and Sarlahi District (lower watershed) is significantly declined for both districts due to development of Sunkoshi Marin Diversion Project but again increased on unmet demand at Rautahat and Sarlahi district because of high growth in irrigated area.
- Reference and Scenario 1 shows tentative similar results (unmet demand) due same irrigated area for both scenarios.
- The development of future projects through integrating possible interventions has shown reduction in unmet demand to some extent on all sectors even after future possible growth as well. This illustrates future interventions as inter basin transfer and reservoirs will decrease the unmet demand partly. Therefore, consideration of groundwater is requisite to know the precise water balance between demand and supply for future development.
- Furthermore, the result of uncertainty such as climate change scenario in Bagmati basin has indicate decline in unmet demand for all sectors and increase in production of electricity in future.

*C. Application and usefulness of SimBasin*

Linking of developed water resource model WEAP to SimBasin and the points result display in SimBasin has provided better visualization that could be useful for decision making process. Hence, balancing available water resources of study area using scenario analysis through WEAP and adaptation of SimBasin as an interactive tool to incorporate integrated and participatory approach shall be appropriate for the planning and management of Bagmati basin, Nepal.

*D. Limitations of the research*

Although the study area has tremendous potential of ground water, this research is performed only by taking into account of surface water due to absence of groundwater data and model as well. Furthermore, reliability of meteorological and hydrological data, lack of demand and input data, consultation with stakeholders and time as well are major limitations.

*E. Recommendations*

- Further analysis of WEAP model either using Groundwater – Surface water flow method (directly) or linking WEAP with MODFLOW to consider groundwater in study area is essential to understand precise water balance between supply and demand for future management of study area in an integrated manner.
- Limitations of lack of availability of updated and reliable data some practical and theoretical assumptions are made for input parameters of hydropower, land use data (Kc, effective precipitation) demand sites, environmental flow, energy demand in Bagmati Basin which may require more update for future works.
- Economic analysis of hydropower and irrigation projects in WEAP is prerequisite to analyse the benefits for economic development of Bagmati basin.
- The study area is highly affected by flooding and sedimentation however because of limited time and data as well for research these two sectors are not taken into consideration, so it is highly recommended to consider flooding and sedimentation for future studies.
- Additionally, modification of SimBasin for study area has particularly done for hydropower, irrigation and domestic water supply due to research time constraints and other sectors such as flooding, sedimentation etc. has not include in WEAP model. Hence, adaptation of all these sectors shall be prerequisite for game SimBasin to use as an interactive tool in forthcoming years.

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