J. Indian Water Resour. Soc.,
Vol. 39, No. 2, April, 2019

MICRO-WATERSHED MODELLING USING GIS AND WEAP OF AMLASOLE MICRO-WATERSHED: A CASE STUDY

Sujit Choudhury

ABSTRACT

The study demonstrates the application of GIS technologies and digital model for watershed management in Amlasole Micro-watershed, India. Extensive processing of spatial and attribute data for the study area were performed using GIS technologies for use in WEAP model. DEM for the study area has been created from SRTM data and where Survey of India topographic map was used for validating. Satellite interpreted data for the land use and District level meteorological data were used to prepare the land use and climatic input files for the model run. Various other inputs are used based on field data and experience. With this setup, model was run successfully and the runoff results could be tested against the observed discharged data from the main stream which shows small variation from the model results. Other results could not be verified at field level. However the trend in simulated monthly inflow outflow from the catchment followed the trend in observed rainfall which indicates that the framework can be used for assessing monthly demand supply of the water in the catchment for watershed management and implementation. The model shows alternative results in "what if" questions satisfactorily for deciding more acceptable options for the watershed management purpose.

***Keywords**: Micro-watershed, modeling, WEAP, GIS, simulation,*

INTRODUCTION

Watershed management is a key issue in large part of India. The water related problems are quite diverse particularly in country like India. The undulating peninsular, central & Western Indian states are facing drought regularly. Govt. of India had initiated watershed development (WSD) program since last 4 decades. While WSD receives a significant amount of government attention and funding, there is not a clear understanding among practitioners of the overall effectiveness of WSD programs in meeting the objectives of food security and poverty alleviation (Gray Erin, Srinidhi Arjuna, 2013).

The reason of lack of understanding & clarity is due to complexity of the natural resource base of watersheds in India. It involves a wide range of biological, geological, chemical, and physical processes with complex human, social, and economic activities across spatial and temporal scales. To address these wide-ranging factors often require the application of suitable analytical tools. Practitioners and academics have worked on these kinds of problems for years using different approaches. Spatial technologies like GIS play a very crucial role in watershed planning. Advances in space research have enhanced the availability of spatial and temporal data (Wani Suhas P, Rao AVR Kesava and Garg Kaushal K, 2011). It continues to rapidly advance towards more detailed and extensive mathematical representations of watershed management issues using modeling software.

Considering the above the present study intended to understand the water demand and supply dynamics in a micro-watershed of Chhotonagpur plateau using such modeling tools. It is often said that good modeling is common-sense and understanding reduced to calculation for the purposes of gaining insights into a real problem (Lund Jay R, Scheierling Susanne M, Milne Grant ,2010). Watershed model has been used to understand the relationship and complexity of the hydrological regime of a watershed and provide critical knowledge input to watershed development practitioners about the terrain. This is extremely important to assess the magnitude of the problem of a micro-watershed area and to discuss the same with the stakeholders to arrive at a particular decision. But despite advances in modeling, a 2010 World Bank working note on water indicated that modeling and other related tools have so far been applied in watershed management, only to a very limited exten(Lund Jay R, Scheierling Susanne M, Milne Grant ,2010).

Effective watershed management requires coordination of various natural components like groundwater, land use and stream flow along with various water resource supply and demand components. Systemic integration of various components at the Amlasole micro-watershed level and its sub-surface water has taken into consideration in the study. The Amlasole micro-watershed model has been developed using GIS and WEAP developed by Stockholm Environment Institute, Massachusetts, USA. The model provides a framework for water assessment and planning. It represents current water conditions in the area and to explore a wide range of demand and supply options for balancing environment and development. It operates at a monthly step on the basic principle of water balance accounting (Shirke A.J., Suryawanshi R. A., Deshpande P. K., Take A.R., 2012).The WEAP model forms part of ongoing research work in Amlasole Micro-Watershed.

THE PROBLEM

In recent years in India, watershed management practices that were perceived for their broad benefits to society have become the focus of criticisms for large number of failures and poor socioeconomic impacts after spending thousands of crores of public money. Often lack of reliable and

1. *Secretary, Integrated River Basin Management Society, 69B, Rahim Ostagar Road, Jodhpur Park, Kolkata- 700045*
Email: minervacal123@gmail.com
Manuscript No. 1505

scientific planning is reflected in too general strategies or prescriptions in a DPR and inappropriate selection as well as placement of interventions leading to ineffective implementation of a plan (Sikka Alok K, Sena D R, Sharda V N and Kurothe R S, 2011). Amlasole micro-watershed (AMWS) is situated in Chotonagpur Plateau. People of Amlasole and Amjharna villages of AMWS face continuous water scarcity during pre-monsoon period. This micro-watershed is situated on the hilly undulating terrain surrounded by forest areas and majority of the agriculture is rain fed here. Very little water conservation structures are there. Large volume of the monsoon rain water goes out of the AMWS as run off. As a result in dry season there is always scarcity of water in a dry rain deficient year and drought takes place in these villages.

This is the typical condition of the thousands of micro-watersheds in Jharkhand, Chhattisgarh, MP, Western Maharashtra, Telengana, etc. In majority of the micro watershed development area the main focus is water and soil conservation through various watershed development measures. It is very difficult to know how much water is to be conserved without proper quantification. In most of the cases a broad annual water budget calculation is done keeping in mind annual rainfall and a volume of water conservation figure arrived without considering various parameters in detail. The main question like monthly water demand & supply for agriculture, villagers& cattle's are not estimated in detail and then how much water are to be conserved over next 10 years that also to be assessed considering various rainfall years scenarios like normal rainfall year, wet year or very dry year.

The study intends to understand those aspects of Micro-watershed Management.

THE STUDY AREA

The AMWS is present in the Binpur-2 block of Jhargram District of West Bengal. East Singhbhum District of Jharkhand is situated in the South Western ridge boundary of AMWS. It is situated between North Latitude 22° 41' to 22° 43' and East Longitude 86° 33' 30" and 86° 36'.It is situated in the Kharsoti River watershed area which is in the Subarnarekha River basin. As per Water Resource Information System of India the watershed code No. is CO6SUB25 and as per Soil and Land Use Survey of India the micro watershed code No. is 4H3A8g3. The micro-watershed is mostly in the forest areas of the West Bengal part of Dalma range of hills. The Micro-watershed is within 160m above MSL[1] to 430 m above MSL. The highest peak in this area is Lakaisini Pahar, 494 m above MSL in the North-western side in Jharkhand.

This micro watershed situated in the Agro-ecological sub region No. 12.3, Chhotonagpur Plateau and Garjat Hills, hot, dry sub humid ESR with moderately deep to deep loamy to clayey Red and Lateritic soils, medium AWC and LGP [2]of 150-180 days. The surrounding hills and the valley with one main stream with two main tributaries and few small tributaries in between have formed this Micro-watershed area. The Micro-watershed hill areas are covered with forest and the valley areas are mostly used for agriculture. The annual average normal rainfall is around 1500mm.

THE WATERSHED MODEL

For the integrated watershed management, there is a need for *integrated watershed management models*. Here models has been defined that (1) are developed for modeling watershed management alternatives with the goal of understanding *the effects of management decisions on the watershed system* in order to support decision making and stakeholder negotiations; (2) integrate all relevant components of the natural watershed, human water system, and applicable management tools; and (3) are formulated in a systems context, preferably with management optimization capabilities to aid in the selection of promising combinations of management strategies. In addition, models are to be technically and financially accessible to allow their application to watersheds with diverse characteristics (Zoltay Viktoria I., Vogel Richard M., Kirshen Paul H., Westphal Kirk S.,2010).

AMWS is modeled to facilitate well-studied water conservation estimation for informed management decisions. In natural resource management practices, it is important to understand complex interactions occurring in present time as well as predict impacts years, into the future. The AMWS model will help us estimate the Demand Supply Gap at micro-watershed level more accurately and predict future impacts of projects and management policies, which in turn contributes to improved water resources system design, planning, and operation, and thus more sustainable water resources management (Mirchi Ali, Watkins David Jr., Madani Kaveh, 2009).

To have a comprehensive detail idea about quantification of water conservation for targeted specific intervention measures a model of the AMWS has been created. The model is an integrated Decision Support System (DSS) designed to support water planning that balances water supplies generated at micro-watershed scale. It incorporates physical hydrologic processes and multiple water demands characterized by spatially and temporally variable demand - priorities and supply preference. The database of the model provides a system for maintaining water demand and supply information. As a forecasting tool, the model simulates water demand, supply, flows, and storage.

a) *GIS Database*

The data related to the AMWS has been prepared in GIS database in Manifold Systems. It was necessary to design a database for our GIS purposes that facilitate a mechanism by which spatial and attribute data is stored, modeled, analyzed and queried (Choudhury Sujit, Chakrabarti

[1]*MSL= Mean Sea Level*

[2]*LGP= Length of Growing Period; AWC= Available Water Capacity*

Deepankar, Choudhury Suchandra, 2009). The spatial data related to the drainage, land use has been used from Satellite images and Survey of India 1:50,000 scale top sheet No.73J/10. The digital elevation model data prepared from **SRTM 1 Arc-Second Global** elevation data at a resolution of 30 meters. For plot level information village Cadastral map was digitized and been made part of the database. The attribute data collected from field visit and secondary sources like Census data 2011.

b) *Land use*

The total micro watershed area is 700 ha. Two villages, Amlasole and Amjharna and part of Mayurjharna village are present within this Micro-watershed area. The Land use land cover categories are shown in Fig. 1 below.

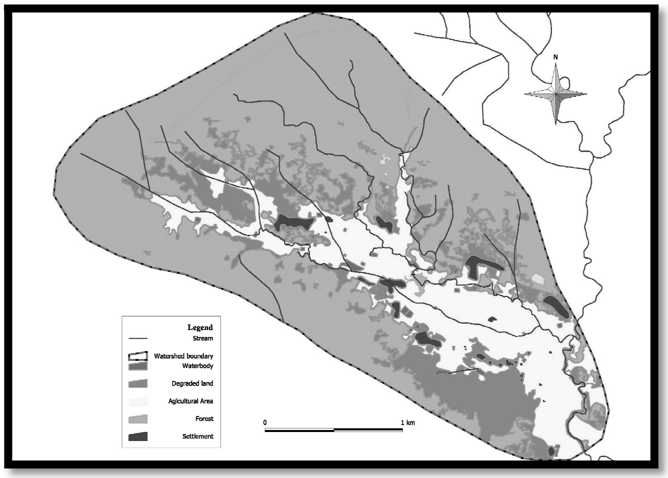

Fig.1: Amlasole Micro Watershed Land use Map

From the GIS database the land use map of the watershed area has been prepared and the land use areas were calculated and given in table- 1. The majority area, 63% of the micro-watershed is covered with forest. These land use areas and proportions were used in WEAP model.

Table-1: Land Use Distribution of Amlasole Micro watershed

Land use type	Area in Ha	% of Total Area
Forest	443	63
Agricultural land	140	20
Degraded land	103	15
Water Body	3	0 (minor Fraction)
Settlement	11.00	2
Total	700.00	100

There are 24 small ponds and tanks with total water storage capacity is around 0.087 M Cum and the two check dam with reservoir having total water storage capacity is around 0.048 M Cu M.

c) *Model Preparation*

Initially a GIS database has been created in GIS system. The delineation of watershed boundary took place from Survey of India Top sheet and SRTM data. From the satellite images the various land use were identified and demarcated. GIS is used related to spatial modelling and visualization. For time-consuming numerical simulations, it is necessary to couple GIS with WEAP tools designed for high performance in dynamic modelling (Matejicek Lubos, 2014).In order to set up the WEAP model, first, we start with a watershed schematic that can be arranged on top of an imported the watershed vector data from GIS database prepared in Manifold system in .shp format, and then takes care of data input with a series of dialogue boxes for water use, loss and reuse, demand management, priorities, etc. The results are then displayed in the same graphic user interfaces in charts and tables and on the schematic the river system. Scenarios that describe different demand and supply measures are driving the system, and are connected with the various results (Kiniouar Hocine, Hani Azzedine, Kapelan Zoran, 2017).Figure 2 shows the distribution of demand sites and supply site model in WEAP.

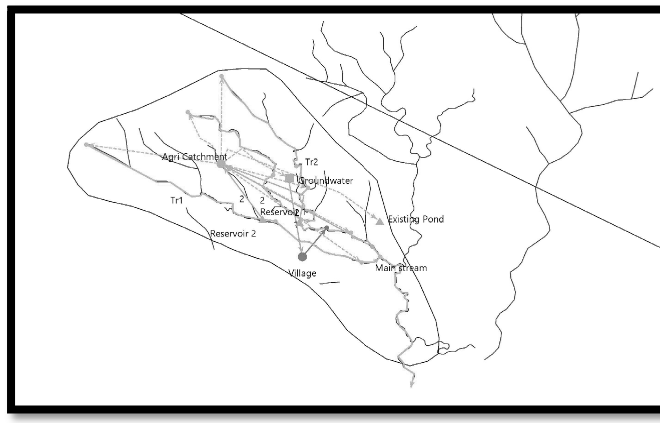

Fig. 2: ***Amlasole Micro Watershed WEAP Model Schematic***

d) *Data types*

The major data types that are used in this study are hydrological time series data, water demand data, water supply schemes and their corresponding geographical locations. Meteorological data like rainfall, temperature, humidity were used at district level which is taken from West Medinipur District Handbook 2014. Jhargram district has been created in 2017 from West Medinipur District, , and there is no weather monitoring stations in Binpur II blocks as a result the climate data of West Medinipur District has been used, as they are fairly representing the same agro-ecologic zone of the AMWS. Considering the available data time the model has been built from 2014 to 2024 period where current account year was 2014 and then the same has been validated with 2017 field data study.

From the initial data collection, the initial WEAP application had been created with various important features of the area developed in it. The application was matching with field experience and a preliminary calibration and validation step had been undertaken. Once the initial, provisionally calibrated application has been created, two alternative scenarios were constructed. At this stage, it was decided that further development is not necessary. The outputs from the scenario workshop inform the project in many ways, while the initial data collection and basic WEAP application support the broad "what-if" questions about future water conservation in this Micro watershed. Once the model was reasonably well developed, it was useful for scenario analysis in support of decision-making for the project. Initial scenarios have been assessed for implementation and their implications are explored. Two options were considered for water conservation.

The model in WEAP employs a priority based optimization algorithm, as an alternative to hierarchical rule-based logic that uses a concept of Equity Groups to allocate water in times of insufficient supply. The model aims to incorporate these values into a practical tool for water resources planning, it places the demand side of the equation—water use patterns, reuse and allocation—on an equal footing with the supply side stream flow , groundwater, reservoirs and water transfers. The model is like a laboratory for examining alternative water development and management strategies.

In one scenario under no intervention in land use, leads to unchecked runoff based on various rainfall scenarios for next 10 years, then that is an indication that some intervention for water conservation in land use pattern is necessary which should conserve more water in different rainfall year. Various scenarios are a prompt for reflection which was accompanied by discussion, interpretation, and analysis.

e) ***Demand sites and supply sources***

The demand sites of the micro-watershed and their corresponding annual activity levels have been identified from the GIS data and field study. The major demand sites in the micro-watershed are agriculture, domestic water consumption and water consumption by cattle. The irrigation was necessary for all the agricultural lands. Small-scale irrigation from farm pond and lift irrigation from stream are the two potential irrigation possibility; irrigation from dug well has not been practiced here and not considered also.

The groundwater is mostly used from domestic consumption and for cattle. The demand sites are scattered in the micro-watershed all over the sub-basin. But for model purpose two Demand sites has been marked 1) Agri-Catchment in which agriculture irrigation is the main demand and 2) Village; this is for domestic human consumption coupled with cattle requirement. The main stream and two tributaries Tr1 & Tr2 are passing through the watershed. All the demand and supply sides are shown in the model Schematic figure-2.

In AMWS the agricultural land is mostly single crop. Rice sowing starts in June-July and Harvesting took place in November-December. In some of the field, Rabi crop i.e. winter crop is sown after harvesting of paddy.

The area of the Agri- catchment taken from GIS data and the crop coefficient K_c for Rice (Kar Gouranga, Singh R, Kumar A, Sikka A K, 2014) has been used for July to October but remaining time the land covered with grass. . The FAO warm grass data has been used here. The Degraded and deforested lands are also covered with grass in most of the year (FAO Corporate Document Repository,1998) mostly used for cattle grazing.

All supply sources of the AMWS are the main stream of the AMWS, its tributaries and groundwater. Currently, there are two check dams with reservoirs on the streams and 24 small ponds and tanks as surface water supply sources for domestic water supply, for village settlement areas in the micro-watershed tube well, and dug wells are used.

f) ***Annual water use rates***

Annual water use rates in the model have been calculated based on the irrigation water demand and water used by the village population and cattle. Irrigation water demand has been estimated for a crop that requires the large amount of water that is rice as it is the main crop of the region. Majority of the farmers are small and practice traditional rice cultivation method.

The total population of Amlasole and Amjharna Village who use the water in AMWS is 600 and considering decadal population growth from census data it has been the annual population growth has been calculated as 1.7%. The cattle population was considered from field study as 1200.

g) ***Rainfall Runoff Method (Soil Moisture Method)***

In this model calculation of debit is done by using soil moisture method. This method uses data of rainfall and monthly climatology as input data. The data is then processed to produce the output of evapotranspiration, discharge, and storage of ground water. Water availability calculation scheme by WEAP (Indriani Siti Nurlaila, Setiawan Ahmad Agus and Budiarto Rachmawan,2018) is shown in Figure 3 below:

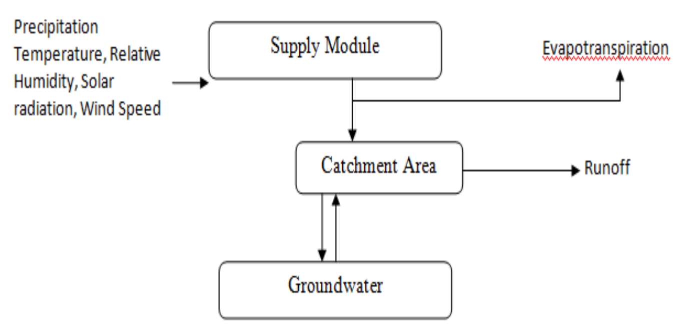

Fig.3: Water availability calculation model

In the model the Soil Moisture method has been adopted, representing the catchment with two soil layers. In the upper soil layer, it simulates evapotranspiration considering rainfall and irrigation on agricultural and non-agricultural land, runoff and shallow interflow, and changes in soil moisture. This method allows for the characterization of land use and/or soil type impacts to these processes. Base flow routing to the river and soil moisture changes are simulated in the lower soil layer. The Soil Moisture Method requires more extensive soil and climate data to simulate these processes.

For deeper percolation within the catchment which can also be transmitted directly to the groundwater in the model by creating a Runoff/Infiltration Link from the catchment to the groundwater node. The method essentially becomes a 1-layer soil moisture scheme if this link is made.

h) *GW-SW flows Model*

For Ground water estimation GW-SW flows Model has been used in WEAP, in this hard rock area the groundwater is mainly present top subsurface soil profile above the hard rock. The average thickness of the aquifer here is around 4 m. This aquifer is not directly connected with adjacent aquifers because of high ridges except the south eastern watershed outlet side. In AMWS surface waters and groundwater are hydraulically connected. The 1) Agri-catchment area and main stream at its different reaches contributes to groundwater recharge and/or can gain water from the aquifer depending on the level of groundwater in the aquifer. Groundwater levels respond to natural recharge from precipitation, but can also be influenced by irrigation in the watershed.

i) *The Results*

In the existing land use condition of AMWS and based on various other data the result in the simulation model for Micro-watershed Inflows and outflows has been shown in Table-2 and fig-4 below. The inflows where water adding the system and outflows where the water leaving to the system are shown in positive.

Table 2: The Catchment inflow outflow results (figures are in Million Cubic Meter)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
Base Flow	-0.01												-0.01
Decrease in Soil Moisture	0.05	0.02	0.03	0	0	0	0	0	0.01	0.12	0.22	0.14	0.58
Evapotranspiration	-0.22	-0.27	-0.36	-0.31	-0.42	-0.51	-0.72	-0.74	-0.65	-0.48	-0.27	-0.26	-5.19
Flow to Groundwater	-0.02	-0.02	-0.02	-0.02	-0.04	-0.11	-0.11	-0.11	-0.11	-0.1	-0.06	-0.03	-0.75
Increase in Soil Moisture	-0.01	0	0	-0.07	-0.26	-0.22	-0.01	0	0	0	0	-0.01	-0.59
Interflow	0	0	0	0	-0.01	-0.02	-0.02	-0.02	-0.02	-0.02	-0.01	-0.01	-0.13
Irrigation	0.11	0.1	0.12	0	0	0	0	0	0	0	0	0.12	0.44
Precipitation	0.1	0.18	0.24	0.41	0.77	1.82	2.25	2.35	1.84	0.65	0.13	0.06	10.79
Surface Runoff	0	0	0	-0.01	-0.04	-0.97	-1.4	-1.48	-1.07	-0.18	-0.01	0	-5.15
Sum	-0.01	0	0	0	0	0	0	0	0	0	0	0	-0.01

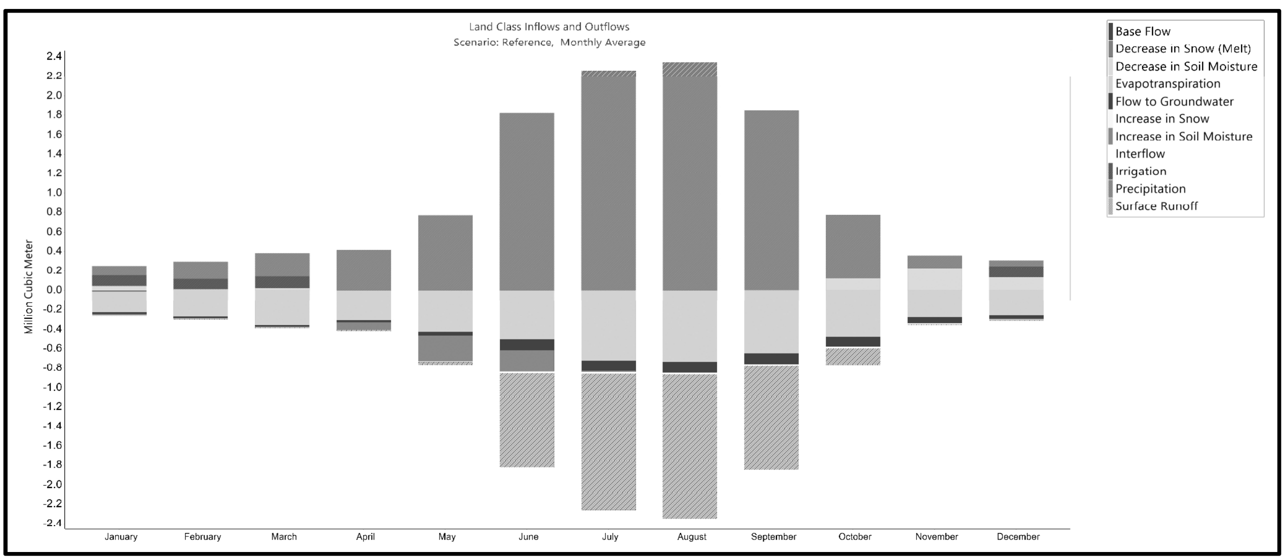

Fig.4: Catchment area Water Inflow Outflow results from WEAP Model

The result shows that majority of the precipitation takes place in 4 months of monsoon the water and soil conservation strategy are targeted to harvest maximum monsoon water and stop soil erosion during heavy rain mainly in monsoon when soils are saturated.

In the watershed with existing 20% agricultural land and 15 % degraded land the movement of water during these four months from the above results following pattern has been observed;

1) During the monsoon period when the total annual precipitation is 10.79 M C M and from June to September is 76 % of annual precipitation takes place
2) Whereas the total annual surface runoff is5.15 MCM and during the same period 95% of the total annual surface runoff takes place. Significant Surface runoff can be seen from April to Nov.
3) In case of evapotranspiration in these 4 months 50% evapotranspiration takes place out of the total annual figure of 5.19 M Cu M.
4) In case of flow to groundwater in these 4 months 58% flow takes place out of the total annual flow of0.75 M Cu M.
5) The Irrigation for agriculture for Rabi crop is mostly required from December to March.

j) *Validation of Simulation Result:*

The total surface runoff in the month of August is showing 1.48 Million Cubic Meter, The discharge rate measured at the end of the main stream in Aug is 1.34 Million Cubic meter which is 9% less than the simulated figure.

k) *Groundwater*

As the aquifer water is mostly used for drinking water purpose as a result the groundwater depletion compare to recharge is much low the results of the simulation are shown in fig-5 below;

In Ground water inflow and outflow from various stretches of the stream and the catchment but significant inflow is from mainly from infiltration from Agri- Catchment and groundwater storage is increasing mainly from June to Nov. whereas it is decreasing from Dec. to May. The demands from village remain same round the year.

l) *Simulation for Alternative Land use changes Result*

The land use practices depend on the availability of the water resources, and the surface and groundwater in the watershed are deeply interrelated. Any change of land use must consider this interrelationship factor (Choudhury Sujit, Chattopadhyay G S,2008). It is well established that adoption of appropriate conservation agronomic practice is more beneficial to reduce soil loss in watershed conservation than other measures (Dhruva Narayana V.V., Sastry G, Patnaik U S, 1997). In this context the simulation results of two alternatives of conversion of degraded land has been discussed below:

A) In case the total degraded land converted to agricultural land then we can observe the following significant changes in the catchment inflow outflow model. The significant changes are as follows;

   1) Total annual surface runoff is reduced to 4.41 MCM which is 14 % of total annual surface runoff and during 4 months of monsoon 97% of the total annual surface runoff takes place. Significant Surface runoff can be seen from June to Oct.

   2) On the other hand annual evapotranspiration increases nearly to 6.22 MCM which is 20% and in 4 monsoon months share is 51% of total evapotranspiration.

1) Annual flow to groundwater reduced marginally to 0.78 MCM which is 4% and in 4 monsoon months 60% of annual flow takes place.

2) Irrigation requirement increases substantially.

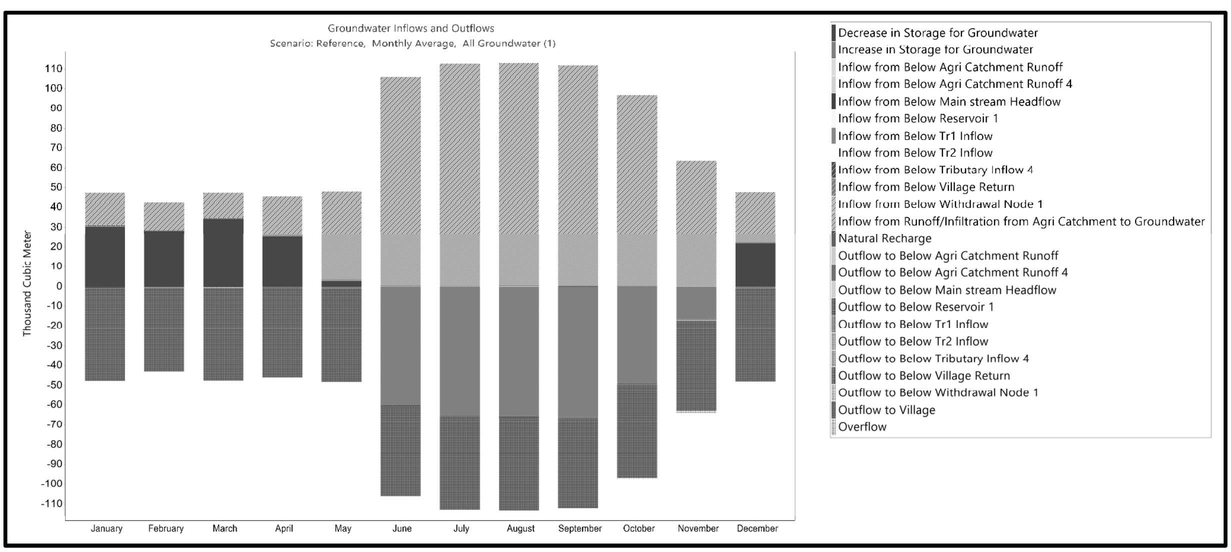

Fig. 5: Groundwater Inflow outflow results (figures are in Thousand Cubic Meter)

B) In case, only in Land Use category the 7% degraded land converted to forest land and remaining 8% converted to Agricultural Land then the following simulation results are noticed;

1) Total annual surface runoff is reduced to 4.7 MCM which is 9% of annual surface runoff and during 4 months of monsoon 97% of the total annual surface runoff takes place.

3) On the other hand annual evapotranspiration increases nearly to 5.78 MCM which is 11 % of annual evapotranspiration and in 4 monsoon months share is 50% of total evapotranspiration. Significant Surface runoff can be seen from June to Oct.

2) Annual flow to groundwater reduced to 0.79 MCM which is 5 % of the annual flow to groundwater and in 4 monsoon months 59% of annual flow takes place.

3) Irrigation requirement increases substantially.

Considering the effect of above two land use changes A) and B) it can be noticed clearly that 15% degraded land changes to forest and agriculture to 7% and 8% respective provides reduction of total annual surface runoff from 14% to 9%, evapotranspiration reduced from 20% to 11% and during monsoon groundwater recharge increases from 4% to 5% compare to converting the total land to Agriculture.

CONCLUSION

The use of Geoinformatics technology and hydrologic modelling provide very important input for Micro Watershed management in India. The simple model in WEAP was used for Amlasole Micro-watershed in West Bengal provide some shows important results in terms of Land use management. The validation of the surface run off data shows the model is providing fairly good results. The simulation results for alternatives in changing the existing land use provide very important insight. Over the years due to encroachment and deforestation in this micro-watershed large patches of degraded land was created. The tendency for the villagers to convert these lands to agricultural land in spite of the fact that these lands are rain fed. The simulation in the model shows alternative results for conversion of the total degraded land into a) total agricultural land compare to b) 7% land converted to forest and 8% land to agriculture. The hydrologic results from the model shows that alternative b) provides a better option from hydrologic perspective. Interestingly the same is more acceptable for the watershed management purpose.In the present water crisis in the country particularly peninsular India more use of Geoinformatics in watershed management and use of more scientific hydrologic modelling will be immensely beneficial for soil and water conservation which will reduce large scale failure of the watersheds development projects. In India such applications are extremely important as the magnitude of water problem is very severe as well as complex at different scales and in different Agro-climatic zones.

ACKNOWLEDGEMENT

The GIS database of the study area was prepared by Mrs. Nilshikha Das and Mr. Mintu Nath and Mr. G S Chattopadhyay continuously provided technical support in the study, all of them are associated with of PAN Network Pvt. Ltd. research team, I am grateful to them. I am grateful to Mr. Birsha Mura of Amlasole village for his relentless support at village and collecting the dug well data and helping us measuring the stream flow there . Finally, I would like to thank the members of Amlasole Birsha Munda Village committee for helping me in the study.

REFERENCES

1. Choudhury Sujit, Chakrabarti Deepankar, Choudhury Suchandra, (2009). *An Introduction to Geographic Information Technology.* New Delhi: I K International Publishing House Pvt. Ltd.

2. Choudhury Sujit, Chattopadhyay G S (2008). Use of GIS for Natural Resources and Environmental planning for sustainable Rural development:A Case Study. In M. S. Pandey (Ed.), *Geoinformatics for Decentralised Planning and Governance* (p. 228). Jaipur: Rawat Publications.

3. Dhruva Narayana V.V., Sastry G, Patnaik U S, (1997). *Watershed Management.* New Delhi: Indian Council of Agricultural Research.

4. FAO Corporate Document Repository (1998). *Crop evapotranspiration - Guidelines for computing crop water requirements.* Rome: FAO .

5. Gray Erin, Srinidhi Arjuna (2013). Watershed Development in India: Washington, DC: World Resources Institute.

6. Indriani Siti Nurlaila, Setiawan Ahmad Agus and Budiarto Rachmawan, (2018). Demand Simulation for Water, Food Irrigation, and Energy from Micro Hydro Power Plant in Sungai Bayang, Bayang Utara, Pesisir Selatan West Sumatra. *ASTECHNOVA 2017* (p. 1). Yogyakarta,: Universitas Gadjah Mada.

7. Kar Gouranga, Singh R, Kumar A, Sikka A K (2014). Farm Level Water Footprints of Crop Production: Concept and accounting. *ICAR Research Bulletin 67* , 20.

8. Kiniouar Hocine, Hani Azzedine, Kapelan Zoran (2017). Water Demand Assessment of the upper Semi-arid Sub-catchment of a Mediterranean Basin. *International Conference on Technologies and Materials for Renewable Energy, Environment and Sustainability, TMREES17, 21-24 April 2017* (p. 870). Beirut Lebanon: Elsevier.

9. Lund Jay R, Scheierling Susanne M, Milne Grant (2010). *Modeling for Watershed Management:*. Washington DC: World Bank.

10. Matejicek Lubos (2014). Integration of Simulation Models for Watershed Management and Data from Remote Sensing in Geographic Information Systems. *International Environmental Modelling and Software Society (iEMSs) 7th Intl. Congress on Env. Modelling and Software,*. San Diego, CA, USA,: Daniel P. Ames, Nigel W.T. Quinn and Andrea E. Rizzoli (Eds.).

11. Mirchi Ali, Watkins David Jr., Madani Kaveh (2009). MODELING FOR WATERSHED PLANNING,MANAGEMENT, AND DECISION MAKING. In E. J. Vaughn, *Watersheds: Management, Restoration and Environmental Impact* (pp. 221-244). Hauppaug: Nova Science Publishers, Inc.

12. Shirke A.J., Suryawanshi R. A., Deshpande P. K., Take A.R. (2012). Watershed Management Using Weap – An Overview. *Proceeding of International Conference SWRDM.* Kolhapur: Department of Environmental Science,Shivaji University.

13. Sikka Alok K, Sena D R, Sharda V N and Kurothe R S (2011). Use of Modeling in Watershed Planning. *Use of High Science Tools in Integrated Watershed Management* (p. 90). New Delhi: International Crop Research Instituite for the Sei-Arid Tropics.

14. Wani Suhas P, Rao AVR Kesava and Garg Kaushal K. (2011). Harnessing New Science Tools through IWMP to Unlock Potential of Rain-fed Agriculture. *Use of High Science Tools in Integrated Watershed Management* (p. 1). New Delhi: International Crop Research Institute for the Semi-Arid Tropics.

15. Zoltay Viktoria I., Vogel Richard M., Kirshen Paul H., Westphal Kirk S. (2010). Integrated Watershed Management Modeling: Generic Optimization Model Applied to the Ipswich River Basin. JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT © ASCE , 566 to 575.