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Modelling future water supply and demand in Jharkhand region of Subarnarekha River basin by using weap model with RCP 4.5

Randhir Kumar*[1], Pratibha Kumari[1], Ajai Singh[4], P.K. Parhi[2] and V.K. Tripathi[3]

[1,2,3]Department of Water Engineering and Management (DWEM), Central University of Jharkhand (CUJ), Brambe, Ranchi, Jharkhand, India
[4]Department of Farm Engineering, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, U.P., India

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ABSTRACT

The allocation of scarce available water resources requires careful planning and implementation. This can be accomplished only when complete information about water availability and demand for water of all the stakeholders is known. The present study applies the Water Evaluation and Planning System (WEAP) Model to evaluate water resources vulnerability under future climatic conditions inthe middle reach of the Subarnarekha river basin, Jharkhand, India. The Subarnekha river basin covers the area in the states of Jharkhand, Odisha and a comparatively smaller parts in West Bengal. The WEAP model was developed by the Stockholm Environment Institute (SEI) for evaluating the planning and management of water resource systems. Demand sites were classified as an industry, water demands of institutional, agriculture, and human and livestock population. Each demand site was connected to its source and where applicable a return link mas made to a river. Annual water use rate/person, per hectare for agriculture and per head of livestock were determined and changed into cubic meter per annum and used as input to the WEAP model. For the WEAP modeling framework, the year 2017 was chosen as a current year for which all available required information and input data were given to the model and future water demand situation was analyzed for the period 2018 – 2030. The projected annual rainfall (mm) over the middle reach of Subarnarekha river basin, for GFDL-ESM2M with RCP4.5, during 2017-30 (14 years) was determined. Dry conditions with an annual rainfall of nearly 716 mm for the year 2022 was predicted. Whereas, the year 2026 would experience high rainfall (1945 mm) indicating a wet condition. The remaining years would experience the normal rainfall condition. The years expected to encounter heavy rains also show high runoff value and vice versa. The model calculated water demands were always on a higher side than actual water use rates of population and livestock. These higher demand calculations are reflected in unmet demands. Demands are higher in non-monsoon months than in monsoon months as expected. Annual (2017-2030) domestic/ population and livestock unmet demand for the Subarnarekha river basin was also estimated and it was observed that the unmet demands would experience a decrease in the years 2019, 2021, 2024, 2026, 2028.

Key words : *Water availability, Demand, Water supply, WEAP model, Subernarekha, Jharkhand.*

([1],[2]Research Scholars, [2]Assistant Professor, [3]Assistant Professor, [4]Professor)

Introduction

Water is an important component of our life and its availability is at the core of sustainable development of any region. The appropriate management of scarce available water resources is essential to ensure livelihood security to address poverty. Many regions are facing serious water resources shortage and especially dwindling freshwater resources management challenges the water resources managers and planners. Allocation of available water resources, keeping in view the environmental concern, variability in climate and uncertainty, need to be planned and implemented for sustainable water use strategies. The Water Evaluation and Planning System (WEAP) model is able to consider a wide range of issues such as analysis of water demand of different stakeholders, water rights and priorities of allocation, simulation of runoff, optimal operation of reservoir, ecological requirements and cost-benefit analysis of any water resources project (Metobwa *et al*., 2018). Recently many applications of the WEAP model have been noted in optimal water resources planning and allocation under future climate scenarios (Metobwa *et al*., 2018; Bhave *et al*., 2018; Berredjem and Azzedine, 2017; Agarwal *et al.,* 2017; Kanani *et al.,* 2017; Mansouri *et al.,* 2017; Yates *et al.,* 2009). Bhave *et al.* (2006) applied the WEAP model to determine the water availability and demand in the Kangsabati river basin, India. WEAP model can also be used to water supply system to study the future water demand, delineate the risk and flood-prone area, and to study rainfall-runoff processes (Singh *et al.,* 2014; Saxena and Yadav, 2016; Shahraki *et al.,* 2016; Bharati *et al.,* 2008).

The Subarnarekha River basin is one of the major river basin of the Chhotanagpur Plateau in the state of Jharkhand, India. Different water users such as Agriculture, Rural and Urban settlement, Mining, Forestry and, Industries are present in the catchment. The erratic change of pattern of hydrologic variable and the possible impact of climate change makes it difficult to quantify the available water resources to satisfy the increasing water demands. Future water need also needs to be ascertained under climate change conditions. Keeping the above points in view, this study undertakes the application of a water allocation model to evaluate the availability and demand scenario of water resources by using WEAP Model under future climatic conditions in the middle reach of the Subarnarekha river basin, Jharkhand, India.

Materials and Methods

Description of study area

The Subarnekha river basin covers the part of the states of Jharkhand, Odisha and comparatively smaller part in West Bengal and its total geographical area is 25792.15 km^2. Its principal tributaries are the Kanchi, Karkari and Kharkai. The basin is generally dominated by the south-west monsoon which onsets in the month of June and extends up to October. The river basin receive the annual rainfall as 1400mm and average annual maximum temperature prevails as around 30 ^{o}C. The sub-basin has a tropicalclimate with hot summer and mild winter. The agricultural land covers around 53.8% of the basin area, forests covers 25% and around 2.40 % of the basin area is covered by water bodies. The location map of the Subarnarekha basin lying within Jharkhand is shown in Fig. 1. The Ghatshila, Jamshedpur and Adityapur are the main hydrological site where regular stream flow is measured. The annual rainfall pattern is shown in Fig. 2.

Fig. 1. Location map of the study area

WEAP Model Application

The model was developed and validated to practical application by the Stockholm Environment Institute (SEI) and being used for evaluating the planning and management of water resource systems. WEAP is applied to watershed dominated by urban areas

Fig. 2. Trend analysis of observed rainfall (2010-2017)

as well as for agricultural watershed and tackle a large number of issues such as analysis of sectoral demand, provisions for water conservation, water rights and allocation, stream flow simulation, optimum operation of reservoir and water requirement for ecological balances. WEAP has the ability to perform simulation of all the hydrological processes which helps in thedetermination of the total available water within a watershed and it also takes care of consumptive and non-consumptive demands of water (Sieber, 2006).

The water demand and supply system includes the various water sources such as surface water, groundwater and water reuse elements, withdrawal of water, and connections of various sources and withdrawal points, optimum operation of reservoirs, and different sectoral water demands. The data structure and complete details are provided by connecting the demand sites to its all the requirements and limitations. A mass balance of flow in a river system takes care of the withdrawals and inflows during the modelling process. The river is divided into reaches in order to simulate the complete water resources systems. The reach boundaries are ascertained by the points in the river where there is a change in flow due to confluence with a tributary, abstraction, return flow, or due to the presence of a dam or a flow gauging structure.

In the WEAP modelling, a baseline year is chosen for which the water availability and demands are determined. Further, alternative scenarios are made and the model is used to simulate to assess the impact of different development and management options. An iterative Linear Programming algorithm is applied to optimize the water use in the basin with an overall objective to maximize the water delivered to demand sites according to the priorities set earlier. All the demand sites are prioritized with a number ranging from 1 to 99, where 1 indicates the highest priority and 99 the lowest. When water is limited, the algorithm has been formulated to gradually reduce water allocation to those demand sites having the lowest priority. More details of the model are elaborated (Sieber, 2006; SEI, 2006).

Preparation of schematic and input data structure

The preparation of schematic is the initial activity in the WEAP modelling process wherein the physical elements such as the water demand-supply system and their spatial relationships, the study time period, units and the hydrologic pattern are defined. The detail methodology followed in the study is shown by a flow chart given in Fig. 3. The graphical interface is quite helpful in describing the physical features of the water supply and demand system of the catchment. Different GIS vector layers are added as overlay or background on the schematic as shown Fig. 4. Solid arrow lines represent transmis-

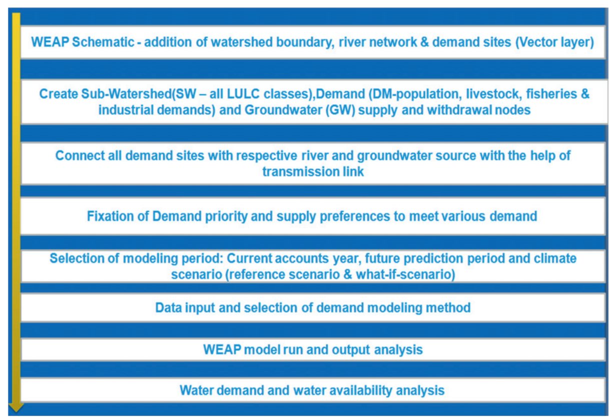

Fig. 3. Flowchart of WEAP model for Subarnarekha river basin

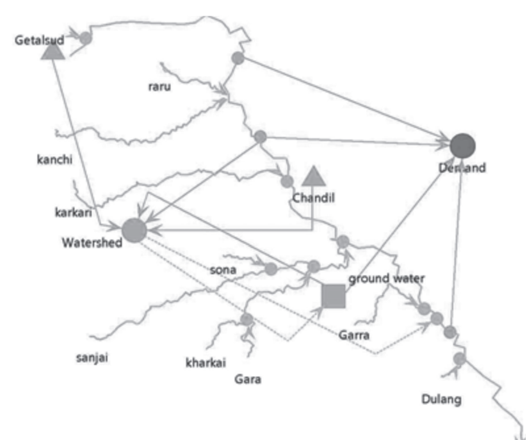

Fig. 4. Schematic of WEAP model for Subarnarekha river basin

sion line for demand management and dotted arrow line represents Runoff/Infiltration whereas solid circles on Main River indicates water withdrawal and inflow nodes. A demand site is the set of water users that share the water through a physical distribution system. Demand sites used in this study were classified as industry, institutional water demands, agriculture, and human and livestock population. Each demand site was connected with the help of a transmission link to its source and a return link was also connected directly to a river, if required. In this study, annual water use rate/person, per hectare and per head of livestock were determined and converted in to cubic meter per annum and used as input to the WEAP model.

The data pertaining to groundwater, reservoir storages, land uses, agricultural crops, topographic features, demography were collected from different sources. The various GIS layers such as river and water bodies, canal network, land use map and topography of the watershed were used to extract information for input to WEAP model. Agriculture is the primary source of income of the people in Subarnarekha river basin. Wheat, Potato, Pulses and vegetables are the major crops grown in the area. Areas under major crops were collected from Department of Agriculture, government of Jharkhand. The land use land cover map was prepared and shown in Fig. 5. The land use was classified in the category such as Agricultural Land, Built-up Land, Dense Vegetation, Sparse Vegetation, Barren Land and Water Body. The agriculture accounts for 45% of total land area.

Priorities for Water Allocation

In WEAP model, a standard linear program has been developed to address topriorities the water allocation scenario with an objective to maximize fulfilment of the demand, ensure supply preferences, preferences to a demand site, mass balances and other constraints. Demand sites having higher priorities (1) are taken up first followed by the lesser important demand site. Reservoirs are assigned 99 which indicates that they will filled after satisfying all other demands. Different demand sites can share the same priority status. If there is more than one source of water to meet the requirement of aparticular demand site, accordingly supply preferences can be assigned. The WEAP model fixes the allocation order keeping in view the demand priorities and supply preferences. The order of allocation of sources and demand site represents the way actual calculations are made by WEAP model (Fig. 6). Domestic and livestock was ranked at number 1 followed by agricultural water demand.

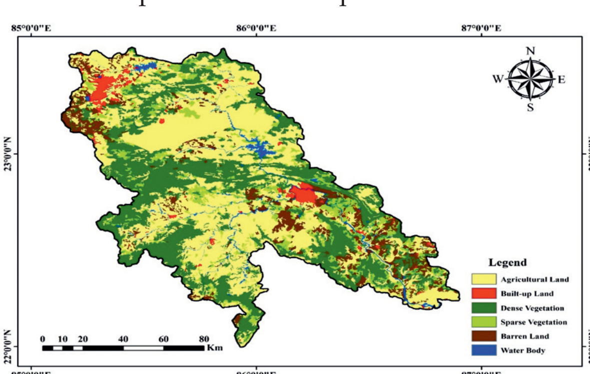

Fig. 5. Land use/land cover map of Subarnarekha river basin

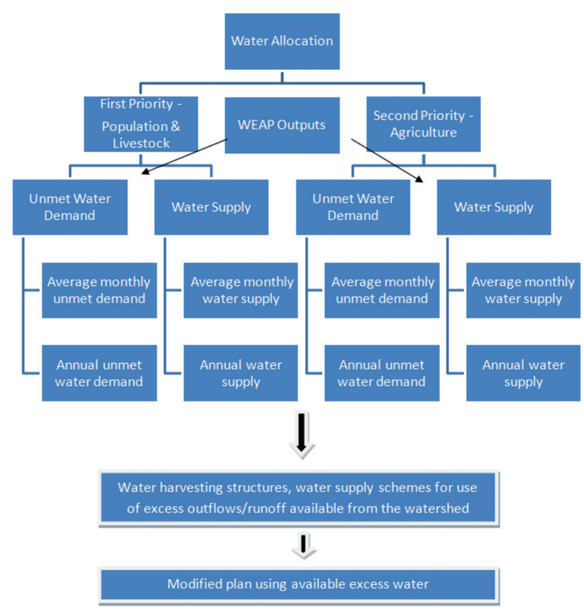

Fig. 6. Flow chart representing water allocation (demand and supply) in Subarnarekha river basin

Scenario Analysis

Scenarios are formed with the help different alternative sets of course of actions or policy initiatives and followed by careful evaluation of these scenarios with respect to water availability and sufficiency, costs and benefits, compatibility with environmental guidelines, and sensitivity to uncertainty in key parameters. The scenarios generation deals with the assessment of impact of possible course of action on available water resources. Scenarios formation can be helpful in answering the impact of population growth, land use change, increase in urbanization, and implementation of modern methods of irrigation and economic development patterns on available water resources and how the demand of water may change? All scenarios start from a common year or baseline year, for which a Current Accounts data is made. The comparison of different alternative scenarios determine the optimum development policy for water resources system. "Current Accounts" year is chosen to serve as the base year of the model. A reference scenario is made from the Current Accounts in order to assessthe possible development of the system without any considerable intervention. The computation of the Subarnarekha river basin model was carried out by formulating the complete model for the reference scenario which was generated by using Current Account information for the specified period of the time for the project. For WEAP modeling framework, the year 2017 was chosen as a current year for which all available required information and input data were given to the model and future water demand situation was analyzed for the period 2018 – 2030. WEAP model has the capability of inclusion of the effects of demand sites management on water systems of the catchment. The agricultural sector was taken by crop types, irrigated areas and irrigation techniques. An urban and rural sector water demand was estimated by census data of 2011. Industrial demand was assessed by visiting the concerned industry which was included in domestic water demand Priorities for allocating the water sources for a particular demand sites was specified.

Results and Discussion

Hydrologic Analysis

This study demonstrates the ability of WEAP model to simulate changes in water demands and unmet demand. The results are divided into three section viz. Hydrologic analysis, Water allocation and Scenario generation for watershed. The hydrologic analysis of Subarnarekha river basin includes the rainfall pattern during 2010 - 2017 over the watershed, groundwater flow/storages, runoff pattern and water demands for the domestic (population and livestock) and agricultural sectors. The projected annual rainfall (mm) over the Subarnarekha river basin, for GFDL-ESM2M with RCP4.5, during 2017-30 (14 years) is shown in Fig. 7. It has been predicted that the conditions to be very dry with an annual rainfall of nearly 716 mm for the year 2022. Whereas, year 2026 would experience high rainfall (1945 mm) resulting in to wet conditions. Remaining years would experience the normal rainfall condition. The climate model predicted the future dry and wet conditions for the watershed which will help in amending or improving the already existing water conservation strategies in Subarnarekha river basin where surface runoff is very high. The planning of future water resources project can include the harvesting of excessive projected rainfall of wet years to use it in dry year/period or to recharge ground water storage to improve water table level for future water use for domestic as well as agricultural sectors. Without the effective water resource management, the domestic and agriculture sectors would have experience the severe water problems.

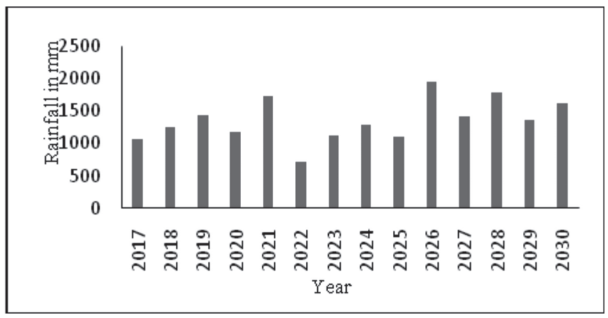

Fig. 7. Projected annual rainfall over Subarnarekha river basin

The Fig. 8 depicts average monthly flow to Groundwater from different Land use/land cover classes of Subarnarekha river basin. The maximum flow to the groundwater storage has been found in the monsoon months as compare to the non-monsoon months as an obvious phenomenon. The Fig. 8 depicts the same tradeoff in flow to groundwater from the rainfall. This figure also shows the flow to groundwater in winter months because of the fact that Subarnarekha river basin also receives winter rainfall frequently. Further, Fig. 9 shows the total annual flow to the groundwater from the watershed. Year 2022 contribution to the flow to groundwater is lowest among other years because of the fact that the year 2022 is predicted to be driest year and receiving minimum rainfall of about 716 mm. Being the highest rainfall year, 2026, shows maximum flow to the groundwater. Rest of the years also shows the same tradeoff of that respective predicted rainfall. This shows the good simulation modeling capability of the WEAP with respect to the natural system. This estimate could help in planning groundwater recharging structures in the watershed to replenish the water table for dealing demands in the water scare period.

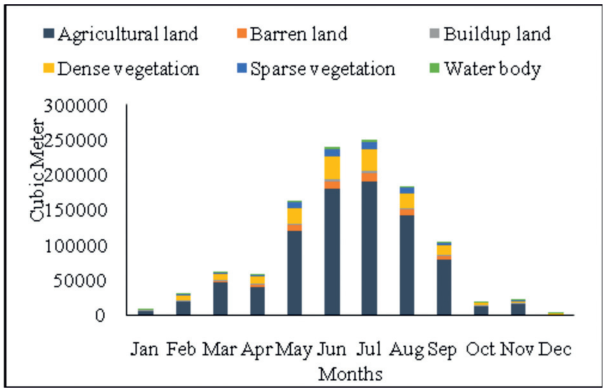

Fig. 8. Average monthly flow to groundwater from watershed

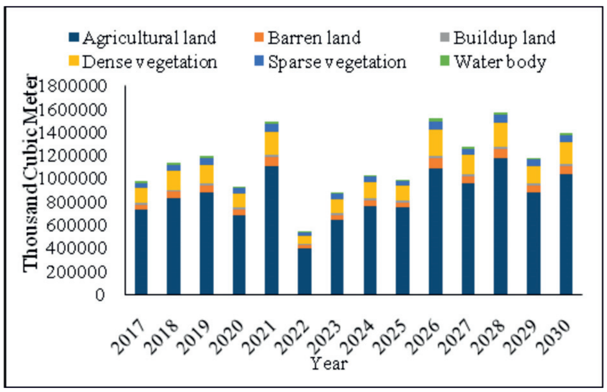

Fig. 9. Annual flow to groundwater from watershed

Another important observation here is that the flow from the forest land to the groundwater is maximum because of the fact that Subarnarekha river basin is agricultural watershed with agriculture area of about 45% of total watershed area. Contribution from buildup land to the groundwater flow is minimum among the all land use/land cover classes of the watershed because of two reasons: being imperious (infiltration process suppressed) area due to settlement activity and lowest percentage share (about 1%) of the total watershed area. This flow to the groundwater helps in increasing the water table of the area which can further be used in dry years and with-in-year water scarcity period if any groundwater schemes developed in the area.

Surface Runoff

The Fig. 10 represents the average monthly surface runoff of 14 years predicted to be occurring in the Subarnarekha river basin. The WEAP model uses Natural Resources Conservation Service - Curve Number method (NRSC-CN) to calculate the surface runoff. Runoff gradually increases from May to August and is highest in the month of July. As watershed also receive the winter rainfall, thereby showing runoff in winter months. Fig. 11 represents the annual total surface runoff from the Subarnarekha river basin and is showing the projected rainfall-runoff tradeoff of 14 years, e.g. year 2022 shows lowest surface runoff among the other years because of the fact that year 2022 is projected to be driest year among others and year 2026 shows highest surface runoff being wet year. The annual variation in runoff value is in correlation with the annual rainfall behavior expected. The years expected to encounter heavy rains also show high runoff value and vice versa.

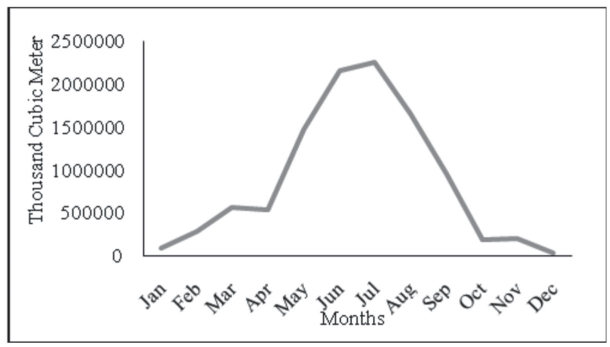

Fig. 10. Average monthly surface runoff from watershed

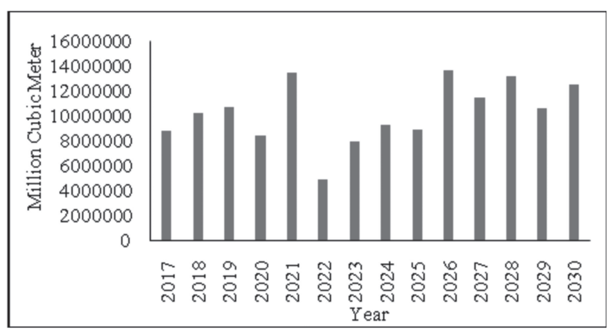

Fig. 11. Annual total surface runoff from watershed

Water demands

Population and Livestock water demands

Fig. 12 shows the average monthly water demands for the population and livestock computed by the WEAP model separately. The graph gives a clear picture of average monthly water demands of population and livestock in Subarnarekha river basin. For calculation of monthly water demands, the standard use rates defined by Bureau of Indian Standards have been used (annual water use rate: For Domestic = 25.55 m^3/person (70lpd) and for Livestock = 70m^3/ livestock). The demands are calculated as per the number of days in the month.

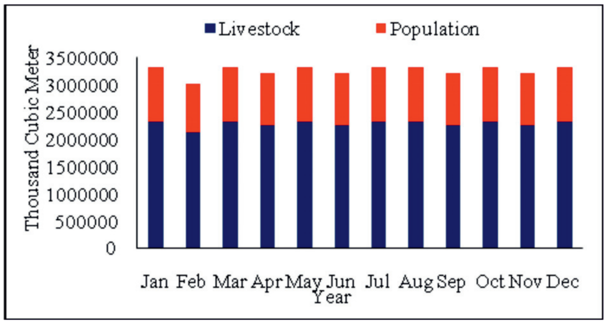

Fig. 12. Average monthly demand of Population and Livestock

Agriculture water demand

The WEAP model calculates the agricultural demand on the basis of Crop coefficient (Kc) approach of Rainfall-Runoff (Simplified Coefficient Method) method. The projected average monthly agricultural water demand for the year 2017-2030 in Subarnarekha river basin is shown Fig. 13. It can be seen that rain water is available to meet out the crop water demand in monsoon months. The agriculture demand gradually increases from November end, highest in April and decreases June onwards. Average monthly demand of agriculture in March shows less demand than February and April may be because of the fact of winter rainfall. However, WEAP performance to predict the average monthly demand of agriculture of winter months is not showing promising results for Subarnarekha river basin. Fig. 14 gives the representation of projected annual demand of agriculture for 2017-2030. The demand varies with the amount of rainfall to be received in the respective years. Dry condition is predicted in the year 2022; corresponding agricultural demands are thus expected to be high in this year because of more number of hot days, which leads to higher evaporative demands. In year 2026, annual demand of agriculture is expected to be lowest due to high rainfall prediction. On similar account, demands are expected to be low during normal and wet years/ seasons due to low evaporative demands and availability of rain water (Fig. 13 & 14).

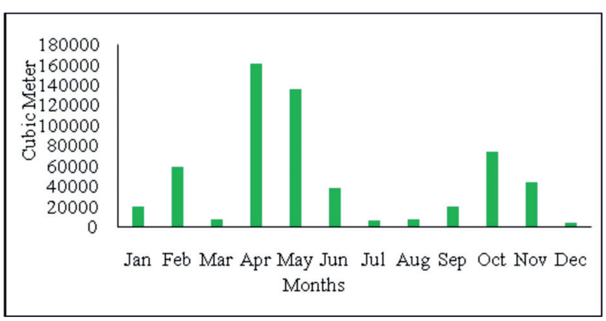

Fig. 13. Average monthly agricultural demand

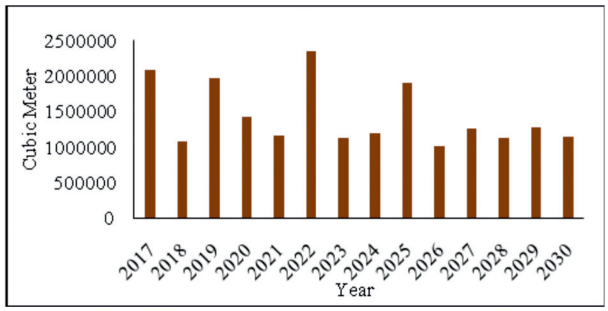

Fig. 14. Annual agricultural demand

Water Allocation

Average monthly and Annual Unmet Water demands of Population and Livestock

Average monthly unmet demands of population and livestock of Subarnarekha river basin are presented in Fig. 15. The model calculated water demands are always on higher side than actual water use rates of population and livestock. These higher demand calculations are reflected in unmet demands. Demands are higher in non-monsoon months than in monsoon month as expected. An-

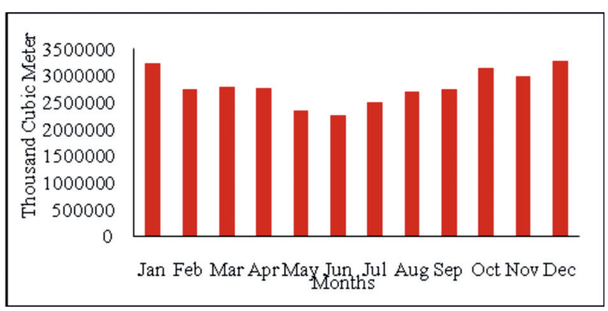

Fig. 15. Average monthly unmet water demands of population and livestock.

nual (2017-2030) domestic/ population and livestock unmet demand for Subarnarekha river basin has been given in the Fig. 16. The unmet demands will experience decrease in the years 2019, 2021, 2024, 2026, 2028 etc. This is directly related to the amount of predicted rainfall in these years which is comparatively higher than in rest of the years (Fig. 7). Unmet demands will be high in the predicted very dry years, i.e. 2017, 2022 and 2025.

Average monthly and Annual Water Supply to Population and Livestock

During formulation of WEAP model for Subarnarekha river basin, the demand priority for domestic and livestock was taken as 1, i.e. highest and second priority was fixed for the agriculture sector. To meet out the demands of population and livestock, the river water withdrawal schemes were set as first preference and groundwater scheme with second preference. The WEAP simulation for average monthly supply delivered to population and livestock is shown in Fig. 17. While simulation, the standard water requirement of population and livestock was kept as per the Bureau of Indian Standard as mentioned in the previous sections. The water supply in monsoon months is significantly related to the projected rainfall over the watershed which increases the river water supply (the first preference) directly. Further, in winter months due to winter rainfall, it is possible to supply the water partially for satisfying the demands of population and livestock in the respective winter months.

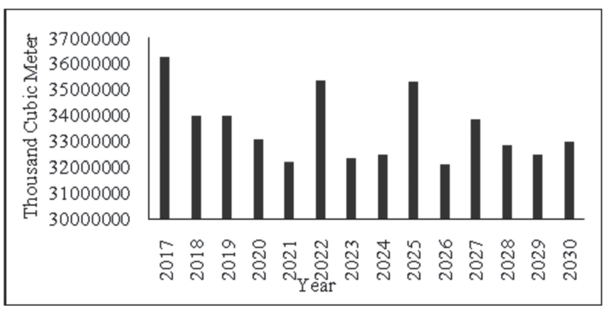

Fig. 16. Annual unmet water demands of population and livestock

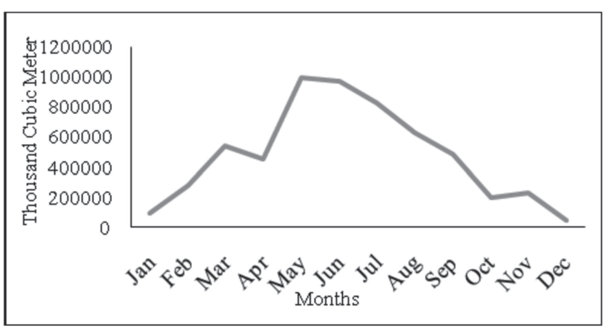

Fig. 17. Average monthly water supply delivered to population and livestock

Conclusion

This study develops a WEAP model for evaluating the annual and monthly unmet water demand, projected monthly and annual rainfall and surface flow for middle reach of Subarnarekha river basin where water scarcity is observed during lean season. In this study, an effort was made to utilize the integrated hydrology and water allocation model to evaluate water resources vulnerability using WEAP Model under future climatic conditions. For WEAP modeling framework, year 2017 was chosen as a current year for which all available required information and input data were given to the model and future water demand situation was analyzed for the period 2018 – 2030. The projected annual rainfall (mm) over the Subarnarekha river basin, for GFDL-ESM2M with RCP4.5, during 2017-30 (14 years) was determined. It has been predicted that the conditions to be very dry with an annual rainfall of nearly 716 mm for the year 2022. Whereas, year 2026 would experience high rainfall (1945 mm) resulting in to wet conditions. Remaining years would experience the normal rainfall condition. The years expected to encounter heavy rains also show high runoff value and vice versa. The model calculated water demands are always on higher side than actual water use rates of population and livestock. These higher demand calculations are reflected in unmet demands. Demands are higher in non-monsoon months than in monsoon month as expected. The monthly variations in water availability for different sectoral water demand should be considered when formulating any economic development plans and policies. The WEAP model could prove to be a powerful and useful tool for water resources managers and planners, with its user-friendly interface and robust evaluating and scenario analysis capability. It can be coupled with the models of water quality, groundwater, energy, and climate to help policy makers to understand the water availability and their allocation for current and future periods, which are important basis for any rational water policy initiatives.

References

Agarwal, S., Patil, J., Goyal, V. C. and Singh, Ajai. 2018. Assessment of water supply-demand using Water Evaluation and Planning (WEAP) model for Ur river watershed, Madhya Pradesh, India. *J. Inst. Eng. India Ser. A*, https://doi.org/10.1007/s40030-018-0329-0

Berredjem, A. F. and Azzedine, H. 2017. Modelling Current and Future Supply and Water Demand in the Northern Region of the Seybouse Valley. *Journal of Water and Land Development*. 33 (IV-VI) : 31-38.

Bharati, L., Anand, B.K. and Smakhtin, V. 2008. Analysis of the Inter-basin water transfer scheme in India: a case study of the Godavari–Krishna Link. *Strategic Analyses of the National River Linking Project (NRLP) of India Series* 2 : 63.

Bhave, A. G., Conway, D., Dessai, S. and Stainforth, D. A. 2018. Water Resource Planning Under Future Climate and Socioeconomic Uncertainty in the Cauvery River Basin in Karnataka, India. *Water Resour. Res.* 54 (2) : 708–728.

Bhave, A.G., Mittal, N. and Mishra, A. 2016. Integrated assessment of no-regret climate change adaptation options for reservoir catchment and command areas. no. January.

Kanani, H.,Yadav, S. M. and Waikhom, S. I. 2017. Evaluation of drinking water supply demand for peri-urban region. *International Journal of Advance Research in Engineering, Science & Technology*. 4 (4).

Mansouri, S., Ouerdachi, L. and Remaoun, M. 2017. Inter-region planning and analysis of water resources by using WEAP model Seybouse (Annaba) and Coastal East of Constantine (El-Taref). *Journal of Water and Land Development.* 33 (1) : 115-122.

Metobwa, M.G.O., Khaldoon, A.M. and Lars, R. 2018. Water Demand Simulation Using WEAP 21: A Case Study of the Mara River Basin, Kenya. *International Journal of Natural Resource Ecology and Management*. 3(1): 9-18.

Saxena, S. and Yadav, S. M. 2016. Application of Water Evaluation and Planning Model to Assess Future Water Demands of Surat City, *Global Research and Development Journal for Engineering, Recent Advances in Civil Engineering for Global Sustainability*, March.

Shahraki, S. A., Shahraki, J. and Monfared, S. A. H. 2016. An Application of WEAP Model in Water Resources Management Considering the Environmental Scenarios and Economic Assessment Case Study: Hirmand Catchment. *Modern Applied Science; Canadian Centre of Science and Education*. 10 (5) : 1913-1852.

Sieber, J. 2006. WEAP Water Evaluation and Planning System, In: *Proceedings of the 3rd International Congress on Environmental Modelling and Software, Burlington, VT, USA, 9–13, July.*

Singh, M., Shinde, V., Pradhan, S. K., Chalodiya, A. L. and Shukla, K. N. 2014. Hydrologic Modelling of Mahanadi River Basin in India Using Rainfall-Runoff Model. *Nature Environment and Pollution Technology*. 13 (2) : 385-392.

Stockholm Environment Institute (SEI). 2006. Water Evaluation and Planning System of User Guide; Stockholm Environment Institute: Stockholm, Sweden.

Yates, D., Purkey, D., Sieber, J., Huber-Lee, A., Galbraith, H., West, J.,Herrod-Julius, S., Young, C., Joyce, B. and Rayej, M. 2009. Climate driven water resources model of the Sacramento Basin, California. *J. Water Resour. Plan. Manag.* 135 : 303–313.