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Water Budgeting in the Jhelum River Basin: Application of Hydro-Economic Water Evaluation and PlanningModel

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ABSTRACT

In the world water demand is increasing due to climate change, high population growth rate, high urbanization, food insecurity, high energy demand, changing living standards of the society and other factors. The main aim of economics is to maximize net returns from limited natural resources by optimizing the available resource to satisfy needs and wants. Nowadays, doing so is also a difficult task due to the lack of strong integration and holistic approach that influence the process. However, the best way of optimizing water demand and increasing water supply is through integrated water resource management measures that bring sustainability to water resource by challenging water-based conflicts and problems. The present study emphases on Jhelum River basin of the Kashmir valley of India to assess the existing and future water demand and supply situation along with generating suitable policy scenario metrics for integrated water resource management. Water Evaluation and Planning Model was used for analysing the data. The model was established by creating 2020 as the current account year and 2050 as future scenario year. Three major scenarios for future water demand and supply prediction were created as reference, external driving factor and management scenarios. The result of the study shown current water demand of 3249.5 million cubic meters for all demand sectors, whereby demand for domestic, livestock and poultry; and industrial and commercial sectors satisfied fully and agricultural sector has shown unmet water demand of 271.23 million cubic meters by 2020. In 2050 the water demand increase in all scenarios whereas the unmet water demand decreases by reference and management scenarios and increase by external driving factor scenarios. Depending on the result obtained policy implications and water allocation strategies were proposed on the enhancing of water supply, managing water demand and considering cross-border water resource management problems.

Keywords: Economics, Integrated water resource management, Scenario, Demand, Supply, Water evaluation and planning

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1. Introduction

In 1951 the world population was around 2.58 billion whereas now in 2020 the population was increased to 7.79 billion. Even if the population is increasing at decreasing rate the globe is expected to have around 9.6 billion population in 2050(Worldometers, 2020). The high population will happen in the emerging countries where food is frequently limited and water and land resources are under pressure. Therefore, in 2050 to feed this growing population the globe needs to produce more food without expanding the area of cultivation due to shortage of freshwater availability for irrigation and fragmentation of land. Food producers are also faced with climate change, rapid urbanization and other factors in addition to high population growth rates that influence food production, apart from land and water restrictions (Esteve et al., 2015; McCornick et al., 2013). Agriculture is the sector that is responsible for high water demand globally by 70 per cent water withdrawal and 93 per cent water consumption. Similarly, industrial and domestic sectors also withdraw water by 20 and 10 per cent with a water consumption percentage of 4 and 3 respectively(Anonymous, 2003; Chen et al., 2020). Industry consumes more than half of the water required for human use in developed countries. Belgium, for example, consumes (80%) of water available for the industrial sector (Mark Koba, 2014). Therefore, one of the best measures for the sustainability of water resources in the world is considered to be integrated water resources management. It is a process of implementation, common vision formulation, management planning strategies for the sustainable use of water resources development by taking in to account all temporal and spatial interdependencies between human, natural process and ecological use of water. Although, Water resource management is one of the 17 sustainable development goals in the 2030 Growth (Miletto, 2015). Among different integrated water resource management models, Water Evaluation and Planning model is one of the outstanding applications which connect demand side and supply side requirements for the analysis (Stockholm Environment Institute (SEI), 2015). The model was created for the first time by the non-profit research and global policy organization called Stockholm Environment Institute. Besides, water budgeting is examined by the linkage between the inflow and outflow of water through a given region. It offers a comparison between water source and demand(Afzaal et al., 2020). To balance the expected amount of demand and supply of water in any area, research would contribute to increasing economic growth and a better strategy. It would also enable decision-makers, policymakers, managers, planners and water resource practitioners responsible for water resource management to develop and enforce sustainable water resource management systems.

Based on the above facts, the water resource system of river basin needs critical and suitable policy for balancing water supply and demand situation among the economic, social, political and environmental sectors. The objective of this research study was to assess the Jhelum River basin surface water supply-demand situation and generate an appropriate policy scenario matrix for integrated water resource management by using hydro-economic water evaluation and planning model to achieve economically, socially and environmentally sustainable water resource management.

2. Methodology

2.1. Study Area

The study area covers the Jhelum River basin of Kashmir region of Jammu and Kashmir union territory of India that located between 33°25' N and 34°40' N latitude and 73°55' E and 75°35'E longitude with an average elevation of around 1830 meters above mean sea level. The region has an area coverage of 15,948 km2 out of 42,241 km2 out of total area coverage of union territory(Romshoo et al., 2020). The Jhelum River originated from the Verinag spring found in Dooru tehsil of the Anantnag district in the north-west corner of the PirPanjal of Jammu and Kashmir union territory. The river flows through the valley of Kashmir from the southern division to the northern division by crossing Srinagar city and joins the wular lake. After the river leaving the Baramulla district, it joins with Chenab River near Muzaffarabad in Pakistan.

The total human population of Kashmir valley for 2020 was obtained from the public health engineering department of Kashmir, India. According to the 2011 census report, the human population of the region was 6,888,475(Bose, 2011; Dar, 2018). But in 2020 the population is projected to be 9,368,369 in addition to the floating population. The floating population was around 562,792 in the urban area and 544,692 in the rural area(Public Heath Engineering, 2020). Kashmir region is also rich in livestock population like sheep, goats, cattle, buffalo, poultry and others. The region gives better foreign exchange currency from the production of livestock products like carpets, shawls, blankets and others for the nation. The total population of livestock and poultry in 2020 according to the 2019 livestock census was 8,352,820(Directorate of animal husbansdary, 2020). The climate of the Jhelum basin is temperate. During the summers the outside plains and hills are precipitated by monsoon winds, while during the winters the Mediterranean winds cause snow and rain in the Kashmir valley(Romshoo et al., 2020).

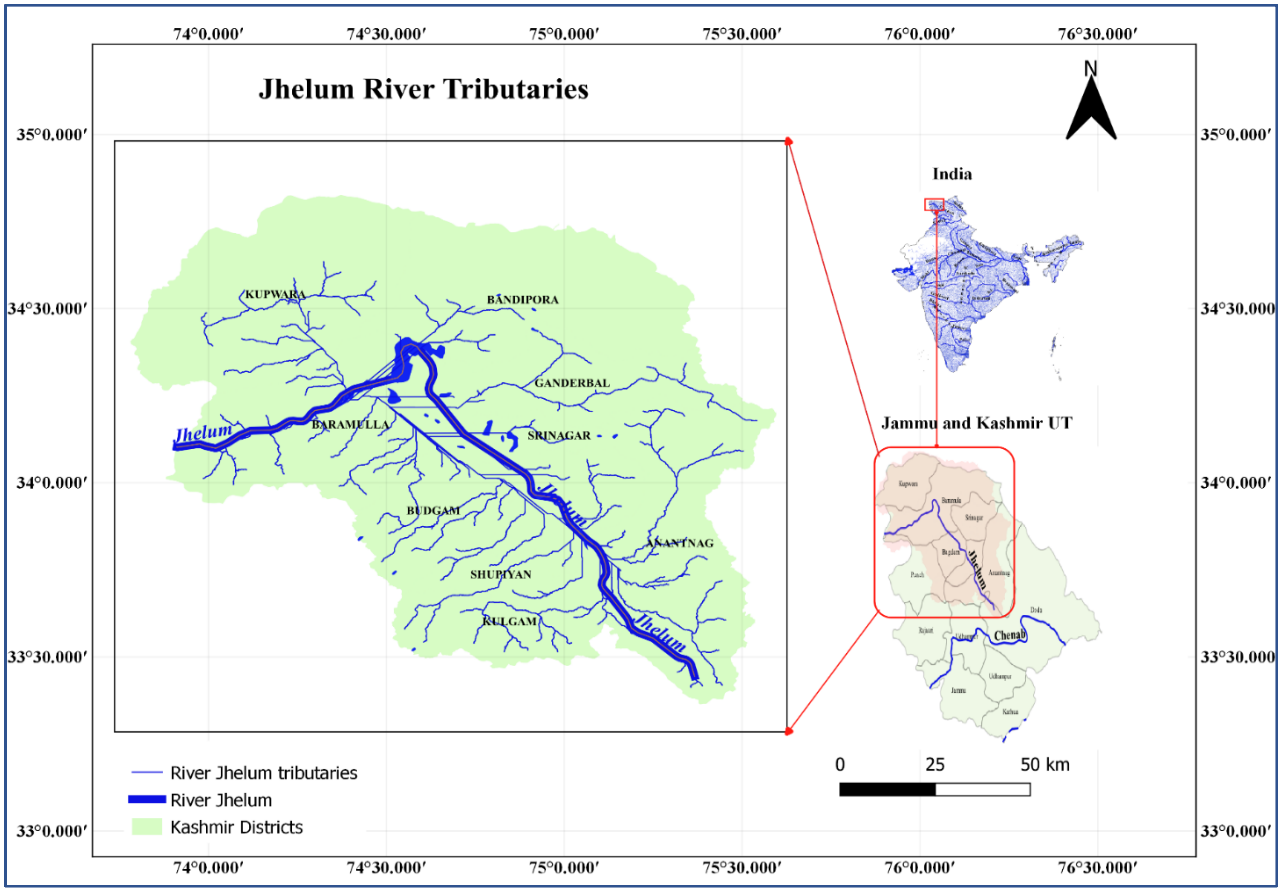

Fig.1: Study area map

2.2. Software used

The software used for this study were listed below one by one:

a QGIS: to refine the study area borders, map and geo-reference the acquired dataand demarcate the study area

b WEAP: It is usedto assess water resources, estimate water demand and create scenarios.

c MS-Excel: Used for data processing according to the WEAP model requirements.

d GPS: Used to collect the location of the study area at different places.

2.3. WEAP Calculation Algorithm

2.3.1. Calculating Demand

Water demand for the demand site is determined as the sum of all demand sites.

Annual activity level = (overall activity Level x Water Use Rate)

……………...................(a)

Whereas, theoverall activity level was given as:

Overall Activity Level = (Activity. A x Activity. B x Activity .C x...........) ....(b)

Monthly demands have been determined according to the fraction of each month indicated in the following terms under request\monthly changes in the adjusted yearly demand:

Monthly Demand=Monthly Variation Fraction* Adjusted Annual Demand………..… (c)

2.4. Methods of data collection

To achieve the objective of the study both primary and secondary data have been used. Primary data were employed by observation of the Jhelum River basin from its origin to the tail of the river leaves the study area boundary. Thus, the latitude, longitude and altitude of the area were collected by using GPS. Secondary data was collected from a review of previous research studies and different departments of Kashmir. The previous research studies secondary data was collected from books, journals, newspapers and websites. Whereas secondary data like water discharge flow of Jhelum River and its tributaries, population of human and livestock, agricultural irrigated area, number of industrial and commercial units, water demand for each sector (domestic, livestock and poultry, agricultural, industrial and commercial), meteorological data (rainfall, temperature and humidity), DEM data have been collected from different departments of Kashmir valley as shown below in table.1.

Table.1: Short description and obtained data source for research study

S. N	Data	Description	Source
1	Hydrological data	Discharge flow data	Kashmir irrigation and flood control department, Srinagar
2	Meteorological data	Rainfall, Temperature and Relative humidity,	Indian Meteorological Department, Meteorological Centre, Srinagar
3	Spatial data	DEM of Study area	USGS (https://earthexplorer.usgs.gov/)
4	Sewage treatment plant data	Wastewater treatment data	Lakes and Waterways Development Authority and Urban Environmental Engineering Department
5	Agricultural data	Irrigated area and Crop water requirement data	Directorate of Agriculture, Kashmir (Srinagar) and Agromet Field unit, SKUAST-K.
6	Livestock data	Livestock population and water demand data	Government of India, Ministry of Fisheries, Animal Husbandry and dairying, 20th Livestock census-2019 and FAO standard
7	Domestic data	Human population and water demand data	Census 2011, PHE and Jammu and Kashmir UT water resource regulatory authority
8	Industrial and commercial unit data	Number of units	Directorate of Industries and commerce Kashmir, Srinagar

2.4.1. Research design

Before undertaking the WEAP model analysis the research design was prepared properly for successful and smooth implementation of the study as shown below in figure 2.

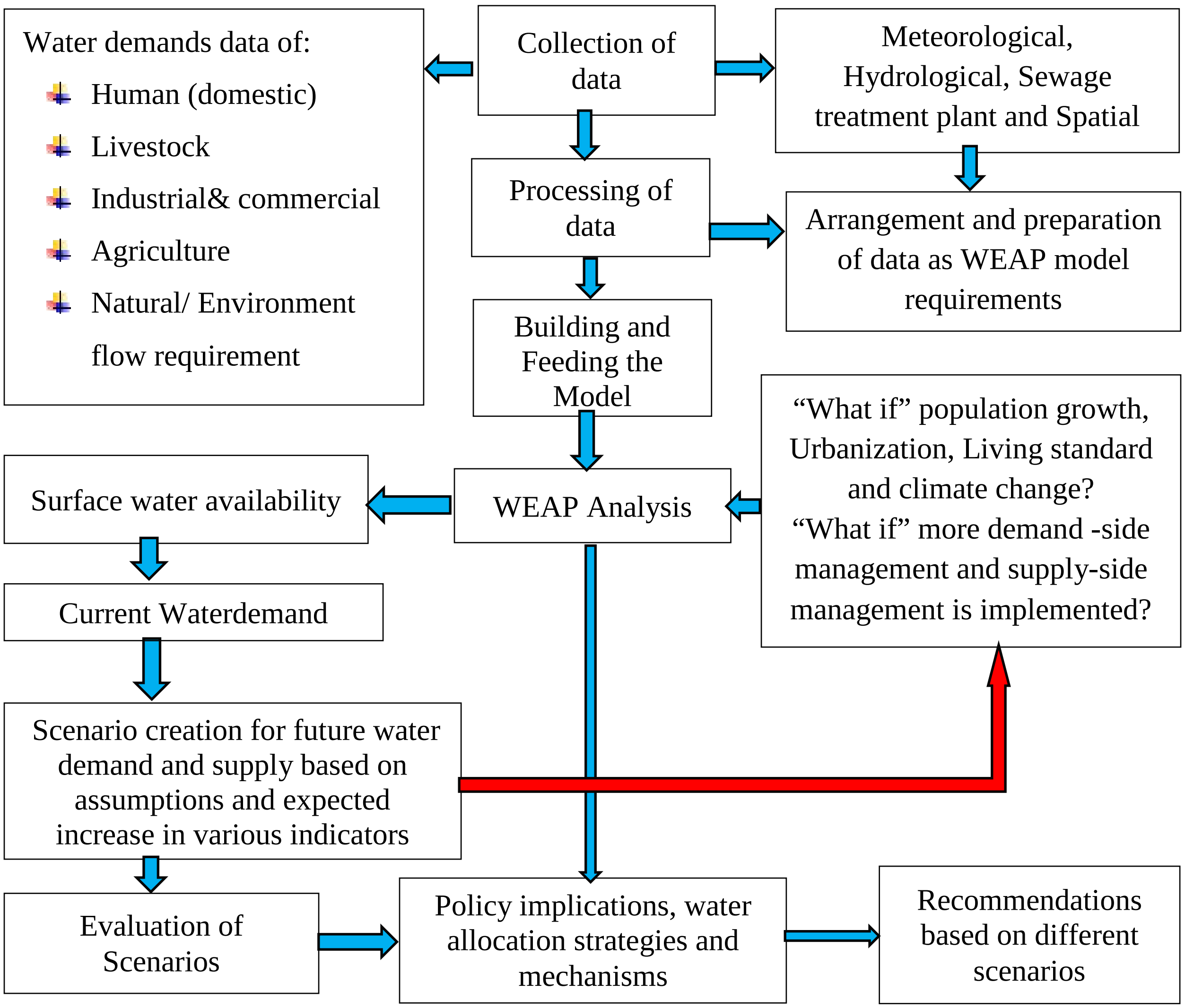

Fig.2. Research design

2.5. Method of data analysis

2.5.1. Data analysis

For analyzing the data Water Evaluation and Planning (WEAP) model was used to assess the current and future water demand and supply situation of the study area to bring sustainable and efficient use of water among different sectors (i.e., domestic, industrial and commercial, agricultural, livestock and poultry, natural /environmental flow and others) based on the capability of the software analyzing tools(Stockholm Environment Institute (SEI), 2015).

2.5.2. Determining surface water resource

Based on the discharge flow data obtained from ten reading stations of Jhelum River and

38 reading stations of tributaries of Jhelum River, the WEAP model used to determine and analyze the surface water resource in the study area. Thus, the discharge flow data was entered into the WEAP model monthly wise after already prepared on the Ms-excel as WEAP model requirement in CSV format to determine the water resource supply of Jhelum River basin monthly and annual basis.

2.5.3. Determining the water demands of Jhelum River basin

First of all, before analyzing the current and future scenarios of water demand the necessary steps of creating the model was employed according to the following procedures:

- Study area and time frame establishment.
- Creation of current account that imitates the existingcondition of the research area's water resources.
- Based on the future assumptions and anticipated growth in key variables development of scenarios undertaken.
- Finally based on the discharge flow of water in the study area assessment of scenarios was done accordingly.

Schematic view: As the procedure indicated above the WEAP model starts with the schematic view. The schematic view shows the physical aspects of the water demand-supply structure after the shapefile prepared on QGIS vector, uploaded to the Model to delineate water supply river and demand sites as shown in fig.3 below.

Demand site View: the WEAP data the tree was used to enter monthly average head flow data of Jhelum River and its tributaries of three divisions of Kashmir region (Southern, Central and Northern Kashmir) for both demand and supply side. Accordingly, the total number of demand sectors with their water use rate, monthly variation and consumption percentage were entered for each demand location to assess general water demand of domestic (urban and rural), livestock (livestock and poultry), agricultural, institutional, industrial and commercial units and environmental/natural flow requirements as shown in fig.3.

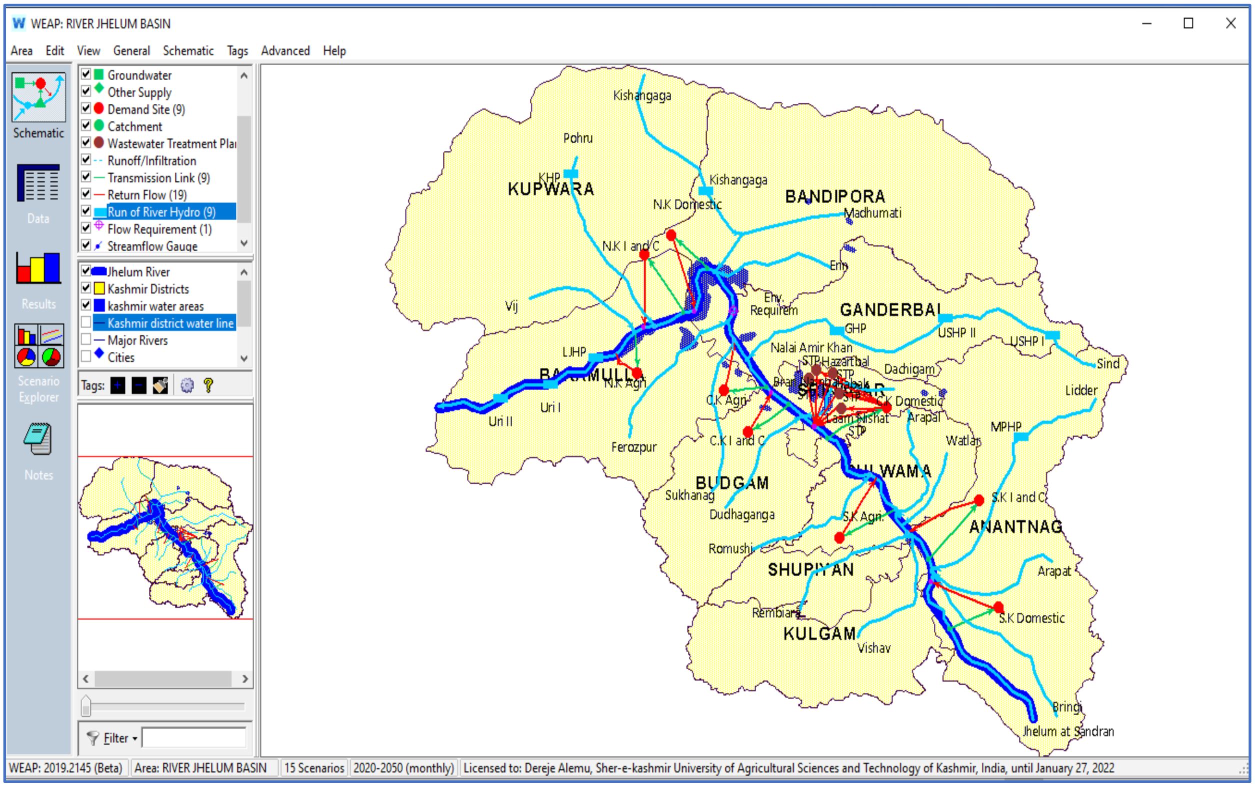

Fig.3. Jhelum river basin Schematic view

2.5.4. Creation of scenario process

Creation of scenarios included the following modelling steps: -

a) Creation of current account year

The data collected from the different departments have been used for the creation of the current account year by which the future scenarios are predicted. Accordingly, the year 2020 is set as the current year and 2050 set as future scenario year. Therefore, for this study, the data that is reliable was used as the current/ baseline account year for predicting the future scenarios.

b) Establishing Scenarios

Totally three scenarios were developed for this study depending on different assumptions.

1. Reference scenarios (2021-2050)

This scenario is created based on the current account year to assess the future water supply and demand situation. The discharge flow data of the Jhelum River basin from 1975 up to 2020 was used to know the discharge flow growth percentage of the Jhelum River which was (0.177%). Whereas the demand-side data of Jhelum River basin included the population growth rate increase by ((2.276 %) per annum, average livestock and poultry population growth rate by (0.04127%), agricultural growth rate by (-0.00038%) and industrial and commercial unit growth rate by (0.26 %) depending on the historical data collected from different departments for proper projection of the scenario.

2. External driving factor scenarios (climate change, growth of population, urbanization and living standards) (2021-2050).

   This scenario was to evaluate the impact of climate change, population growth rate, urbanization and living standards of the society in study area water supply and demand situation in the future. Under this scenario, two sub-scenarios were developed, namely; medium and high growth rates with four sub- scenarios of climate change representative concentration pathways (RCP-2.6, RCP-4.5, RCP-6.0 and RCP-8.5). The discharge flow data projection was based on the weather data generated from MarkSim Global circulation model that produces daily weather data for present and future climate scenarios for any location on the globe using the Google Earth interface(Gismap, 2020). Therefore, the discharge flow of the Jhelum River for both medium growth and high growth rate will increase by 0.0247, 0.0499, 0.0406 and 0.0720 per cent for RCP-2.6, RCP-4.5, RCP-6.0 and RCP-8.5 respectively. The water demand for medium and high growth rate sub-scenarios were assumed by "what if population growth in terms of both rural and urban, livestock and poultry, agricultural irrigated area, industrial and commercial units and living standards growing by 25% and 50% respectively. In addition to the above-mentioned forecasts what if the living standard of the society increased by water demand up to 481.3 liters per day per person for urban and 250 liters per day per person for rural area in the medium growth rate and increased by 578 liters per day per person for urban and 300 liters per day per person for rural areas in the high growth rate.

3. Management scenarios (2021-2050).

   Under this scenario four sub-scenarios were employed to know the future water supply and demand situation in the Jhelum River basin by applying the assumptions of improved irrigation efficiency, shifting some part of paddy area to horticulture and wastewater re-use for irrigation at full capacity. The first and second sub-scenario was by the assumptions of applying 10 per cent and 20 per cent improved irrigation efficiency, what will happen on the water supply and demand in the future. Thirdly by shifting 20 per cent irrigation area of paddy to horticulture what will happen on the future water supply and demand. The fourth sub-scenario was wastewater re-use for irrigation purpose under full potential of treatment plants was applied to forecast both future water supply and demand in the study area.

c) Obtaining the result by running the model

Once the data have been entered properly to the data view the next step was running the model and obtaining the result of the analysis. The result from WEAP model displayed in different forms like table form, graphical display form or schematic map.

3. Result and Discussion

3.1. Assessment of Jhelum River basin surface water resources and water demandfor the current year (2020)

Jhelum river basin wasdivided into three divisions to assess the current surface water supply potential based on the discharge flow reading and sectoral water demand. The result of both current surface water supply and sectoral demandwere given below in table.2 and table.3respectively monthly wise.

Table.2: Current Jhelum River basin surface water supplydivision wise in million cubic meters, 2020

Divisions	Monthly discharge flow in million cubic meters												Total	Average (%)
	January	February	March	April	May	June	July	August	September	October	November	December		
Southern Kashmir	78	121	274	476	535	537	447	380	563	145	109	90	3753	53.9
Central Kashmir	44	58	138	226	286	288	238	200	220	69	59	43	1868	26.8
Northern Kashmir	47	78	185	209	206	134	109	117	107	49	57	44	1341	19.3
Total	169	256	597	911	1027	959	794	697	890	263	224	177	6962	100

As indicated above in the table.2, the current total Jhelum River basin surface water supply varied from division to division. Based on the result obtained from the model, the current year (2020) surface water discharge flow was contributed from southern Kashmir tributaries by 3753 million cubic meters with 53.9 per cent, central Kashmir by 1868 million cubic meters with 26.8 per cent and northern Kashmir by 1341 million cubic meters with 19.3 per cent. Thus, the current year total discharge flow of Jhelum River was 6,962 million cubic meters. The maximum discharge flow was observed in May, June, April and September whereas the minimum discharge flow was observed in January and February.

Table.3: Current Jhelum River basin sectoral water demand monthly wise in million cubic meters, 2020

S.	Sectoral	Monthly water demand in million cubic meters	Su m	ra ge

N	water demand	October	February	March	April	May	June	July	August	September	October	November	December		
1	Domestic	0.21	0.20	0.21	0.20	0.21	0.20	0.21	0.21	0.20	0.21	0.20	0.21	2.50	0.077
2	Agricultural	0.00	0.00	0.00	0.00	50.8	1180	847	736	376	44.4	12.9	0.00	3246.6	99.91
3	Livestock	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.10	0.003
4	Industrial and commercial	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.25	0.008
Total		0.24	0.23	0.24	0.23	51.0	1180	847	736	376	44.6	13.2	0.24	3249.5	100

Based on the result obtained above in the table.3, the water demand in the Jhelum River basin varied from sector to sector. The total sectoral water demand for the entire Kashmir valley was 3249.5 million cubic meters in the year 2020. The maximum water demand was observed by the agricultural sector with 3246.6 million cubic meters (99.9 %), and followed by domestic and industrial and commercial sectors by 2.50 and 0.25 million cubic meters with (0.077%) and (0.008%) respectively. The minimum water demand was observed by the livestock sector with 0.10 million cubic meters (0.003%) out of total sectoral water demand in 2020. Agricultural sector demands more water as compared to other sectors. Due to climate change the water availability for irrigation and crop yields affected and resulted with increasing irrigation water requirements (Esteve et al., 2015; Farrokhzadeh et al., 2020).

3.1.1. Total Jhelum River basin water supply, demand and unmet demand for the current year (2020)

The total water supply and demand as well as unmet water demand was analyzed for the currentyear (2020) andrevealed below in fig.3 and fig.4 respectively.

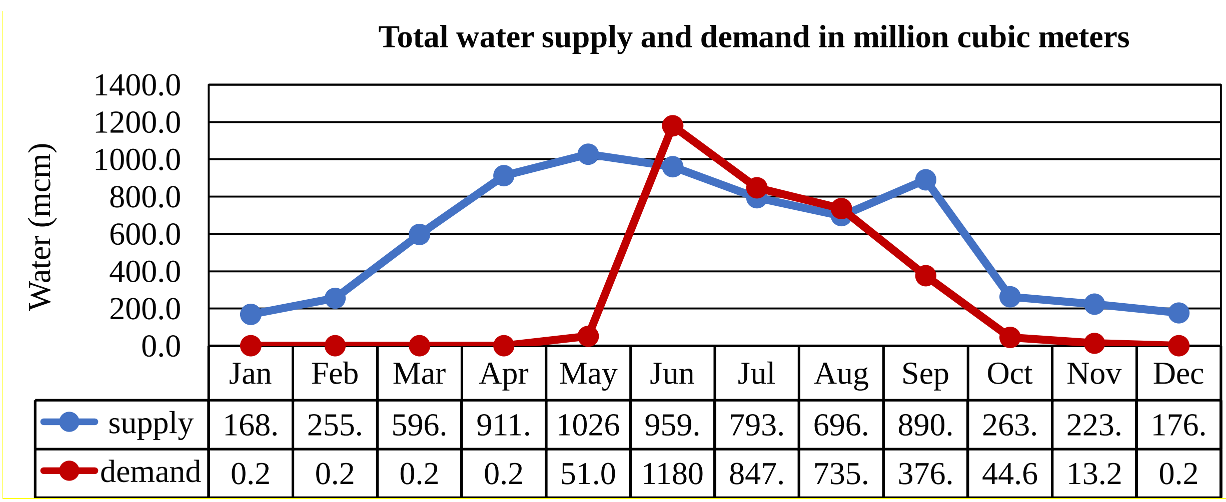

Fig.4. Jhelum River basin water supply and demand for the current year (2020) (mcm; million cubic meter)

Based on figure-4, the total Jhelum River basin available water supply and demand in 2020 were 6961.8 and 3249.5 million cubic meters respectively. Both the supply and demand of water varied from month to month. The maximum water supply was observed in April, May, June, July, August and September whereas the minimum water supply was observed in the months of December and January. On the other hand, the maximum water demand was observed in June, July, August and September, whereas the minimum water demand was indicated in December, January, February and March.

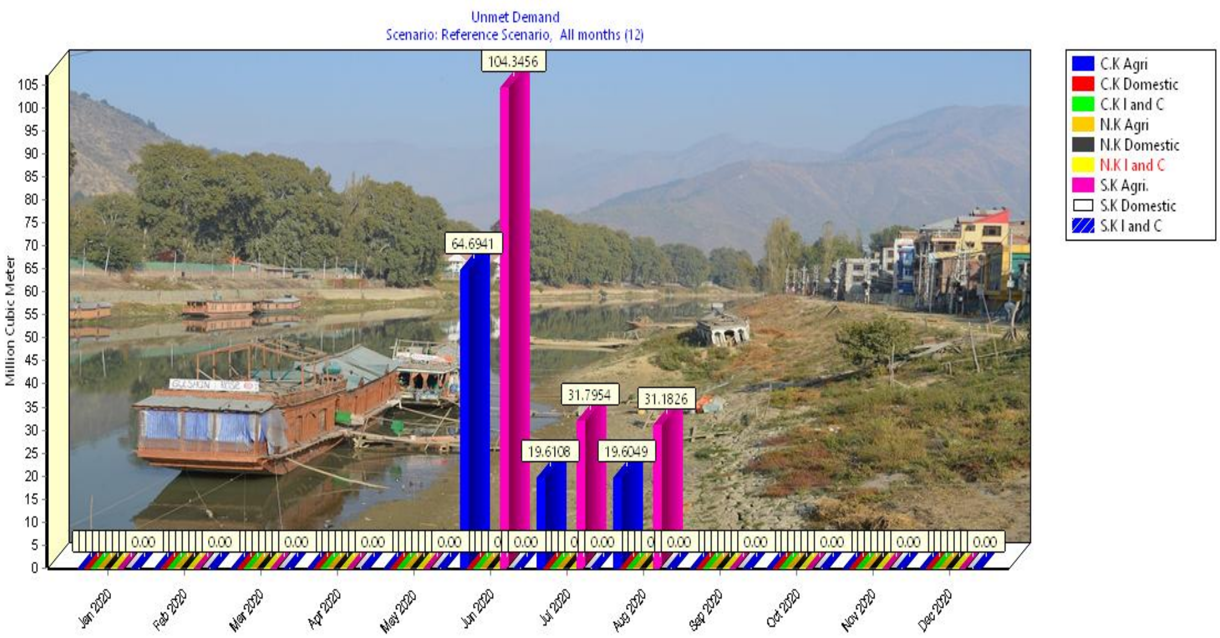

Fig.5. Jhelum River basin sectoral unmet water demand for the current year (2020)

Fig.5, above shows unmet water demandin the southern and central Kashmir divisions by the current year. The maximum unmet water demand occurred in the southern Kashmir division by 104.34, 31.79 and 31.18 million cubic meters in June, July and Augustrespectively. While, theminimum unmet water demand happened in the central Kashmir division with 64.69, 19.61 and 19.60 million cubic metersrespectively in the same specified months.

3.2. Scenario Analysis

3.4.1. Future annual availability of water supplies under various scenarios

The water supply availability varies from scenario to scenario depending upon different assumption described briefly in the creation of the scenario process. The future surface water availability of Jhelum River basin and its tributaries projection output was indicated below in table.4 by every five-year difference from 2020-2050.

Table.4: Every five-year annual water supply under various scenarios in the Jhelum River basin bybillion cubic meters

S. N	Types of Scenarios		Discharge flow in BCM							Percentage increase between 2020 and 2050
			2020	2025	2030	2035	2040	2045	2050	
1	Reference	Reference	6.96	7.01	7.08	7.14	7.21	7.27	7.33	5.30
2	External driving factor	HGR with RCP-2.6	6.96	6.96	6.97	6.98	7.00	7.00	7.00	0.62
		HGR with RCP-4.5	6.96	6.97	6.99	7.01	7.03	7.04	7.06	1.38
		HGR with RCP-6.0	6.96	6.97	6.98	7.00	7.02	7.02	7.04	1.10
		HGR with RCP-8.5	6.96	6.98	7.00	7.03	7.06	7.08	7.10	2.05
		MGRwith RCP-2.6	6.96	6.96	6.97	6.98	7.00	7.00	7.00	0.62
		MGRwith RCP-4.5	6.96	6.97	6.99	7.01	7.03	7.04	7.06	1.38
		MGRwith RCP-6.0	6.96	6.97	6.98	7.00	7.02	7.02	7.04	1.10
		MGRwith RCP-8.5	6.96	6.98	7.00	7.03	7.06	7.08	7.10	2.05
3	Management	IIE by 10 per cent	6.96	7.01	7.08	7.14	7.21	7.27	7.33	5.30
		IIE by 20 per cent	6.96	7.01	7.08	7.14	7.21	7.27	7.33	5.30
		SPH by 20 per cent	6.96	7.01	7.08	7.14	7.21	7.27	7.33	5.30
		WWRFIFP	6.96	7.04	7.13	7.22	7.32	7.40	7.50	7.66

HGR: High growth rate, MGR: Medium growth rate,IIE: Improved irrigation efficiency, SPH: shifting paddy to horticulture, WWRFIFP: Wastewater re-use for irrigation at full potential, RCP: Representative pathways, BCM: Billion cubic meters.

As observed in the table.4 above, the availability of surface water resources increases from 6.96 to 7.33 billion cubic meters with (5.3%) change from 2020-2050 in the case reference, improved irrigation efficacy by10 per cent, improved irrigation efficiency by 20 per cent and shifting by 20 per cent paddy irrigation area to horticulture scenarios. While the wastewater re-use for irrigation at full potential scenario shows an increment of surface water supply from 6.96 to 7.5 billion cubic meters with a 7.66 percentage change from 2020-2050.

On the other side, the external driving factor scenarios shows a different increment of surface water availability from 2020 to 2050. The surface water availability increases from 6.96 to 7.00, 7.06, 7.04 and 7.10 billion cubic meters with percentage changes of 0.62, 1.38, 1.10 and 2.05 respectively for RCP-2.6, RCP-4.5, RCP-6.0 and RCP-8.5 from 2020-2050.

3.4.2. Future annual water demand under various scenarios

3.2.2.1. Reference scenario

The reference scenario reflects the future changes by assumptions of 17,657,875 population of human, 8,456,852 population of livestock and poultry, 310,009 hectares of agricultural irrigated area and 4,343 units of industrial and commercial sectors. For the specified demand sites, the result of the analysis was indicated below in table-5.

Table.5: Sectoral annual water demand and unmet water demand under reference scenario by 2050

Description	Annual sectoral water demand					Natural / Environmental flow
	Agriculture	Domestic	Livestock	Industrialand commercial	Total water demand	
Annual activity in (Ha &No)	310,009	17,657,875	8,456,852	4,343		
Water demand in (MCM)	3226.43	5.24	0.0970	0.274	3232.04	4099.06
Unmet demand in (MCM)	178.12	-	-	-		

Ha: hectare,&: and, No: Number, MCM: million cubic meters

As shown above in table.5, the annual reference scenario water demand increases in domestic, and industrial and commercial sectors while, decrease in livestock and poultry, and the agricultural sector in 2050. Thus, the annual water demand increase from 2.50 to 5.24 million cubic meters for domestic, and 0.25 to 0.274 million cubic meters for industrial and commercial sectors from 2020 to 2050. Whereas, annual water the demand of livestock and poultry decrease from 0.10 to 0.0970 million cubic meters and agriculture water demand decreases from 3246.6 to 3226.43 million cubic meters from 2020 to 2050 year due to a decrease in livestock population and irrigation area of paddy crop that demands more water. The unmet water demand drops from 271.23 to 178.12 million cubic meters however, natural/environmental flow increase from 3712.3 to 4099.06 million cubic meters from 2020 to 2050 respectively.

3.2.2.2. External driving factor scenarios (climate change, growth of population, urbanization and living standards) (2021-2050)

i. Medium growth rate with various climate change scenarios (2021- 2050)

By assuming a general medium growth scenario for 2050, the human population has grown to 20,985,807; livestock and poultry has grown to 8,483,063. At the same time the industrial and commercial units increased to 4,430. Whereas the agricultural sector irrigation area decreased to 310,017 hectares as compared to the current account. The result obtained by this scenario shows, an increment of annual water demand by domestic, and industrial and commercial sector to 7.98 and 0.279 million cubic meters respectively in 2050. In contrast, the livestock and poultry, and irrigation sector annual water demand decreases to 0.0973 and 3226.52 million cubic meters respectively in 2050. Under this scenario, the results of sub-scenarios with different climate change (i.e., RCP-2.6, RCP 4.5, RCP-6.0 and RCP-8.5) shows similar water demand in the study area. Whereas, the unmet water demand and the environmental or natural flow of each sub scenario varied from one to another as described below in table.6 up to table.9 respectively. For all sub-scenarios, the domestic, livestock and poultry; industrial and commercial water demand share was about 0.258 per cent out of total water demand while agricultural water demand share was 99.74 per cent out of total annual water demand in 2050.

Table.6: Medium growth rate with RCP-2.6 scenarios future water demand by2050

Description	Annual sectoral water demand					Natural / Environmental flow
	Agriculture	Domestic	Livestock	Industrial and commercial	Total water demand	
Annual activity in (Ha &No)	310,017	20,985,807	8,483,063	4,430		
Water demand in (MCM)	3226.5	7.98	0.0973	0.279	3234.88	3,769.92
Unmet demand in (MCM)	251.69	-	-	-		

Ha: hectare, &: and, No: Numbers, MCM: million cubic meters

Table.7: Medium growth rate with RCP-4.5 scenarios future water demand by2050

Description	Annual sectoral water demand					Natural / Environmental flow
	Agriculture	Domestic	Livestock	Industrial and commercial	Total water demand	
Annual activity in (Ha &No)	310,017	20,985,807	8,483,063	4,430		
Water demand in (MCM)	3226.52	7.98	0.0973	0.279	3234.88	3,823.02
Unmet demand in (MCM)	239.72	-	-	-		

Ha: hectare, &: and, No: Numbers, MCM: million cubic meters

Table.8: Medium growth ratewith RCP-6.0 scenarios future water demand by2050

Description	Annual sectoral water demand					Natural / Environmental flow
	Agriculture	Domestic	Livestock	Industrial and commercial	Total water demand	
Annual activity in (Ha &No)	310,017	20,985,807	8,483,063	4,430		
Water demand in (MCM)	3226.52	7.98	0.0973	0.279	3234.88	3,803.32
Unmet demand in (MCM)	244.13	-	-	-		

Ha: hectare, &: and, No: Numbers, MCM: million cubic meters

Table.9: Medium growth rate with RCP-8.5 scenarios future water demand by2050

Description	Annual sectoral water demand					Natural / Environmental flow
	Agriculture	Domestic	Livestock	Industrial and commercial	Total water demand	
Annual activity in (Ha &No)	310,017	20,985,807	8,483,063	4,430		
Water demand in (MCM)	3226.52	7.98	0.0973	0.279	3234.88	3,869.82
Unmet demand in (MCM)	229.35	-	-	-		

Ha: hectare, &: and, No: Numbers, MCM: million cubic meters

As specified above table-8 and table-9, the maximum unmet water demand was observed by the medium growth rate with RCP-6.0 sub-scenario, while the maximum natural/environmental flow was observed by medium growth rate with RCP-8.5 sub-scenario. Alternatively, the minimum unmet water demand was observed by medium growth rate with RCP-8.5 whereas, the minimum natural/environmental flow observed by the medium growth rate with RCP-2.6 in 2050 (vide table.9 and table.6).

ii. High growth rate with various climate change scenarios (2021- 2050)

By assuming a high growth rate with different climate change sub-scenarios for 2050, the human population increase to 25,062,832; livestock and poultry population grown to 8,509,582; the industrial and commercial units also grown to 4,518 whereas the agricultural irrigation area decreases to 310,026 hectares as compared to the current account year. The result indicates, total water demand of 3238.74 million cubic meters with annual water demand of 11.75 million cubic meters for domestic, 0.0976 million cubic meters for livestock and poultry, 0.285 million cubic meters for industrial and commercial units and 3226.61 million cubic meters for agricultural sector in 2050. The high growth rate scenario with different climate change, sub-scenarios also show similar water demand. Whereas the unmet water demand and environmental or natural flow of sub-scenarios give different output due to the variation of water supply influenced by various climate change scenarios (i.e., RCP-2.6, RCP-4.5, RCP-6.0 & RCP-8.5). The total activity level, water demand and unmet water demand of all sub scenarios under high growth rate result were shown from table.10 up to table.13 below.

Table.10: High growth rate with RCP-2.6 scenarios future water demand by2050

Description	Annual sectoral water demand					Natural / Environmental flow
	Agriculture	Domestic	Livestock	Industrial and commercial	Total water demand	
Annual activity in (Ha &No)	310,026	25,062,832	8,509,582	4,518		
Water demand in (MCM)	3226.61	11.75	0.0976	0.285	3238.74	3,766.06
Unmet demand in (MCM)	252.21	-	-	-		

Ha: hectare, &: and, No: Numbers, MCM: million cubic meters

Table.11: High growth rate with RCP-4.5 scenarios future water demand by2050

Description	Annual sectoral water demand					Natural / Environmental flow
	Agriculture	Domestic	Livestock	Industrial and commercial	Total water demand	
Annual activity in (Ha &No)	310,026	25,062,832	8,509,582	4,518		
Water demand in (MCM)	3226.61	11.75	0.0976	0.285	3238.74	3,819.16
Unmet demand in (MCM)	240.34	-	-	-		

Ha: hectare, &: and, No: Numbers, MCM: million cubic meters

Table.12: High growth rate with RCP-6.0 scenarios future water demand by 2050

Description	Annual sectoral water demand					Natural / Environmental flow
	Agriculture	Domestic	Livestock	Industrial and commercial	Total water demand	
Annual activity in (Ha &No)	310,026	25,062,832	8,509,582	4,518		
Water demand in (MCM)	3226.61	11.75	0.0976	0.285	3238.74	3,799.46
Unmet demand in (MCM)	244.75	-	-	-		

Ha: hectare, &: and, No: Numbers, MCM: million cubic meters

Table.13: High growth rate with RCP-8.5 scenarios future water demand by2050

Description	Annual sectoral water demand	n vi ro n m

	Agriculture	Domestic	Livestock	Industrial and commercial	Total water demand	
Annual activity in (Ha &No)	310,026	25,062,832	8,509,582	4,518		
Water demand in (MCM)	3226.61	11.75	0.0976	0.285	3238.74	3,865.96
Unmet demand in (MCM)	229.87	-	-	-		

Ha: hectare, &: and, No: Numbers, MCM: million cubic meters

As indicated above, the maximum unmet water demand was observed by high growth rate with RCP-2.6 sub-scenario while, the maximum natural/environmental flow was observed by high growth rate with RCP-8.5 sub-scenarios (vide table.10 and table.13). On another hand, the minimum unmet water demand was observed by a high growth rate with RCP-8.5 while the minimum natural/environmental flow observed by medium growth rate with RCP-2.6 in 2050 (vide table.13 and table.10).

3.2.2.3. Management scenarios (2021-2050)

a. Improved irrigation efficiency by (10%) scenarios in (2021-2050)

By this scenario the assumption of 10 per cent improved irrigation efficiency was projected and the future activity level, water demand and unmet water demand was described below in table.14.

Table.14: Improved irrigation efficiency by (10%) scenarios future water demand by 2050

Description	Annual sectoral water demand					Natural / Environmental flow
	Agriculture	Domestic	Livestock	Industrial and commercial	Total water demand	
Annual activity in (Ha &No)	310,009	17,657,875	8,456,852	4,343		
Water demand in (MCM)	2903.78	5.24	0.097	0.274	2909.40	4421.7
Unmet demand in (MCM)	54.48	-	-	-		

Ha: hectare, &: and, No: Numbers, MCM: million cubic meters

As shown above in the table.14, the total unmet water demand drops to 54.48 million cubic meters with an increment of natural/environmental flow to 4421.7 million cubic meters in 2050. The demand coverage was improved by an average of 6.48 per cent from (91.65% to 98.13%).

b. Improved irrigation efficiency by (20%) scenarios (2021-2050)

By this scenario the assumption of 20 per cent improved irrigation efficiency was projected and the future activity level, water demand and unmet water demand was shown below in table.15.

Table.15: Improved irrigation efficiency by (20%) scenarios future water demand by2050

Description	Annual sectoral water demand					Natural / Environmental flow
	Agriculture	Domestic	Livestock	Industrial and commercial	Total water demand	
Annual activity in (Ha &No)	310,009	17,657,875	8,456,852	4,343		
Water demand in (MCM)	2645.67	5.24	0.097	0.274	2651.28	4679.82
Unmet demand in (MCM)	0	0	0	0		

Ha: hectare, &: and, No: Numbers, MCM: million cubic meters

As revealed above in the table.15, the total unmet water demand solved totally before 2050 by 2044 with an increment of natural/environmental flow to 4679.8 million cubic meters by the same year. The demand coverage was improved by an average of 8.35 per cent (from 91.65% to 100%).

c. Shifting paddy to horticulture by (20%) scenario (2021-2050)

By this scenario the assumption of 20 per cent shifting paddy irrigation area to horticulture was projected and the future activity level, water demand and unmet water demand was shown below in table.16.

Table.16: Shifting paddy area to horticulture by (20%) scenariofuture water demand by2050

Description	Annual sectoral water demand	n vi ro n m

	Agriculture	Domestic	Livestock	Industrial and commercial	Total water demand	
Annual activity in (Ha &No)	310,009	17,657,875	8,456,852	4,343		
Water demand in (MCM)	2747.62	5.24	0.097	0.274	2753.24	4577.86
Unmet demand in (MCM)	0	0	0	0		

Ha: hectare, &: and, No: Numbers, MCM: million cubic meters

As indicated above in the table.16, the total unmet water demand solved totally before 2050 by 2048 with an increment of natural/environmental flow to 4577.86 million cubic meters by 2050. The demand coverage was improved by an average of 8.35 per cent (from 91.65% to 100%).

d. Wastewater re-use for irrigation at full potential (2021-2050)

By this scenario the assumption of re-using treated wastewater for irrigation purposes at the full potential treatment capacity of the plants was projected and the future activity level, water demand and unmet water demand was shown below in the table.17.

Table.17: Re-using treated wastewater for irrigation at a full potential scenario future water demand by 2050

Description	Annual sectoral water demand					Natural / Environmental flow
	Agriculture	Domestic	Livestock	Industrial and commercial	Total water demand	
Annual activity in (Ha &No)	310,009	17,657,875	8,456,852	4,343		
Water demand in (MCM)	3226.43	5.24	0.097	0.274	3232.04	4768.86
Unmet demand in (MCM)	134.05	0	0	0		

Ha: hectare, &: and, No: Numbers, MCM: million cubic meters

As indicated above in the table.16, the total unmet water demand drops to 134.05 million cubic meters with an increment of natural/environmental flow to 4768.86 million cubic meters by 2050. The demand coverage was improved by 4.20 per cent (from 91.65% to 95.85%).

3.3. Overall water supply and demand situation of the Jhelum River basin in the future

Generally, the current research finding shows the increment of water demand with respect to domestic and industrial and commercial sectors due to external driving factors and decrease by agricultural and livestock and poultry sectors because of declining of irrigation area of paddy and decreasing population of cattle in the study area. The historical census data of paddy irrigated area and cattle population were collected from the directorate of agriculture and livestock census of the government of India, by which both paddy and cattle demand more water than others. The external driving factor (i.e., increasing population growth rate, changing of climate, high urbanization and changing living standard of the society) scenario assumptions analysis shows accelerated unmet water demand in the Jhelum River basin as compared to reference and management scenarios in the future. Similar studies have been done by different researchers all over the world. The study by (Amin et al., 2018; Mourad and Alshihabi, 2016) on the Upper Indus basin of Pakistan and Syrian respectively to assess the future water supply and demand situation. Both studies found out unmet water demand in 2050 due to external driving factors. Similarly, (Agarwal et al., 2019)also discovered unmet water demand in the agricultural sector, due to the fact that the first priority was given to the domestic sector which puts the agricultural area in the watershed of the Ur River of India with less water supply. Indirectly this unmet water demand puts further problems on groundwater exploitation and related difficulties. Furthermore, as a result of global climate change in 2100 the competition of surface water among domestic, livestock, tourist, and agricultural sector will rise and puts pressure on the Rheraya's watershed of Morocco (Rochdane et al., 2012). Two studies have been done on the Jhelum River basin and Srinagar city to assess the water supply and demand situation. The first one was done by(Kahil et al., 2016) and investigated the Jhelum River basin experiencing mild to extreme water shortage due to reckless urbanization, rapid population growth that is responsible for climate variation in the basin. The other study by (Malla et al., 2014)shows deficiencies in domestic water demand in the urban city of Srinagar in 2016, 2017, 2018, and 2020 due to changing climate scenarios.

Depending upon the current study result and related research discussed above the following policy intervention and water allocation strategies were developed to bring a sustainable balance of water supply and demand situation in the study area.

3.4. Policy interventions and water allocation techniques

To bring a sustainable solution for the unmet water demand in the study area, enhancement of water supply, demand management and trans-boundary water resource management policy intervention and water allocation techniques were developed.

3.4.1. Enhancement of water supply

Development of mini-dams and river diversions on the tributaries of Jhelum River: Development of mini-dams and reservoirs on the tributaries of Jhelum River has a significant impact on the balance of water supply and demand in the Jhelum River basin by ensuring a constant water flow. However, this water supply enhancement policy should be applied according to the Indus water treaty (IWT) agreement unless otherwise, it will bring transboundary disputes between the two neighboring nations.

Use of both surface and groundwater: Using both surface and groundwater improve the future water supply. However, the present study focuses only on surface water resources due to a lack of information on groundwater which shows unmet demand currently, so groundwater study is a priority activity for the near future to improve the water supply availability.

On farm water management techniques: Water resource efficiency improved at the farm level as a result of better system design, regular maintenance, and good drainage, as well as equitable processes for sharing water among farmers when there is a shortage.

Re-use of treated wastewater for irrigation: This option will improve the unmet water demand of agriculture by increasing water supply enhancement in the study area. Beside this technology will benefit in solving the environmental pollution that indirectly impacts climate change. According to a study by (Paul and Elango, 2018) re-using treated waste water will increase the water supply reliability by 30 per cent, as compared to using the new reservoir and desalination plants which have 19 and 10 per cent supply reliability respectively on the water resources system of Chennai megacity of India.

Soil and water conservation management: It has a big role in the water supply enhancement of the Jhelum River basin. Physical and biological soil and water conservation structures improve the overall water supply availability in the near future.

Plantation of trees: Planting new seedlings every year improve the vegetation coverage and help in water supply availability of the Jhelum River basin. Currently, the global vegetation coverage was declining continuously due to deforestation which aggravates the climate change in the world.

3.4.2. Demand Management

The second policy intervention and water allocation technique developed by this research study was demand management. Demand management is the efficient use of available water resources without any loss by maximizing the net returns through various techniques that improve economic water use efficiency within and across sectors. The overall objective of demand management is to produce more output from less input. In agriculture, this means producing more valuable and less water-intensive crops rather than less valuable and high-water intensive crops.Managing demand side helps in saving money and preserve the environment in addition to reducing water usage in the demand sites (Saleem et al., 2021).

As indicated above in the table 15 and 16, the unmet water demand totally improved in the improved irrigation efficiency by 20 per cent and shifting paddy area to horticulture by 20 per cent. Those two scenarios are the demand management policy intervention and water allocation techniques that show clear future direction to improve the imbalance of water supply and demand situation in the Jhelum River basin.

3.4.3. Trans-boundary water resource management issues

In 1960, India and Pakistan negotiated the Indus Water Treaty (IWT) under the direction of the World Bank. It was created to divide the waters of the Indus River Basin after the two countries were separated in 1947. The agreement provided India exclusive usage rights to the Sutlej, Beas, and Ravi eastern tributaries and Pakistan usage rights to the Chenab, Jhelum and Indus western rivers properly (Biswas, 1992). However, the 1960 Indus water treaty were based on what was known and available at the time but now days so many things have changed. The population of two-nation was increased from 495.5 million in 1960 to 1.533 billion in 2020 (Anonymous, 2020). Besides the Indus and the treaty that governs its usage are being pressured by climate change and inefficient irrigation practices that brings the fragile relationship between the two nations (Nayani, 2013). Unless the Indus water treaty is revised, external driving factors such as; climate change, population growth, urbanization and the living standard of the society have the capability of complicating the surface water availability(Sarfraz, 2013). But, the breakable connection between India and Pakistan is likely to make the revision difficult to achieve the goal for both countries (Choudhury and Islam, 2015). Even though, the only option for both countries to bring mutual benefit and create a bright future for the coming generation was an integrated and holistic approach for sustainable water resource management. Therefore, the revision will help to improve the Jhelum river basin water supply and demand situation at the future if possible efforts undertaken from both side countries, since the river is under the Indus water treaty.

4. Conclusion

The general objective of the study was to assess the current and future surface water supply and demand situation of the Jhelum River basin by using hydro-economic water evaluation and planning model and generate a suitable policy scenario matrix for integrated water resource management. Based on the result obtained from the research study the following summary was concluded:

The total annual surface water supply was 6.96 billion cubic meters with a mean annual discharge flow of 220.2 cubic meters per second for the current (2020) account year in the Jhelum River and its tributaries. Although, the current (2020) total water demand for all sectors were 3249.5 million cubic meters with an unmet demand of 271.23 million cubic meters. The highest Water demand was consumed by agriculture around 3246.6 million cubic meters and followed by domestic, industrial and commercial, and livestock and poultry with an annual water demand of 2.50, 0.253 and 0.101 million cubic meters respectively. Whereas the natural/ environmental flow was around 3712.3 million cubic meters in the same year.

Three scenarios were developed to see the future water supply and demand situation in the Jhelum River basin depending on various assumptions. The future water supply availability increased in all scenarios but with different variation between scenarios. The future water demand increases in the case of domestic, industrial and commercial sectors whereas decreases by agricultural and livestock sector due to decrease irrigation area and livestock population from year to year. The declining of paddy irrigation area and cattle population results with decreasing of future water demand in the region, since both of them are more water consumptive than others.

The future unmet water demand still observed in 2050 by reference, external driving factor and some of management scenarios. However, the unmet water demand, totally solved before 2050 in the case of improving irrigation efficiency by (20%) and shifting (20%) irrigated area of paddy to horticulture sub-scenarios. Finally, the study finds out different policy interventions and water allocation techniques in order to solve the future water supply and demand imbalance in the Jhelum River basin by enhancing water supply, managing water demand and considering transboundary water resource management issues with strong coordination and cooperation among sectors and countries to meet the future unmet water demand sustainably.

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