Assessment of Water Supply and Demand in the Lower Mahi Sub-basin using WEAP Model

ManiRanjan K¹, Shashi Ranjan K², Roshni T¹ and Drisya J³

1 Department of Civil Engineering, National Institute of Technology Patna, India
2 Scientist D, National Institute of Hydrology Patna, India
3 Research Scholar, National Institute of Technology Calicut, India
E-mail: roshni@nitp.ac.in

Abstract. This study deals with the future water demand assessment in Lower Mahi Sub-basin, Bihar, India using Water Evaluation and Planning Model (WEAP). The river Mahi is flowing through the Mahi sub-basin, which is a tributary to the Ganga river. Understanding and analyzing the past and present water supply and demand scenarios and prediction of future scenarios are indispensable for this area. In the WEAP model development phase, two scenarios are considered: past scenario (2004-2013), present and future scenarios (2016-2021) together. The water supply nodes used are Mahi river, groundwater and canals from Gandak river. The results from the trend of supply and demand shows that the sub-basin is water deficit for most part of year except during July to September. The water deficit is also observed during Rabi season when there is no rainfall or availability of surface water is nil for the crops, especially wheat. This results in more and more usage of groundwater and hence leads to groundwater depletion. By analyzing the results of the WEAP Model for the present and future scenario, a depletion in groundwater storage at a faster rate is observed with the existing climatic conditions and increased population, livestock and industry.

1. Introduction
The balance between supply and demand of water is marked over time by political and environmental conflicts, the impacts of natural disasters and human actions. Water must be considered as finite resource and that has limits and boundaries to its availability and sustainability for its use. The Indian society is mainly agrarian with about 75% of the people depending on agriculture. The total geographical area of India is about 328 million hectares. In India about 68% of total sown area of the country is drought prone. The scarcity of available land and water resources, due to the growing population, has necessitated the planning and management of the resources. According to UN report, by 2049 there will be an increase of nearly 3.5 billion people in developing countries, and studies have shown that our resources are depleting at a faster rate due to over exploitation. Due to increase in population, the water demand will increase, unless there are corresponding increases in water conservation and recycling of this vital resource. Water for producing food will be one of the main challenges in the decades to come. Access to the fresh water is required to be balanced with the importance of managing water itself in a sustainable way by considering the impact of climatic change, and other environmental and social variables. Therefore it is important to evaluate the water availability. There are many models available for assessing the supply and demand of water. Among those, water supply and demand assessment by WEAP software is common and is found in [1-3]. Jha and Parwin [4] gave an integrated approach to evaluate the water scarcity in Mahi river Gujrat river basin of India using WEAP, and MODFLOW. Al-Juaidi et al.[5] used the optimization model which
was solved using the Generic Algebraic Modeling System (GAMS) for Sustainable Water Resources Management in the Gaza Strip, Palestine. This model considers different management options of building desalination and wastewater treatment plants, tertiary treatment of wastewater, as well as allocating and transferring water between agricultural and urban sectors. Li et al., [6] have analysed the future water scenario by considering different socio-development and urbanization scenarios in coastal Binhai New Area in China. The results indicated that there will be a huge water stress in the near future in the coastal Binhai New Area and several suggestions were put forward to assist the decision makers in water resources planning. In the study of [7], the authors developed a dynamic surface water-groundwater model between MODLOW and WEAP for the irrigated Miyandoab plain in Urmia basin of Iran. The results reveal that the crop water requirement cannot be met during the drought period. This hybrid model is a unique tool for exploring management options that can sustain agricultural production. Another study of WEAP by [8] investigated the effects of alternate wetting and drying on water resources at field for a study area in Central Luzon, Philippines. The results showed that water levels in the reservoir decreases in future period and it leads to severe water stress. Hence, it is critically vital to develop the knowledge and soft skills that are necessary to safeguard our catchments and river basins without altering the socio-economic development. This study is concentrated on small valuable sub-basin in Bihar, Mahi river sub-basin. This sub-basin is not water surplus basin, but has water scarcity at distinct length of river. It is definite that water use in each demand sources would increase in next decades. Further, the changing the value of precipitation may increase due to possible impact of climate change.

The Water Evaluation and Planning System (WEAP), has been developed for evaluating water management approaches. Hence in the present study, total water demand and supply management considering environment scenarios such as temperature humidity etc. investigated in Mahi river sub-basin.

2. Study area and data collection

Mahi river sub-basin is a non-perennial river. It originates from Chaur near Hirapakar now in neighbouring Gopalganj district of North Bihar at latitude 26°28′00″ N and longitude 84°25′47″E comprising the three districts of Bihar: Saran, Siwan, Gopalganj. It joins Ganga river at Chittupaker near Nayagaon station. Its total length is 92 km and basin area is 2500 square km. At present in Saran district, the inland rivers are Dhanauti, Ghaghari, Mahi and Gandaki and marginally by Ganga and Ghaghra rivers. While Gandak is confined within its bank by Saran embankment and has been restricted from the fluvial activities in the district. Gandaki and Daha are the tributaries of Mahi river (Figure 1) and the data collected for this study is shown in Table 1. The data is collected for the period 2004-2013.

![Figure 1. Study area: Mahi sub-basin.](image-url)
Table 1. Data types and its sources

| No | Data Types         | Sources                                                   |
|----|--------------------|-----------------------------------------------------------|
| 1  | Rainfall           | http://www.imd.gov.in/                                  |
| 2  | Discharge          | http://www.cwc.nic.in/                                  |
| 3  | Ground water level | http://cgwb.gov.in/                                     |
| 4  | Ground water uses  | http://biharhydrologyproject.org/ground_water/district_table.html |
| 5  | Metrological data  | Pusa university (Samstipur), Bihar                      |
| 6  | Population         | http://censusindia.gov.in/                              |
| 7  | Land use land cover| http://www.nrsc.gov.in/                                 |
| 8  | Industries water requirement | http://www.dowrbihar.gov.in/                                |

3. Methodology

3.1. WEAP model

The Stockholm Environment Institute has developed the WEAP model, based on the water balance and it requires Metrological, agricultural, population data, industrial data and water quality data. This model investigates and assess the domestic, agriculture, and industrial water demand of the area selected. It is a vital tool to inform the society on the adaptation of climate change towards policy making. The WEAP model uses climatic inputs such as precipitation, temperature, humidity, infiltration, and wind speed. The other input data sets are groundwater level, usage of groundwater for different purposes, population and water consumption, livestock, land use land cover and industrial water requirement. This model has capability to simulate water demand analysis, water conservation, hydropower generation, water allocation priorities, rainfall runoff, base flow and groundwater recharge from precipitation and reservoir operations.

3.2. Building the model

In this work, the main objective is to evaluate the WEAP’s ability to simulate demand and supply of water in domestic, agriculture, and industrial sectors. The river gauge data is collected at the gauging station of Mahi sub basin for a period of 2004-2013.

To run WEAP model, the schematic representation of the water supply and distribution system of the Mahi river Basin is plotted first. For the schematic representation, vector layer of river path is prepared. In Water Evaluation and Planning Model, GIS based vector and Raster layer of world map is given and we define the study area boundaries. Vector data is then added in format of SHAPEFILE. This format is created by GIS or ERDAS software. In this paper, Calibration is done for the period 2004-2007 and Simulation is done for the period 2008-2013. Current Account is selected as 2008 with last year Scenarios is 2013 in Simulation and in Calibration Current account is 2004 and last scenario is 2007. Per year Time steps is 12 and Boundary of time step is based on Month of Calender, starting with the January month. Current accounts is set for the ‘year of this study. Current Account is act as the software base. “Reference Scenario” is called the Default scenario carries forward the data of current account in the whole project. The selected scenarios of water demand management in this study are as follows:

Scenario 1 (2004-2007): This scenario is also known as Reference scenario and represent the status of study area and indeed is used as the basis for comparison with other scenarios. In this period, Calibration is done. During this period Average increasing rate of population, Industries and Livestock are 1.33, 1, and 2.7 percent respectively.
Scenario 2 (2008-2013): This is simulation period for the study area. Due to urbanization, agricultural field is reduced as compared to calibration period.
Scenario 3 (2016-2021): This is the future scenario for the study area. Domestic, agricultural, industrial water demand and future scenario of groundwater is calculated for this period. Calibration is done in the WEAP model by data obtained from gauge station of Mahi river. In the Calibration period, changing the pattern of past demand and the priorities of demand and groundwater requirement is also included between simulated and observed flows graph. The objective of modeling is to find the trend of water supply and Demand in future in Lower Mahi sub-basin.

3.2.1. Demand sites. The water demand is the total water required in domestic, agriculture, and industrial uses. In India average per capita water demand is 135L per day. The population growth rate of the study area has been increasing at 13.27 percent per annum. There are twenty Blocks in Saran district. In agriculture demand, crop water requirement depends upon the many factors such as crop co-efficient, type of soil and also type of crop. Principal crops of the study area are rice, wheat, sugarcane, maize, etc. In agricultural area huge amount of water is required. It is the second most important demand site after the Domestic demand. Due to expansion of urban area agricultural area is reducing over the last ten years. In the year 2004, total agricultural area was about 235093.10 hectare and in the year 2013 that agriculture reduced to 101600 hectare.

3.2.2. Supply and resources. To full-fill the water requirement of all demands, water is supplied from mainly three sources-Mahi river, Groundwater and Canal from other river. Mahi is the non-perennial river and in the month of April and May, the river dries up and the water demand is satisfied by groundwater supply. In the study area, canals are connected to the Gandak river, so canal water is also a source of water supply to the basin. In the month of October and January, water is delivered in the canal about 1425m$^3$/s and 185m$^3$/s respectively. Schematic view of all supply and demand nodes are shown in Figure 2.

4. Results and discussion
The computation of model is done based on the data of Past scenario. The future scenario is generated using current accounts information for the period of time 2004-2007 (Calibration period). The result will be appeared when the computation is complete.

![Figure 2. Schematic view of WEAP model.](image-url)
4.1. Calibration period
During the calibration period, unmet demand is only in Industrial demand site. Agricultural and domestic demand is met with supply delivered. More than 50% demand is going to met with groundwater sources. Canal water is only supplied for Agriculture catchment during October and January. In January, supplied quantity is 385 m$^3$/s and in October, supply is 1425 m$^3$/s. From calibration, it is clear that Saran district mainly depends upon groundwater sources and also found that unmet demand is only for industrial purposes and is shown in Figure 3. After calibration, it was found that observed gauge flow is highly correlated with that of the calibrated gauge flow (shown in Figure 4).

![Figure 3](image)

**Figure 3.** (a) Agricultural water demand, (b) domestic demand (c) unmet water demand and (d) industry demand during calibration period.

4.2. Simulation period
Simulation is done for the period of 2008-2013. All the climatic data is added for the Current and Reference Account. Climatic data such as precipitation, humidity, wind speed, temperature and the Mahi river stream flow data for year 2008-13 is added. Agricultural area is decreased due to urbanization and the reduced area is used for simulation. Results for the simulation period is shown in Figure 5. In the Figure 6, it is clear that the unmet water demand in Agriculture sector is not significant value and unmet water demand by domestic and livestock is zero. Annual unmet water demand in the industry sector is 1.27 million cubic meter in 2008. Mahi river and groundwater are Supply sources of water to Industrial. In City Development plan of Saran district it is mentioned that the 90% water demand is met with groundwater sources. In the above it is mention that annual water supplied in 2013 by groundwater sources is 328 million cubic meter to all demand sites. According to
Report of Central Ground Water Board total annual groundwater draft in 2013 is 430 million cubic meter. This difference is found because according to this study Industrial water demand is going to met with both River and Groundwater sources, because it may possible if some industry have its own waste water treatment plant so they can use River water. In the year 2008, water supplied by the Mahi river is higher than other year in Simulation.

![Figure 4. Comparison between Calibrated and Observed gauge flow.](image)

![Figure 5. (a) Agricultural water demand, (b) domestic demand (c) industry demand (d) groundwater storage during simulation period.](image)
4.3. Future scenario

In future scenario, the trend of water supply and demand of years 2016-21 is shown in Figure 7. For future scenario, climatic data such as precipitation, temperature, humidity, wind speed is taken as that of previous years. Population increasing rate is 13.27% and industrial annual water consumption increasing rate is 10% and Livestock increasing rate is 27.9%. Water Demand, in 2016 Domestic water demand is 360.41 million cubic meter and its value in 2013 is 248.26 million cubic meter i.e after 3 years about 112 million cubic meter domestic water demand is increased. This is the reason that in future, water resources management project is very necessary. In the year 2016 water demand by Livestock is 10.98 million cubic meter and its value in 2013 is 5 million cubic meter. Agriculture water demand value is same to the value of Simulation because same agriculture area is used for the Simulation and Future Scenario.

From the light of the above figures, in the future scenario (2016-21), unmet water demand is only in Industrial sector, other sector domestic and Agriculture demand is going to met with supply sources. In the year 2016, industry water unmet water demand is 2.73 million cubic meter and in the year 2013 this value was 0.72 million cubic meter. In future this Unmet demand in Industry will increase more than this rate because in future may be new industry will established in Saran district. It is also evident that in 2016, annual water supplied by Groundwater is 705.15 million cubic meter and its value in
2013 is 328 million cubic meter. Water supply by Groundwater increased by 372 million cubic meter in 3 years. Water supplied from the River and Canal depends upon the rainfall.

5. Conclusions

(1) In this research the evaluation of trend of water supply and demand in Lower Mahi sub-basin has been conducted. The evaluation of the declination of Groundwater storage capacity and fluctuations on supply and demand in Lower Mahi sub-basin has been accomplished based on the past scenario data.

(2) This research work is important in Lower Mahi sub-Basin due to increase in population in the near future as suggested in the Master Plan reports of Bihar Government, where Saran district will also be a part of Greater Patliputra in the coming years. Thereby population increases, water consumption rate also rises, and industrialization and urbanization grows at a faster rate than the present scenario.

(3) The trend of Supply and demand of Lower Mahi sub-basin illustrates that the basin is water deficit for most part of year except during July to September. The water deficit is observed during Rabi season when there is no rainfall or surface water is not available for the crops, especially wheat. This is reason for exploitation of groundwater resources and hence leads to groundwater declination.

(4) By analyzing the results of the Model for the present scenario, unmet demand shows significant value in Industry sector.

(5) The future scenario result shows a depletion in groundwater storage, with the existing climatic conditions and increased population, livestock and industry.

(6) This study has demonstrated that the WEAP model is useful modeling tool for Integrated Water Resources Management (IWRM).

6. References

[1] Arranz R 2006 Future water demands and resources in the olifants catchment, South Africa; A scenario analysis approach using the WEAP model Msc, Thesis, Colorado state university, Colorado.

[2] Abdo R U K 2009 Evaluation of Urban Water Supply Options Using WEAP: The Case of Nablus City. Master Degree, Thesis, An-Najah National University, Nablus, Palestine.

[3] Alfarra A Kemp-Benedict E Hötzl H Sader N Sonneveld B 2012 Modeling Water Supply and Demand for Effective Water Management Allocation in the Jordan Valley Journal of Agricultural Science and Applications (JASA) Vol 1(1) pp 1-7

[4] Jha R Parwin R 2014 Assessment of Water Resources & Management Strategies of Brahmani River Basin. Unpublished Master Degree Thesis, National Institute of Technology, Rourkela.

[5] Al-Juaidi A E Kaluarachchi J J Moussa A A 2014 A Hydrologic-Economic Model for Sustainable Water Resources Management in the Gaza Strip, Palestine. DOI: 10.1061/(ASCE)HE.1943-5584.0000960

[6] Li X Zhao Y Shi C Sha J Wang Z-L Wang Y 2015 Application of Water Evaluation and Planning (WEAP) model for water resources management strategy estimation in coastal Binhai New Area, China. Ocean and Coastal Management Vol (106) pp 97-109.

[7] Dehghanipour A H Zahabiyoun B Schoups G Babazadeh H 2019 Multi-objective calibration and quantification of historical drought impacts. Agricultural Water Management Vol 22, 105704. https://doi.org/10.1016/j.agwat.2019.105704

[8] Schneider P Sander B-O Wassmann R Asch F 2019 Potential and versatility of WEAP model for hydrological assessments of AWD in irrigated rice. Agricultural Water Management. 224(1) 105559. https://doi.org/10.1016/j.agwat.2019.03.030