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Development of a GIS Based River Basin Bodel

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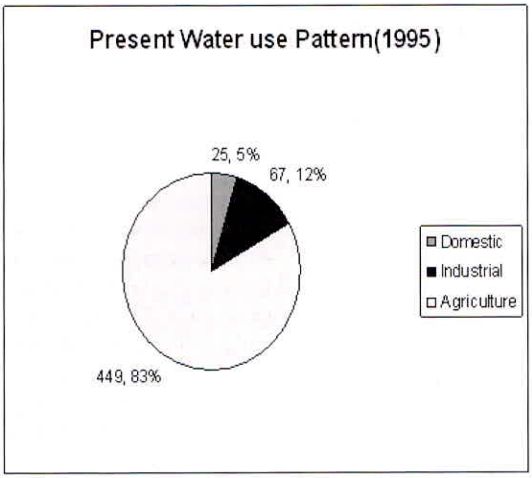
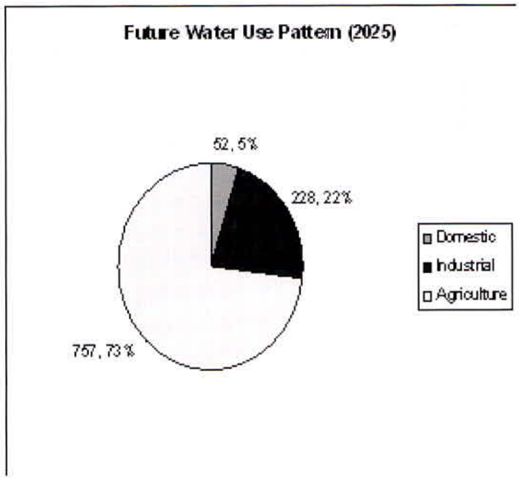
Abstract : This study is focused on the development of a GIS based river basin model WSDCM (Water Demand and Supply Calculation Model). WDSCM analyzes water demand and supply at sub-basin level and then, by system water balance, identifies the sub-basin with water deficit and water surplus. The graphical user interface (GUI) and coding of the present version of WDSCM is developed in Microsoft Visual Basic 6. The integration of GIS with WDSCM is done with the help of ESRI Map Object 2.2 to make the model more flexible and user-friendly. The model is applied in the Kangsabati basin, located between latitudes 22^0 and 23^0 N and longitudes 86^0452 and 88^0 E of 4217.52 km^2, covering Bankura, West Midnapur and East Midnapur districts of West Bengal. The various data files required to run the model, such as soil data, land use data, groundwater data and population data were prepared at sub-level with the help of Erdas Imagine 8.5 and Arc GIS 9.1. After preparation of all the data required, the model simulations were done over two simulation periods firstly, for the water year 2002-03 (June 2002 to May 2003) and secondly for the Kharif season of the year 2003 (June 2003 to Nov 2003). It is found that for the first simulation period, out of 44 sub-basins, 32 sub-basins are under water deficit condition and the remaining 12 sub-basins are under water surplus condition. The amount of water deficit ranges from 0.24 Mm^3 to 20.67 Mm^3 and the amount of water surplus ranges from 1.67 Mm^3 to 22.06 Mm^3. For the second simulation period out of 44 sub-basins, 41 sub-basins are under water surplus condition and the remaining 3 sub-basins are under water deficit condition. The amount of water deficit ranges from 0.01 Mm^3 to 2.82 Mm^3 and the amount of water surplus ranges from 0.63 Mm^3 to 57.38 Mm^3. However, the results may not be the true representation of the condition in the basin as the data related to water supply through canal were not considered due to non-availability and so was the industrial demand data. Even with this shortcoming, the developed model highlights the uneven distribution of water in the basin.

INTRODUCTION

River basin modelling is carried out for planning, developing, managing and the sustainable use of the natural water resources in a river basin so as to provide for the society's social, cultural and economic development by taking into account, the basics of hydrology and ecology. Problems arising from the scarcity of appropriate resources in the face of the rising demand for water parallel to the rapid growth of population in recent years, excessive industrial use along with various pollution parameters due to the growing industrial and agricultural activities, have increased the importance of river basin based water resources management. A study conducted by the Ministry of Water Resources, Govt. of India (Annual report, 2004) reveals that in the year 2025, all the water use sectors will consume more than double the quantity of water than they presently consume (Fig.1).

Thus, the challenges in water resources management are enormous. To meet these challenges, over the last few years, scientists and researchers have been trying to develop proper river basin management models which will provide an optimal solution to all water management problems in a river basin. WEAP, AQUARIUS, MIKEBASIN, AQUATOOL (Andreu et al.1996; Brown et al. 2002; Jensen et al. 2007; Sally et al. 2007) are some of the river basin models which are the product of this research. Most of these models work best when data on the physical characteristic of the basin are available at the model grid scale. This kind of data is rarely available even in heavily instrumented research watershed. Now remote sensing (RS) and Geographic information system (GIS) make it easier to extract these physical characteristic of the watershed. In our country, in the past, very little work has been done on river basin planning and management. However, recently a few efforts have been initiated in the country to develop





(Source: Ministry of Water Resources, Govt. of India ,Annual report, 2004)
Note: Values are in BCM

Fig.1. Present and future water use pattern of India

river basin models through World Bank funded "Water Sector Restructuring Projects" in various states. Also, "Hydrology Project –II" aims at utilizing the Hydrological Information System (HIS) data for the development of a Decision Support System (DSS) for integrated planning of water resources in river basins in the different states of the country, such as, Andhra Pradesh, Chhattigarh, Gujrat, Himachal Pradesh, Kerala, Karnataka, Madhya Pradesh, Punjab, Tamilnadu etc. Different central government agencies, such as, Central Water Commission (CWC), Central Pollution Control Board (CPCB), Central Groundwater Board (CGWB), Central Water and Power Research Station (CWPRS), Bhakra Beas Management Board (BBMB), National Institute of Hydrology (NIH) etc. are working together as a unit to implement this project. In this research also, an attempt is being made to develop a river basin model which will assist, river basin authorities to identify the available water resources and estimate water demand in a river basin, so that they can efficiently manage the water resources. The present study, therefore, has been taken up with the following objectives:

1. To develop a GIS based river basin model, WDSCM (Water Demand and Supply Calculation Model)
2. To apply the model to assess water surplus and water deficit areas in a river basin.

DATA AND METHODOLOGY

Model Description

The model WDSCM analyzes water demand and water supply at sub-basin level and then by system water balance, it identifies the sub-basins with water deficit and water surplus. The flowchart for the model's calculation procedure is shown in Fig. 2. The model has three modules, viz., water supply module, water demand module and water balance module.

In water supply module, different components of water supply, i.e., surface runoff, groundwater potential, and canal water availability, are calculated. Surface runoff is estimated by SCS curve number technique (SCS, 1972), groundwater potential is estimated within the recommendations and guidelines of Groundwater Resource Estimation Committee (1997) and canal water is estimated by analyzing daily canal discharge data at sub-basin level.

In water demand module, different components of water demand, i.e., agricultural demand, domestic and industrial demand, are calculated. Agricultural water

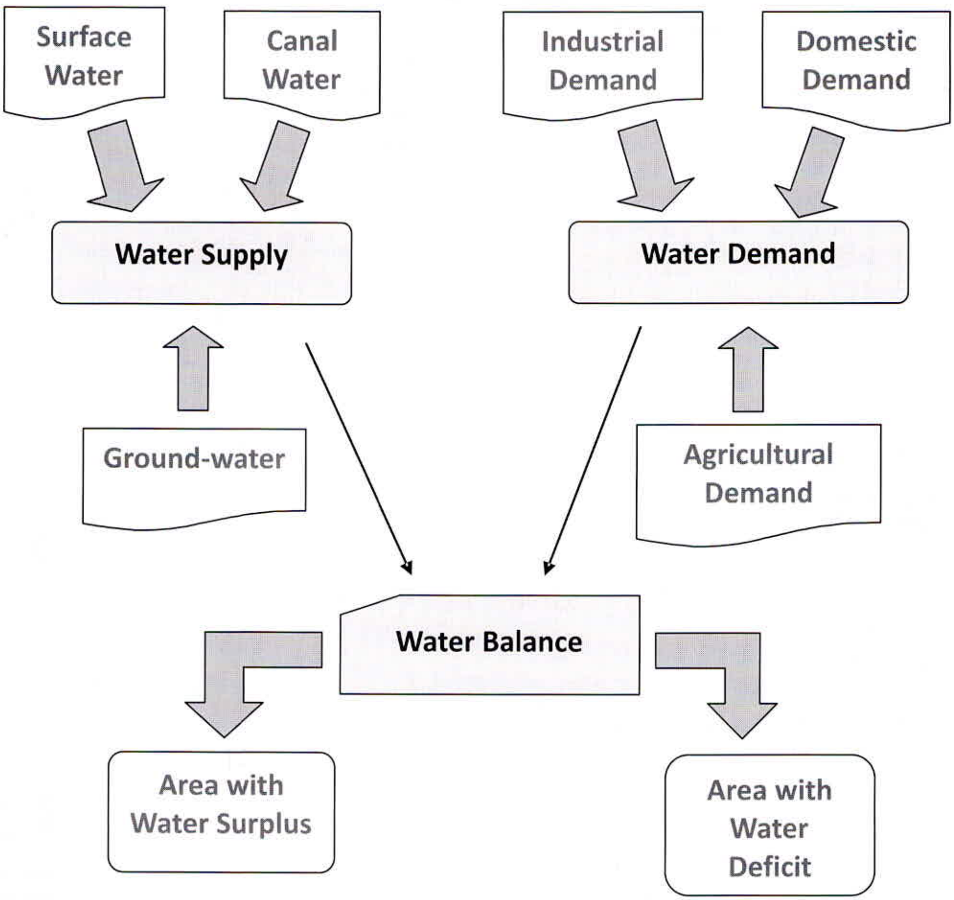


Fig. 2. Flowchart for the WDSCM's calculation procedure

demand is calculated by the FAO-56 modified Penman Monteith method. Domestic and industrial water demands are estimated by analyzing daily domestic demand based on per capita water consumption and industrial water use data respectively. In Water balance module, by water balance, water surplus and water deficit areas are identified. This module also shows different components of water supply and water demand for a sub-basin at a glance. The GIS interface of the model helps the users to easily identify the sub-basin for which water balance needs to be calculated. Once the sub-basin is selected, all the data corresponding to the sub-basin are automatically transferred to the model. The graphical user interface (GUI) and coding of the present version of WDSCM is developed in Microsoft Visual Basic 6. The integration of GIS with WDSCM is done with the help of ESRI Map Object 2.2 to make the model more flexible and user friendly. The required shape file of the sub-basin, which is the main input to the model, is created by AVSWAT 2000 and Arc GIS 9.1. All the data at sub-basin level is incorporated into the attribute of the shape file so that when the user clicks on any of the sub-basin, all the data corresponding to that sub-basin goes to model automatically. All other input files of model was prepared in .txt format and kept in a specified folder. During run time, the required .txt file is called and the data get automatically transferred into the model.

The graphical user interface (GUI), with integration of GIS, is the most important feature of the model as it provides a better interaction between the model and the user. The model is based on mouse driven approach with pop-up windows, pop-up menus and button controls. On clicking on the wdscm.exe the starting window of the model (Fig. 3) appears. In this window the sub-basin map is inputted by clicking the "Open" button to browse the location of the map.

The selected sub-basin is turned into red and the all the data corresponding to the selected sub-basin goes to model automatically. After selecting the sub-basin for which calculation would be done, "OK" button is clicked, and the window showing the modules of the model appears (Fig. 4). This window navigates to the different components of the module. In Water Supply Module there are three components, Surface water, Groundwater and Canal Water, and in Water Demand Module there are two components, Agricultural Demand and Domestic and Industrial Demand. All the components appear by clicking subsequent buttons. In the window showing the modules of the model (Fig. 4), the user has to input the simulation period for which the model will run.

The surface runoff is calculated by the SCS curve number method (SCS, 1972). Fig. 5 shows the snapshots of the data input windows for the calculation of the surface runoff.

Groundwater potential at sub-basin level is estimated within the recommendations and guidelines of Groundwater Resource Estimation Committee (1997). Fig. 6 shows the data input window for the groundwater potential estimation.

Canal water availability is estimated by analyzing daily canal discharge data at sub-basin level. Fig. 7 shows the data input window for the calculation of canal water availability.

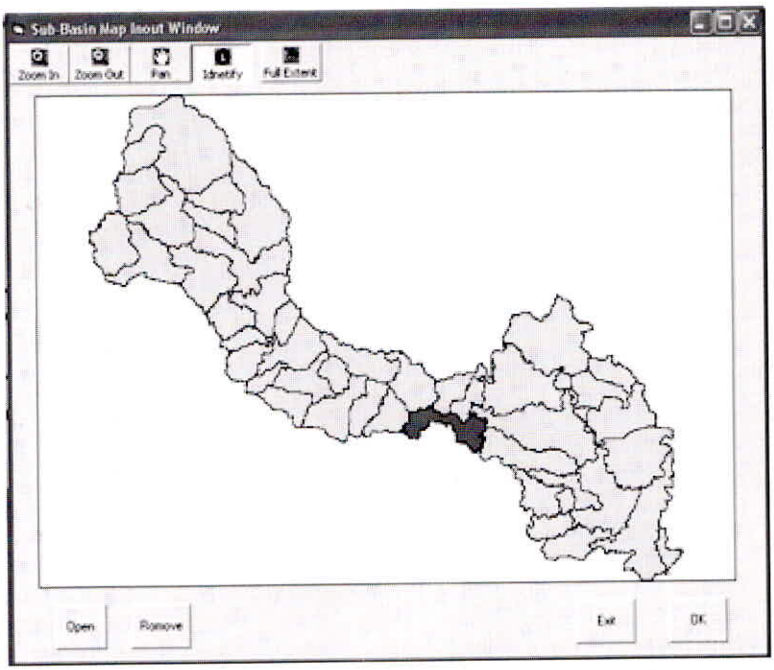


Fig. 3. Sub-basin map input window

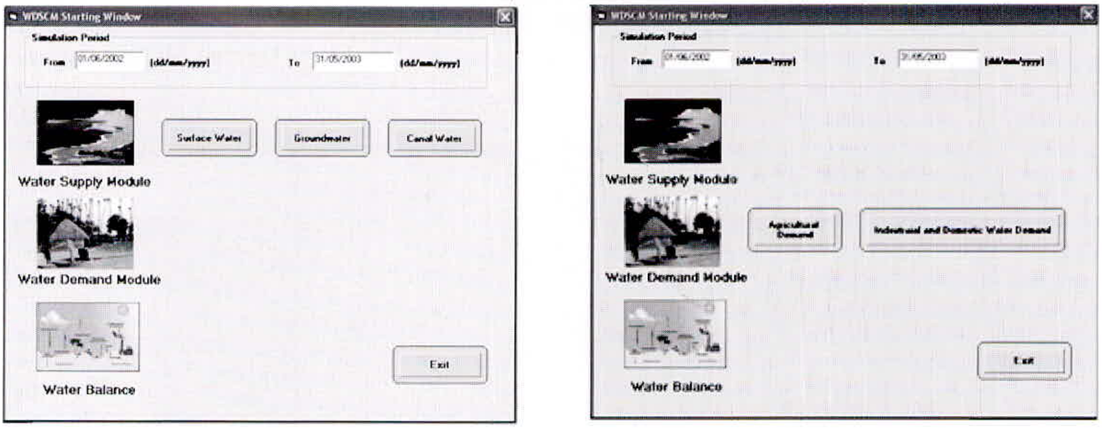


Fig. 4. Window showing modules of the WDSCM

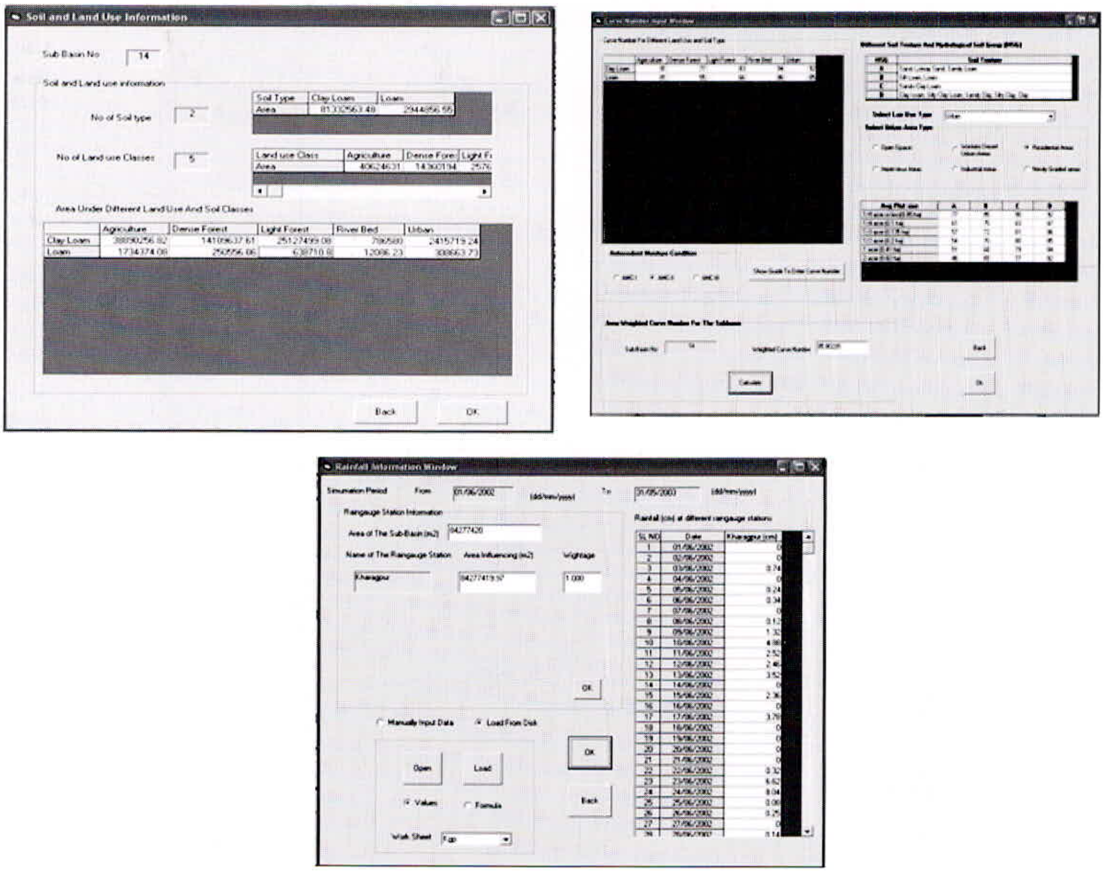


Fig. 5. Data input windows for Surface run-off estimation

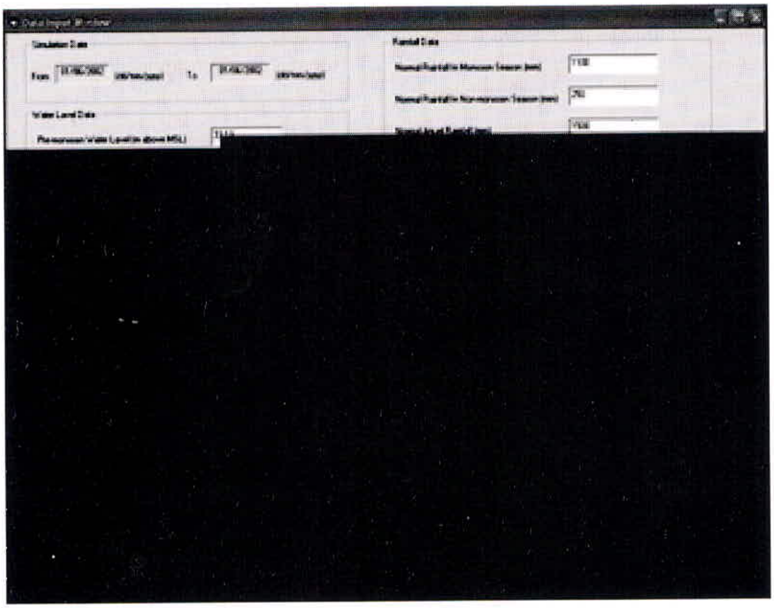


Fig. 6. Data input window for groundwater resource estimation

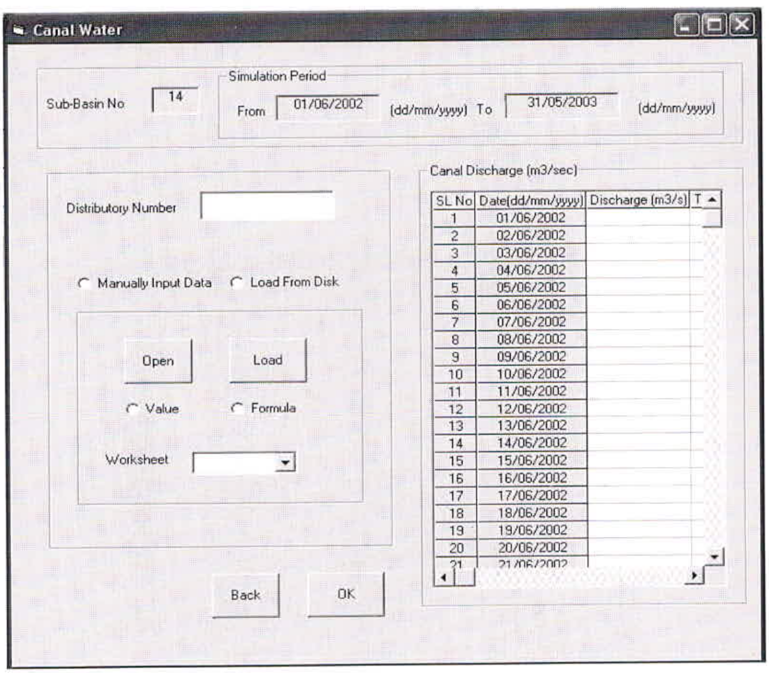


Fig. 7. Data input window for canal water estimation

Agricultural water demand is calculated by the recommendation and guideline as prescribed in FAO-56 modified Penman Monteith method. Data input windows for agricultural water demand is shown in Fig 8.

Domestic and industrial water demands are estimated by analyzing daily domestic demand based on per capita water consumption and industrial water use data respectively. Fig. 9 shows the data input window for the domestic and industrial water demand calculation. After calculation of all the components of water supply and water demand module, calculation of water balance is done in the water balance module. This module shows the different components of water supply module and water demand module, total water supply, and total water demand for the selected sub-basin within the simulation period (Fig 10). It also shows whether the selected sub-basin is under water deficit or water surplus condition, and amount of water surplus or water deficit. The user can get the output in the map form (Fig. 11) when the user clicks on the button "Show Output Map". The output maps show the sub-basin with water deficit in red and the sub-basin with water surplus in blue.

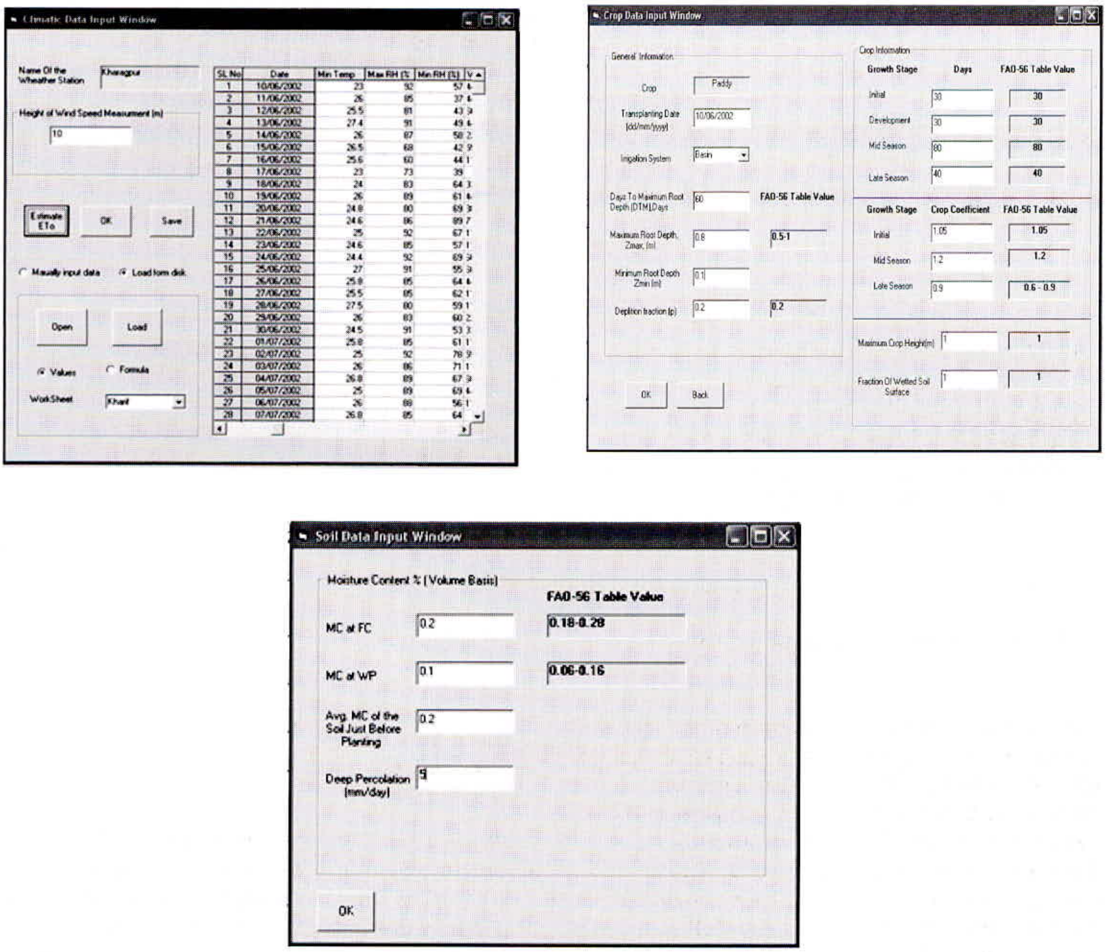


Fig. 8. Data input window for Agricultural water demand estimation

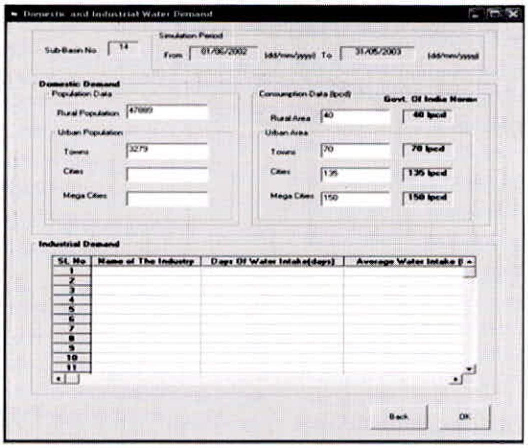


Fig. 9. Data input window for the domestic and industrial water demand calculation

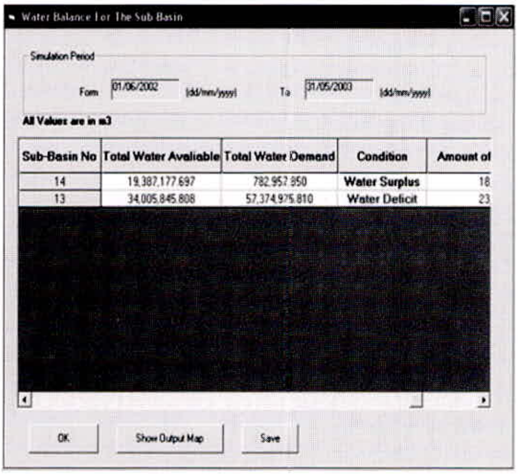


Fig. 10. Water balance window for the sub-basin

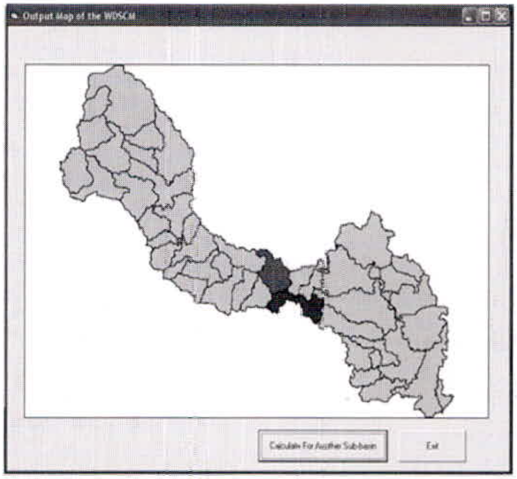


Fig. 11. Output map of the WDSCM

When the user selects any sub-basin in the window "Output map of the WDSCM" (Fig. 11), a window (Fig. 12) pops-up which shows the summary of the different water demand and supply components of that sub-basin at a glance. The model runs for another sub-basin when the user clicks on the button "Calculate for another Sub-Basin" in the "Output map of the WDSCM window" (Fig. 11) which shows the "Sub-basin map input window" (Fig. 3) with previously loaded sub-basin map. The user has to select another sub-basin to continue the calculation.

Model Application

STUDY AREA

The study area is located between latitudes 22^0 and 23^0 N and longitudes 86^0452 and 88^0 E and consists of 4217.52 km^2 within Bankura, West Midnapur and East Midnapur districts of West Bengal. The main river in the study area is Kangsabati which originates from the Chotanagpur hills. It flows South-Easternly and meets with the Hoogly river near Haldia of East Midnapur

	Value (m3)
Sub-Basin No	14
Kharif Demand	26,108,800.350
Rabi Demand	23,059,840.544
Domestic Demand	782,957.850
Industrial Demand	0.000
Surface Water	48,558,730.658
Groundwater	13,815,766.015
CanalWater	
Total Water Avaliable	62,374,496.673
Total Water Demand	49,951,598.743
Condition	Water Surplus
Amount of Surplus or Deficit	12,422,897.930

Fig.12. Pop-up window showing the summary of the calculation of the selected sub-basin

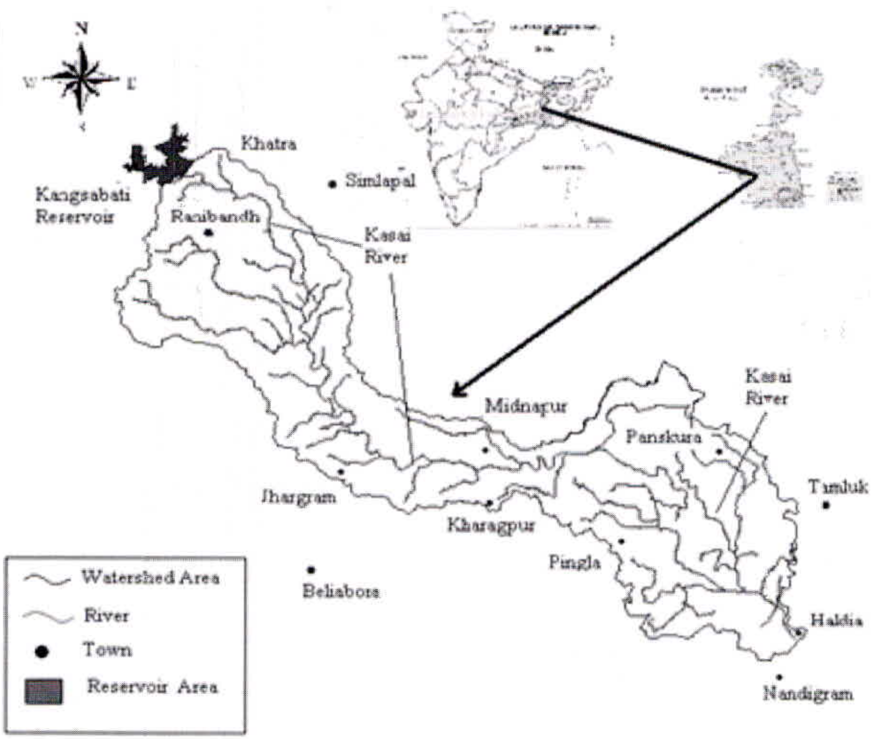


Fig. 13. Study area along with drainage network

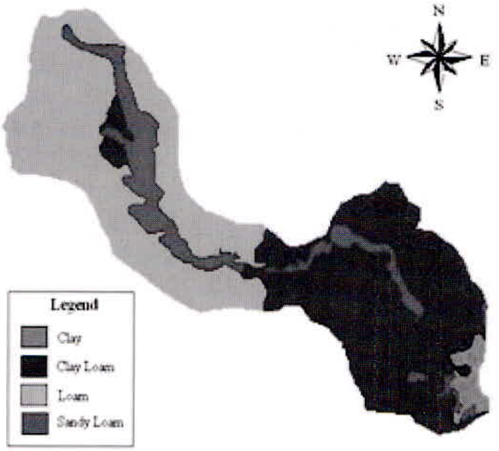


Fig. 14. Soil map of the Study area

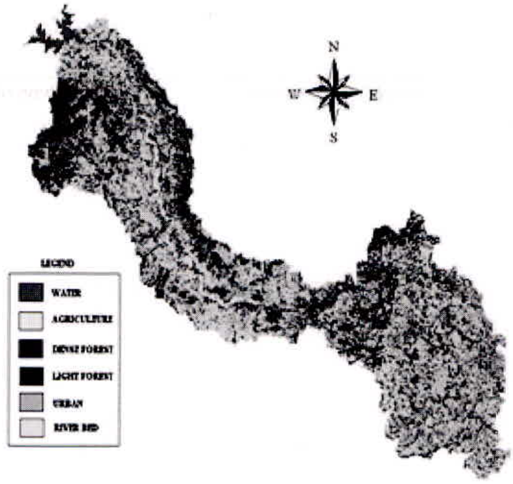


Fig. 15. Land use map of the Study area

district of West Bengal. Other than Kangsabati there are two other rivers namely Bhariabbanki and Tarafani. Both of these originate from Chotanagpur hills and finally meet with the Kangsabati. The study area along with drainage network is shown in Fig. 13. The topography of the study area is more or less flat. The slope ranges from 1% to 6%. The predominant soils of the area are loam and clay loam. The soil map and the land use map of the study area are shown in Fig. 14 and Fig. 15 respectively.

The elevation of the area ranges from 3 m to 197 m above MSL. Annual rainfall varies over the area between 963 mm to 1974 mm with an average of 1400 mm. About 80 to 95 percent of the annual rainfall takes place during the period of June to October. The temperature varies from 47.6^0 C to 5^0 C. The overall climate of the area can be classified as sub-humid tropical. Major crop grown in the area is paddy

DATA ACQUISITION

Since present study deals with the river basin modelling, the data requirement is large. For data acquisition various state government and central government offices were approached. Summary of data collected is presented in the following table.

Model Setup Preparation

Delineation of sub-basin

At first, with the SRTM of study area as an input to AVSWAT 2000, the stream network of the study area was generated. According to the stream network, the study area was divided into the sub-basins (Fig 16). All other data required for the model was prepared according to these sub-basins classification

The collected soil map was digitized in Erdas Imagine 8.5. Then this digitized soil map was intersected with the sub-basin map in Arc GIS 9.1 with the help of intersection tool. The different types of soil present in each sub-basin were obtained from the above mentioned intersected map.

Land use data at sub-basin level

The land use map (Fig. 15) of the study area was prepared by the unsupervised classification of the IRS-1C LISS-III satellite image using Erdas Imagine 8.5. Then the land use data at sub-basin level was obtained by intersecting the land use map of the study area with the sub-basin map in Arc GIS 9.1 using the intersection tool.

Table 1. Source of the data and type of data collected.

Sl No	Source	Type of Data
1	IMD,Kolkata	Meteorological data: Daily Precipitation, temperature, evapotranspiration, solar radiation, wind speed and RH.
2	Survey of India, Kolkata	Topographic Maps of the study area (12 Nos, scale 1:50000)
3	NBSS & LUP, Kolkata	Soil maps for the study area.
4.	ISRO, Govt. of India	IRS -1C LISS-III image.
5.	CGWB, Govt. of India.	Pre- and Post- monsoon groundwater levels.
6.	Ministry of Home Affairs, Govt. of India.	Population data at Block lavel.
7.	Dept of Agricultural and Food Engineering. IIT, kgp	SRTM of the Study area.

(Note: All the data are collected for the year 2002 and 2003)

Fig.16. Sub basin map of the study area

Groundwater elevation data at sub-basin level

The study area has nineteen observation wells. The locations of the observation wells were identified from the toposheet and digitized using Erdas Imagine 8.5. With the digitized location map of the observation well as an input to the Arc GIS 9.1, the contour maps for the pre- and post- monsoon groundwater level at an interval of 2 m were drawn. Then these contour maps were intersected with sub-basin map in Arc GIS 9.1 to get the pre- and post- groundwater level data at sub-basin level. The average of the contours passing through a particular sub-basin was taken as the groundwater elevation of that sub-basin.

Population data at sub-basin level

For the preparation of population data at sub-basin level, block map of the East Midnapur, West Midnapur, Bankura and Purulia districts were digitized in Erdas Imagine 8.5. Then this map was intersected with the sub-basin map in Arc GIS 9.1 to get the population data at sub-basin level.

RESULT AND DISCUSSIONS

After the preparation of all the data req uired to run WDSCM, the model simulations were done over two simulation periods. Firstly, for the water year 2002-03 (June 2002 to May 2003) and secondly for the Kharif season of the year 2003 (June, 2003 to Nov, 2003). For both simulation periods, different components of the water demand and water supply for all 44 sub-basins were estimated. Table 2 presents the details of different components of water demand and supply for all 44 sub-basins, and for the total study area for the first simulation period. Fig. 17 presents the output map of the WDSCM for the first simulation period.

it is evident that for the first simulation period out of 44 sub-basins, 32 sub-basins are under water deficit condition. The maximum water deficit of 20.67 Mm3 is for the sub-basin-31 and minimum water deficit of 0.24 Mm3 for the sub-basin-23. The remaining 12 sub-basins are under water surplus condition, with maximum water surplus of 22.06 Mm3 for the sub-basin-42 and with minimum water surplus of 1.67 Mm3 for the sub-basin-36. However, the results may not be the true representation of the condition in the basin as data related to water supply through canals was not considered here due to non-availability and so was the industrial demand data. Fig.18 presents the different components of water demand and water supply for the total study area at a glance. A close look at this figure reveals that water demand for agriculture is dominant over other demands, and the available water is not enough to meet the demand. This leads to a water deficit of 141.82 Mm^3 for the total study area.

Table 3 presents the details of different components of water demand and supply for all 44 sub-basins, and for the total study area for the second simulation period. Fig. 19 presents the output map of the WDSCM for the second simulation period.

From Table 3 and Fig 19, it is evident that for the second simulation period out of 44 sub-basins 41 sub-basins are under water surplus condition. The maximum water surplus of 57.38 Mm^3 is for the sub-basin-44 and minimum water surplus of 0.63 Mm^3 for the sub-basin-15. The remaining 3 sub-basins are under water deficit condition, with maximum water deficit of 2.82 Mm^3 for the sub-basin-40 and with minimum water deficit of 0.01 Mm^3 for the sub-basin-38. Fig. 20 presents the different components of water demand and water supply for the total study area at a glance.

The comparison of two simulation runs clearly shows the uneven distribution of water availability during the year, especially in two seasons, a characteristic feature of most of the river basins in the country. Further, the results show that with proper river basin management, the surplus water in kharif season can be utilized to meet the water demand in the rabi season.

CONCLUSIONS

Water being a prime natural resource, a basic human need and a precious national asset, its use needs appropriate planning, development and management and to achieve this, there is need of a proper tool which will help policy maker to identify the available water resources and estimate demand so that they can evenly utilize every precise drop of water. Keeping the above mentioned fact in view, the present study has been taken up. In the study a GIS based river basin model, WDSCM is developed, which will estimate water demand and water supply in a river basin at sub basin level. After the development the model, WDSCM is applied to the Kangsabati basin, located between

Table 2. Different components of water supply and demand for the sub-basins and that of the total study area for the period June 2002 to May 2003.

Water Demand			Water Supply		Total Water Available	Total Water Demand	Condition	Amount of Surplus or Deficit
Agricultural Demand		Domestic Demand	Surface Water	Ground Water				
Kharif Season	Rabi Season							
19.07	16.77	0.19	8.79	10.09	18.87	36.03	Water Deficit	17.16
11.34	8.71	0.30	17.07	19.12	36.19	20.35	Water Surplus	15.84
35.52	31.26	0.61	16.58	36.14	52.72	67.40	Water Deficit	14.68
13.71	10.55	0.37	18.95	21.48	40.43	24.63	Water Surplus	15.79
33.35	25.65	0.42	28.61	18.35	46.97	59.42	Water Deficit	12.45
20.07	17.66	0.46	15.25	7.57	22.82	38.19	Water Deficit	15.37
45.65	40.22	0.68	44.51	33.72	78.24	86.56	Water Deficit	8.32
35.34	31.13	0.82	13.67	42.33	56.00	67.29	Water Deficit	11.30
19.82	17.47	0.35	10.57	14.20	24.77	37.64	Water Deficit	12.87
23.09	17.80	0.70	15.58	24.65	40.24	41.59	Water Deficit	1.35
19.84	10.24	0.76	21.28	8.82	30.11	30.84	Water Deficit	0.74
31.34	27.65	0.47	23.14	31.59	54.73	59.45	Water Deficit	4.72
30.48	26.90	0.65	40.63	13.85	54.48	58.03	Water Deficit	3.55
26.11	23.06	0.78	48.56	13.82	62.37	49.95	Water Surplus	12.42
25.40	22.42	1.49	38.97	10.10	49.07	49.31	Water Deficit	0.24
37.30	32.94	2.19	17.29	47.61	64.90	72.44	Water Deficit	7.54
59.79	52.81	3.24	93.10	30.17	123.27	115.84	Water Surplus	7.43
9.27	8.20	0.39	11.81	3.99	15.80	17.87	Water Deficit	2.07
68.22	60.34	3.54	89.98	31.98	121.96	132.10	Water Deficit	10.14
17.01	14.97	0.36	19.06	6.78	25.84	32.34	Water Deficit	6.50
33.86	29.80	1.03	30.86	19.06	49.92	64.68	Water Deficit	14.76
11.56	10.20	0.26	5.53	8.81	14.34	22.01	Water Deficit	7.67
11.56	10.20	0.26	5.53	8.81	14.34	22.01	Water Deficit	7.67
96.98	85.27	1.56	36.70	126.44	163.13	183.80	Water Deficit	20.67
18.25	16.10	0.26	8.20	18.33	26.53	34.61	Water Deficit	8.08
8.17	7.20	0.21	4.02	6.09	10.11	15.58	Water Deficit	5.47
7.53	6.64	0.12	4.03	5.81	9.84	14.29	Water Deficit	4.45
24.86	21.93	0.56	10.16	31.34	41.51	47.34	Water Deficit	5.84
11.41	10.07	0.19	3.14	20.19	23.33	21.67	Water Surplus	1.67
19.61	17.29	0.50	6.52	23.24	29.77	37.40	Water Deficit	7.63
21.48	16.56	0.24	10.46	12.59	23.04	38.28	Water Deficit	15.24
22.94	20.24	0.38	7.98	16.14	24.12	43.56	Water Deficit	19.43
42.95	37.92	0.73	22.62	57.49	80.11	81.60	Water Deficit	1.49
12.65	11.17	0.44	10.89	9.04	19.94	24.26	Water Deficit	4.32
57.39	50.62	2.88	101.22	31.73	132.95	110.89	Water Surplus	22.06
50.99	45.00	2.05	53.25	37.61	90.85	98.05	Water Deficit	7.19
52.71	46.61	3.16	95.13	29.32	124.46	102.48	Water Surplus	21.98
1322.02	1138.80	42.65	1342.71	1018.95	2361.65	2503.48	**Water Deficit**	141.82

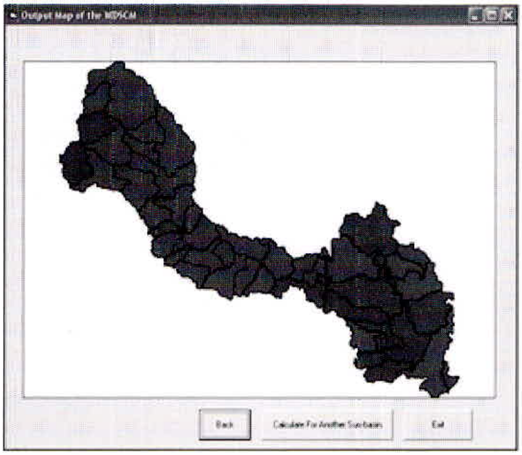


Fig. 17. Output map of the WDSCM for the simulation period June 2002 to May 2003

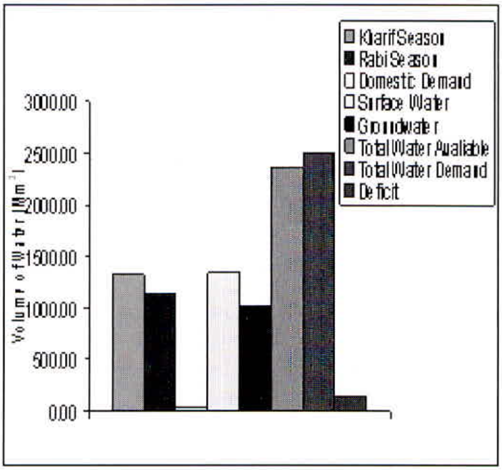


Fig. 18. Different components of water demand and supply of the total study area (June 2002 to May 2003)

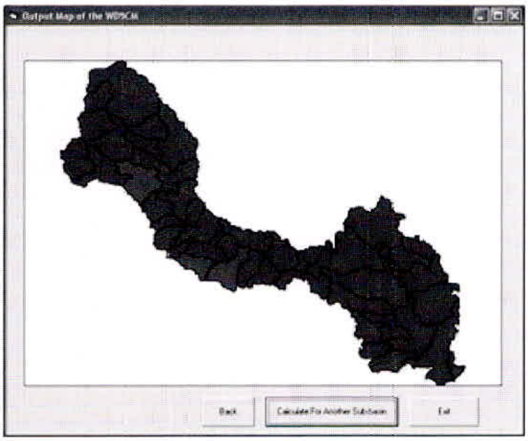


Fig. 19. Output map of the WDSCM for the Kharif season of the year 2003 (June 2003 to Nov 2003)

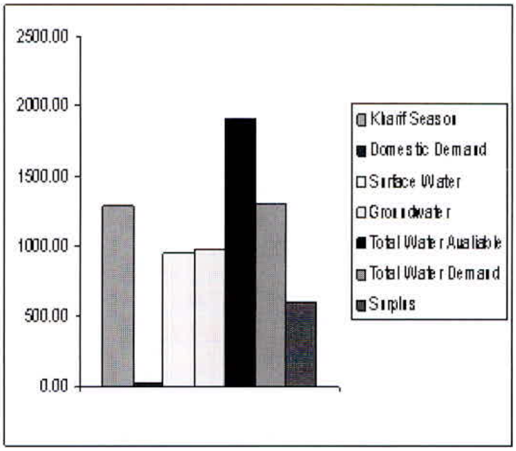


Fig. 20. Different components of water demand and supply of the total study area (June 2003 to May 2003)

Table 3. Different components of water supply and demand for the sub-basins and that of the total study area for the Kharif season of the year 2003 (June 2003 to Nov 2003).

Sub-Basin No	Water Demand		Water Supply		Total Water Available	Total Water Demand	Condition	Amount of Surplus or Deficit
	Kharif Season	Domestic Demand	Surface Water	Ground Water				
1	18.72	0.11	10.05	17.18	27.23	18.83	Water Surplus	8.39
2	11.13	0.17	9.71	24.99	34.71	11.30	Water Surplus	23.40
3	34.86	0.36	14.94	26.97	41.91	35.22	Water Surplus	6.69
4	13.46	0.22	7.59	23.07	30.66	13.68	Water Surplus	16.98
5	32.73	0.24	11.96	30.58	42.54	32.98	Water Surplus	9.56
6	19.70	0.27	9.15	12.59	21.74	19.97	Water Surplus	1.77
7	44.80	0.40	19.62	23.21	42.83	45.20	Water Deficit	2.37
8	34.68	0.48	10.95	25.00	35.95	35.16	Water Surplus	0.78
9	19.45	0.20	11.61	12.55	24.16	19.65	Water Surplus	4.51
10	22.66	0.41	9.82	19.72	29.54	23.07	Water Surplus	6.47
11	19.47	0.45	14.09	10.27	24.36	19.92	Water Surplus	4.44
12	30.75	0.27	23.17	11.72	34.89	31.03	Water Surplus	3.86
13	29.91	0.38	27.41	20.41	47.82	30.29	Water Surplus	17.53
14	26.37	0.46	33.05	24.05	56.10	26.83	Water Surplus	29.27
15	14.36	0.18	6.71	8.46	15.16	14.54	Water Surplus	0.63
16	76.80	1.71	65.99	47.46	113.46	78.51	Water Surplus	34.95
17	38.46	0.75	45.14	36.95	82.09	39.21	Water Surplus	42.88
18	18.91	0.47	21.19	16.61	37.80	19.38	Water Surplus	18.42
19	29.87	0.47	29.43	12.10	41.53	30.34	Water Surplus	11.19
20	14.47	0.32	19.22	14.55	33.77	14.79	Water Surplus	18.98
21	24.89	0.66	28.95	22.82	51.78	25.55	Water Surplus	26.23
22	13.67	0.77	7.66	8.56	16.22	14.44	Water Surplus	1.79
23	24.93	0.87	26.52	11.76	38.28	25.80	Water Surplus	12.48
24	36.61	1.28	9.72	37.08	46.81	37.89	Water Surplus	8.92
25	58.67	1.90	63.30	50.35	113.65	60.57	Water Surplus	53.07
26	9.15	0.23	8.03	5.20	13.22	9.39	Water Surplus	3.84
27	66.95	2.08	61.11	50.44	111.56	69.02	Water Surplus	42.53
28	16.69	0.21	12.01	9.83	21.84	16.90	Water Surplus	4.93
29	33.23	0.60	17.61	39.90	57.51	33.83	Water Surplus	23.68
30	11.34	0.15	6.76	17.84	24.60	11.49	Water Surplus	13.11
31	95.18	0.91	32.70	67.72	100.42	96.10	Water Surplus	4.33
32	17.91	0.15	12.24	11.27	23.52	18.06	Water Surplus	5.46
33	8.02	0.12	6.74	5.48	12.23	8.14	Water Surplus	4.09
34	7.39	0.07	5.95	4.06	10.01	7.46	Water Surplus	2.55
35	24.39	0.33	12.77	18.79	31.57	24.72	Water Surplus	6.84
36	11.20	0.11	5.58	8.14	13.72	11.31	Water Surplus	2.41
37	19.25	0.29	8.68	17.38	26.06	19.54	Water Surplus	6.52
38	21.08	0.24	13.80	7.42	21.22	21.32	Water Deficit	0.01
39	22.51	0.22	13.20	10.72	23.92	22.73	Water Surplus	1.19
40	42.15	0.43	17.30	22.45	39.75	42.58	Water Deficit	2.82
41	12.41	0.26	6.68	16.13	22.81	12.67	Water Surplus	10.14
42	54.29	1.69	67.70	27.11	94.81	55.98	Water Surplus	38.83
43	50.04	1.20	35.24	31.75	66.99	51.24	Water Surplus	15.75
44	51.73	1.85	64.72	46.24	110.96	53.58	Water Surplus	57.38
Total	1285.25	24.85	945.78	966.88	1911.67	1310.11	**Water Surplus**	601.56

(Note: All Values are in Mm^3)

latitudes 22^0 and 23^0 N and longitudes $86^0 452$ and 88^0 E, covering about 4217.52 km^2 of Bankura, West Midnapur and East Midnapur districts of West Bengal. After preparation of all the data required, the model simulations were done over two simulation periods. Firstly, for the water year 2002-03 (June 2002 to May 2003) and secondly for the Kharif season of the year 2003 (June 2003 to Nov 2003). It is found that for the first simulation period out of 44 sub-basins, 32 sub-basins are under water deficit condition and the remaining 12 sub-basins are under water surplus conditions. The amount of water deficit ranges from 0.24 Mm^3 to 20.67 Mm^3, and the amount of water surplus ranges from 1.67 Mm^3 to 22.06 Mm^3. For the second simulation period, however, out of 44 sub-basins 41 sub-basins are under water surplus condition and the remaining 3 sub-basins are under water deficit condition. The amount of water deficit ranges from 0.01 Mm^3 to 2.82 Mm^3 and the amount of water surplus ranges from 0.63 Mm^3 to 57.38 Mm^3. However, the results may not be the true representation of the condition in the basin as the data related to water supply through canal were not considered due to non-availability and so was the industrial demand data. Based on comparison of above mentioned two simulations the following salient conclusions are drawn.

1. For the water year 2002-03, water demand for agriculture is dominant over other demands and available water is not enough to meet the total demand. This leads to a water deficit of 141.82 Mm^3 in the river basin.

2. There is an uneven distribution of water availability during the year, especially in two cropping seasons.

3. With proper water management practices, surplus water in the Kharif season can be utilized to meet the water demand in the Rabi season.

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