Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 4 (2023)

Water Quality Assessment and Nutrient Management by SWAT from Sanitation and Agricultural Sources in Warana River Basin, MH, India

Dr. Shridhar S Kumbhar[1], Bakul Rao[2], Sushma Kulkarni[3]

1. Ph D Scholar, CTARA, IIT, Bombay, Rajarambapu institute of Technology, Rajaramnagar, shridhar.kumbhar@ritindia.edu
2. Centre for Technology Alternatives for Rural Areas (CTARA), IIT Bombay
3. NICMAR, Pune

Abstract:
The Warana river watershed in Western Maharashtra, India has been recognized for exporting some of the highest nitrate-nitrogen loadings in western Maharashtra and is also a major source of sediment and other nutrient loadings. An integrated modeling framework has been constructed with Soil and Water Assessment Tool (SWAT) model and the interactive SWAT CUP. The simulation framework includes a detailed land use and management data such as different crop rotations and an array of nutrient and tillage management schemes, derived from the various source including the state department of Agriculture. This paper presents the calibration and validation of SWAT for the streamflow, sediment losses, and nutrient loadings in the watershed. Streamflow, sediment yield, and nitrate loadings were calibrated for the 1979-1984 period and validated for the 1984-2014 period. Secondary field data on organic nitrogen, organic phosphorus, and mineral phosphorus is used in model to validate for the 2007-2014 period. Model predictions generally performed very well on both an annual and monthly basis during the calibration and validation periods, as indicated by coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (E) values that exceeded 0.7 in most cases. The first scenario set with application of fertilizer and no sanitation practices and set of land use change scenarios based on taking cropland out of production indicated a significant benefit in reducing sediment yield at the watershed outlet. A second scenario set found that relatively small reductions in nutrient applications resulted in significant reductions in nitrate loadings at the watershed outlet, without affecting crop yields significantly.

Keywords: SWAT, Nutrient management, Warana river basin, Western Maharashtra.

INTRODUCTION

Nutrients are dispersed into environment by low or no sanitation and un-seweared area, septic tanks waste, open defecation and surface runoff from agriculture areas into the natural water bodies (Sonawane, 2008). The pollutant disposed follows the flow path in watershed area for surface water and groundwater (Li, 2015). To study of pollutants disposal in a watershed, it is important to understand the dynamics of nutrient movement. The small stretch basin area is ideal to understand the movement and impact of nutrient disposal in a river basin boundary.

HYDROLOGICAL MODELS

The nutrients are majorly transported by water and hence, use of hydrological models is important to understand nutrient movement. To understand the scenario of water quality, assess nutrient inputs in water bodies and nutrient management in Warana river basin, various nutrient models were studied such as a modified load apportionment model (LAM), Soil and water assessment test (SWAT), regionalized agricultural and environmental information system (RAUMIS), decision support systems (DSSs), WEKU, GROWA, Modeling Nutrient Inputs in River Systems (MONERIS) (Chen, 2013).

Physically-based models also known as deterministic, comprehensive or process-based models try to represent the physical processes observed in the real world. Typically, such models contain representations of surface runoff, subsurface flow, evapotranspiration, and channel flow, but they can be far more complicated. The first model to integrate all the required submodels for basin chemical hydrology was the Stanford Watershed Model (SWM). The SWMM (Storm Water Management Model), the HSPF (Hydrological Simulation Program - FORTRAN) and other modern American derivatives are successors to the SWM. Widely used models are described and list of other models is given in annexure. (Chen, 2013)

Field Study

The Warana river basin consists of three hundred and seventeen villages and has a 150 km and basin area is about 2054 sq. km., a large amount of nutrients getting disposed everyday into the river through point and non-point source pollution of each village and agricultural area and average rainfall is 1500 mm/year. The topographical conditions and watershed area is ideal to study the impact of disposed waste in natural water body.

Warana river basin is naturally divided into three zones by the rainfall intensity the population density increases with decrease in rainfall, these two criteria were used to classify the Warana. Zoning is done based on rainfall intensity and population density. The first zone consists of low population density and high rainfall of about 1600 mm with Chandoli National Park and is the catchments of two large dams. The population density of first zone is about 104.99 130 persons/sq km. the second zone consists of agricultural land, residential area and some industries pop. Density 599.35. Rainfall intensity is in between 1600 and 800 mm for second zone. The Zone three consists of eastern most part of the basin which is low lying and plain and has fertile alluvial soils predominantly agricultural land. The population density in the third zone is 563.36 530 persons/sq km. and large area under agricultural practice with a rainfall less than 800 mm. Zone 3 though semiarid with high variability in rainfall, has much greater availability of irrigation because it lies in the command of the upstream dams and is also served by a number of lift irrigation schemes on the river. (Joy,2011).

The Warana river basin area mainly formed during the Late Cretaceous to Palaeogene age (Live diverse, 2011). A number of basaltic flows made the area very compact and hard. The prolonged weathering of these trap rocks gave rise to residual sedimentary rock known as Laterite (at places bauxite) and residual sand deposition along the Warana river channel. Both the weathered products are from Quaternary age. Broadly, in Warana basin area, up to 1000 m depth a thick layer of Basalt can be observed while above that 1000 m residual laterite formation occurs. Bank of stream is covered with alluvium patches. Predominantly the area is covered with thick red and black cotton soils.

Table 1 Total demand of water in Warana basin

Sr. No.	Annual demand for Warana Basin	Quantity (TCM)
1	Agricultural	2057084.98
2	Household	0.018
3	Industrial	820.07
	Total demand	2057905.07

Source : Edathoot A., Kirubaharan (2012),

Water and wastewater sample collection and analysis

Preliminary survey of Warana river basin was done based on topographical conditions and access to water bodies. As shown in fig. no.2 villages situated on the river bank and off the bank selected for sampling and analysis of various physicochemical parameters as per the guidelines given by IS 10500, 2012.

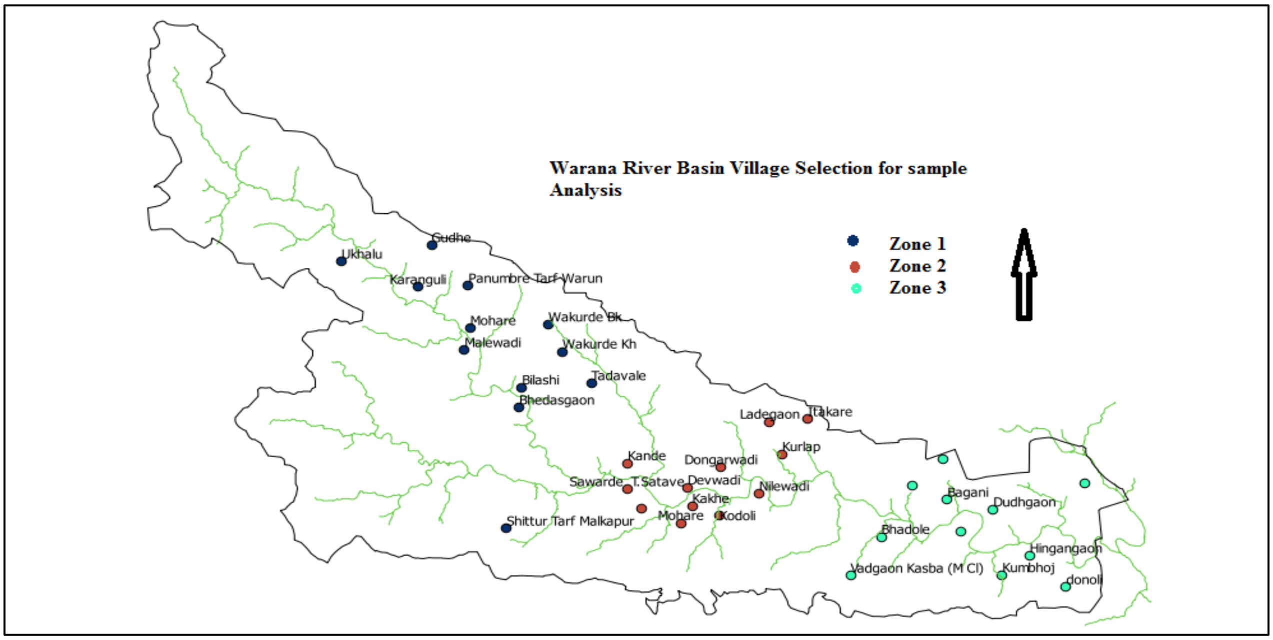


Figure 2 Selected villages in Warana basin for water analysis

Sampling of water and wastewater Post monsoon 2015 at a monthly frequency from the monitoring stations in both sewered and unsewered areas of each zones.. The water and wastewater samples were collected from various sources including river water, borewell water, treated piped supply water, well water and wastewater and analyzed for physical and chemical water quality parameters viz. pH, Conductivity, TDS, Alkalinity, Acidity, Chloride, BOD, COD and NO_3–N. as per the method described in “Standard methods for the examination of water and wastewater”, American Public Health Association (Standard Methods, 2012).

The results of the physico-chemical parameters reveal that, there is increase in TDS and conductivity from zone two and three of Warana River basin. Even though all the parameters were within the permissible limits of drinking water standards (IS: 10500, 2012), there is a need to take appropriate measures of pollution control by the concerned authorities to keep the water quality parameters within the permissible limits as the population is increasing and intensified cash crop agricultural activities in the area are increasing resulting in pollution load on Warana River basin.

SWAT

SWAT is a hydrologic and water quality model developed by the U.S. Department of Agriculture’s Agricultural Research Service (USDA-ARS) (Abbaspour, 2007). It is a long-term continuous watershed scale simulation model that operates on a daily time step and is designed to assess the impact of different management practices on water, sediment, and agricultural chemical yields. The model is physically based, computationally efficient, and capable of simulating a high level of spatial detail. The SWAT is a comprehensive model requiring a diversity of information (Arnold, 1998). The first step in setting up a SWAT river basin simulation is to partition the basin into sub units. The first level of sub division is the sub basin. The sub basin delineation is defined by surface topography so that the entire area within a sub basin flows to the sub basin outlet. The land area in a sub basin is divided into Hydrologic Response Units (HRUs). These portions of a sub watershed possess unique land use/management/soil attributes. The number of HRUs in a sub basin is determined by a threshold value for land use and soil delineation in the sub basin. The use of HRUs generally simplifies a simulation run because all similar soil and land use areas are lumped into a single response unit. The QGIS platform provides the user with a complete set of GIS tools for developing, running and editing hydrologic and management inputs and finally calibrating the model. The spatially distributed data required for

QSWAT include the Digital Elevation Model (DEM), soil and land use data, either as shape files or grid data. The weather and measured streamflow data are also required as input for the calibration and prediction purposes (Artola. 1995).

Creation of Database

The SWAT requires few important datasets and time series data-sets in order to obtain a water balance in the basin. The most important requirement of a hydrological model is to have information about topography, land use/land cover and soil of the basin. To obtain such information about Warana Basin different sources were used.

Digital Elevation Model (DEM): The DEM for Warana Basin used is ASTER 30m resolution from earth explorer. It is used for extraction of flow direction, flow accumulation, stream networking and delineation of the watershed and sub-basins (Yang,0000). Using this DEM, total number of 52 sub-basins were generated using SWAT for the Warana basin after delineating an area of around 2000km^2.

Land Use: The landuse data is obtained from National Remote Sensing Center (NRSC) Resourcesat 2 LISS III imagery 2012-13 year. The landuse is important for the water balance and is directly linked to the properties related to plants and vegetation. There are many landuse classes in the basin. According to the study area and SWAT standard classes, the land use classes are to be converted. Then, the lookup table is defined.

Soil: A soil data file is used for the Warana Basin is used from Harmonized World Soil Database (HWSD). This includes type of soil: clay, silt, sand etc. along with their properties. The amount of water owing at the surface or in the sub-surface is dependent on the permeability of soil. Likewise the quality of water is also directly linked with the properties of soil and amount of nutrients and chemicals present. Hence, the soil is important for the water cycle. The same conversion process is applied to soils as done with land use.

Climate Data: The climate data used is from Global Weather Data for SWAT. The climate data is important as it provides moisture and energy inputs which control the water balance. The meteorological data required are temperature, solar radiation, precipitation, relative humidity and wind speed. The temperature and precipitation are the minimum required inputs whereas other data set are optional. The model has self generating capacity of weather data in case of missing values. For Warana Basin total 3 stations data for each data type is collected. So altogether there are 15 stations data. The time series is of daily basis.

Stream flow data: The stream flow data is required for calibration and validation. The data is collected from Irrigation departments in the Warana River basin. The watershed is of small area and due to poor network connectivity there are only two gauging stations one at upstream near Chandoli Dam and other at the downstream point near Shigaon village.

Table 2 SWAT Input files

Sr. No.	SWAT Stages	Input files	Source	Link	File format
1	Delineate Watershed	DEM	Earthexplorer	http://earthexplorer.usgs.gov/	.tif
			Bhuvan	http://bhuvan.nrsc.gov.in/bhuvan_links.php.	.tif
		Reservoir and Input points	Shapefiles		.shp
		Outlet	Shapefiles		.shp
2	Create HRU	Landuse	Bhuvan		.tif
		Landuse table	LULC details	WGen	Robit_landuses
		Soil Data	Harmonized World Soil Database (HWSD)	http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/	.tif

Sr. No.	SWAT Stages	Input files	Source	Link	File format
		Soil table	Types and details	WGen	Robit_soils
3	Edit Input and Run SWAT	Weather data	Global Weather	http://globalweather.tamu.edu/	SWAT files.
		Select database to edit	User Soil Land cover Fertilizer Pesticide Tillage Urban User Weather Station Septic WQ	SWAT/Edit Input files	
4	Visualize	-	-	-	.dox, .shp, .xlx

The major part of Warana Basin Land use land Cover (LULC) is under agriculture practices (57%) and followed by forest (19%), scrubland (13.5%), water bodies (2.2%). The Double/Triple agriculture is practiced in the 727.28 km^2 it results in excessive irrigation and fertilizer application in the Warana river basin. The area under Built up is 0.1% with population 695051 (census 2011) but the sewage generated is hardly treated and disposed as it is in the Warana river basin.

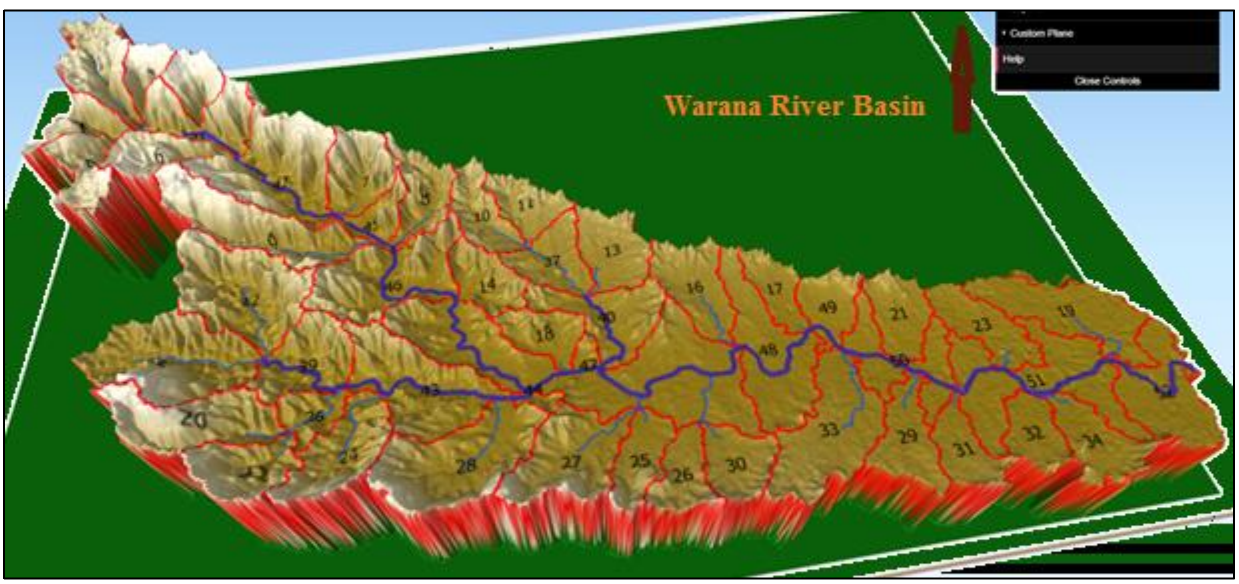


Figure 3 Delineation of Warana River Basin

The simulation shows subbasin flow and erosion of soil, reservoir conditions and nutrient cycles in Warana river basin. The total load of nutrient movement in Warana river basin is given by Visualisation for HRU, RCH and Subbasin. Total nitrogen load in Warana river basin is given in figure.

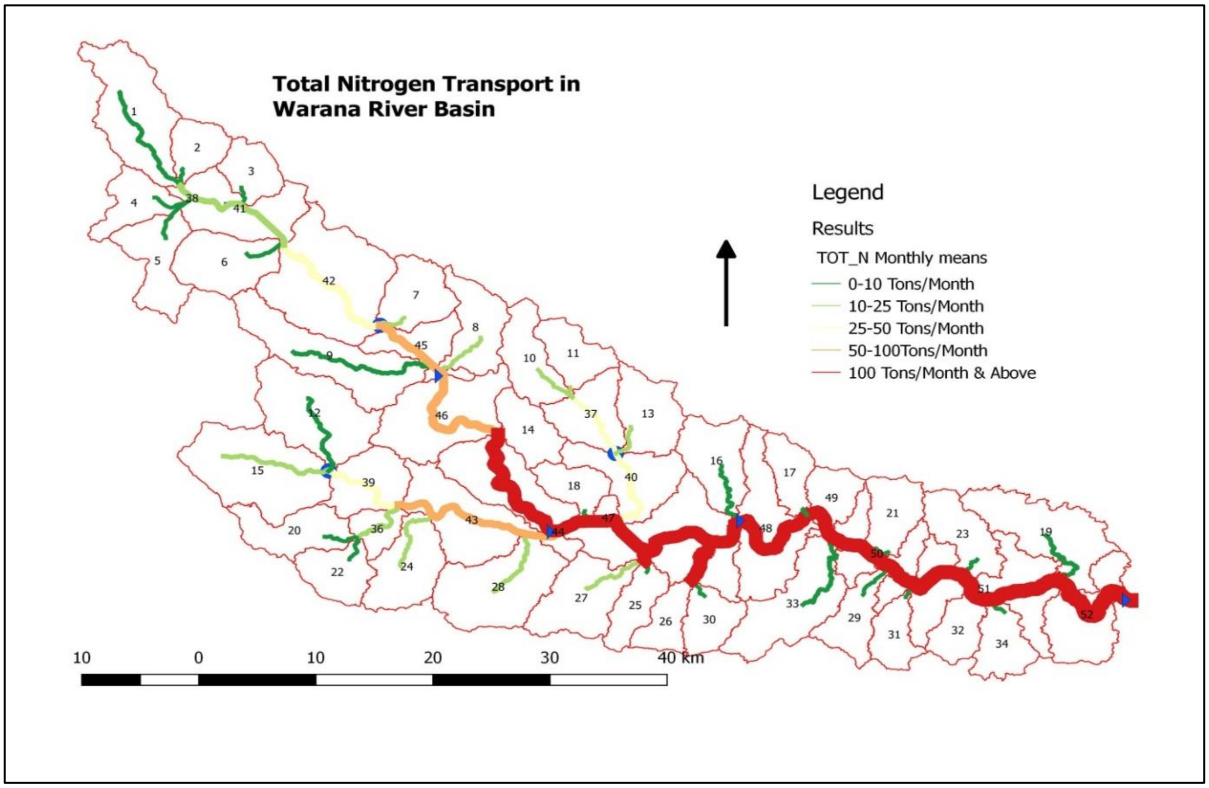


Figure 4 TOT_N in Warana River basin

SWAT CALIBRATION AND VALIDATION

Calibration and validation of water quality models are typically performed with data collected at the outlet of a watershed. The watershed outlet for this study is assumed to be a sampling site located at Van Meter (Figure 1); approximately 95% of the entire watershed drains to this location. An extensive amount of measured data has been collected at this location, especially for flow, sediment, and nitrate.

Daily USGS streamflow data (http://nwis.waterdata.usgs.gov/usa/nwis/discharge) were obtained for station at Warana for the 1981-2003 period. Water quality data including sediment, nitrate, organic N, organic P, and mineral P for the Warana River were obtained from the River Water Quality Network as described by Lutz (2004). These samples are collected on a monthly basis and were analyzed in Civil Engineering Department, RIT Rajaramnagar. Sediment and nitrate data are available for the entire 1981-2003 period, but organic N, organic P, and mineral P data are available only from May 2000 to December 2003. 10 Grab samples of water quality data were extrapolated into continuous monthly data.

Calibration by SUFI-2

The output file of HRU analysis by SWAT consists of total watershed 2060 Km^2 of Warana river basin. The Warana basin is divided in 52 subbasins and 150 HRU's. Landuse pattern in Warana river basin is given in table no

Table 1 Landuse Patterns in Warana River Basin

Watershed	%Watershed	Landuse	Area [ha]	Area [ha]
65.30	54.42	FRST	134536.35	112113.30
0.59	2.12	WATR	1217.88	4366.22
23.59	23.71	AGRL	48599.07	48845.24
1.32	5.94	BARR	2724.58	12236.59

9.16	13.31	SHRB	18872.58	27414.74
	0.10	URBN		196.50
	0.38	ORCD		777.88

Soil types contributing to watershed and area covered by soil is given in table no. 2. NTh (Lomy soil) is the soil type from SWAT is dominating and covers about 26% of Warana river basin.

Table 2 Soil Types with % Watershed and Landuse in Warana river basin

Soil Types SWAT	**%Watershed**	**Landuse**	**Watershed Area [ha]**	**Area [ha]**
MA	31225.05	(32744.69)	15.16	(15.89)
ACh	462.51	(1606.37)	0.22	(0.78)
LVh	6272.92	(8656.74)	3.04	(4.20)
ALh	22161.46	(19625.29)	10.76	(9.53)
NTh	60425.51	(53600.49)	29.33	(26.02)
VRe	5487.09	(5541.16)	2.66	(2.69)
LPe	21614.76	(21032.54)	10.49	(10.21)
CMe	9630.47	(8921.63)	4.67	(4.33)
ARh	670.20	(440.64)	0.33	(0.21)
FLe	1078.04	(1284.02)	0.52	(0.62)
LPk	2211.98	5930.19)	1.07	(2.88)
Lpq	35193.81	(33411.33)	17.08	16.22
NTr	9516.66	(10384.01)	4.62	(5.04)
PHh		(556.30)		(0.27)
RGe		(607.36)		(0.29)
VRk		(897.51)		(0.44)
CMd		(710.22)		(0.34)

Table 3 Description of stream flow calibration

Parameter	**Parameters Description**
r__CN2.mgt	Cure number
v_ALPHA_BF.gw	Base flow alpha factor
v_GW_DELAY.gw	Ground water delay time
v_GWQMN.gw	Groundwater flow time

Threshold depth of water include Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (Parasol), and Sequential Uncertainty Fitting (SUFI-2). In this research work calibrated result using SUFI-2. The sensitivity analysis showed that from 35 parameters, only 4 revealed meaningful effects on the flow simulation. The curve number (CN2), the base flow alfa factor (V_ALPHA_BF.gw), ground water delay time, threshold depth of water (V_GWQMN.gw) are the most sensitive of all controlling the surface flow. For the base flow, threshold water depth in the shallow aquifer for flow (GWQMN), saturated hydraulic conductivity (sol_k), deep aquifer percolation fraction (rchrg_dp), and groundwater revap coefficient (GW_REVAP) have the highest influence.

Table 4 Stream flow calibration parameter uncertainties SUFI-2

Parameter	Minimum value	Maximum value
r__CN2.mgt	-.02	0.2
v_ALPHA_BF.gw	0	1
v_GW_DELAY.gw	30	450
v_GWQMN.gw	0	2

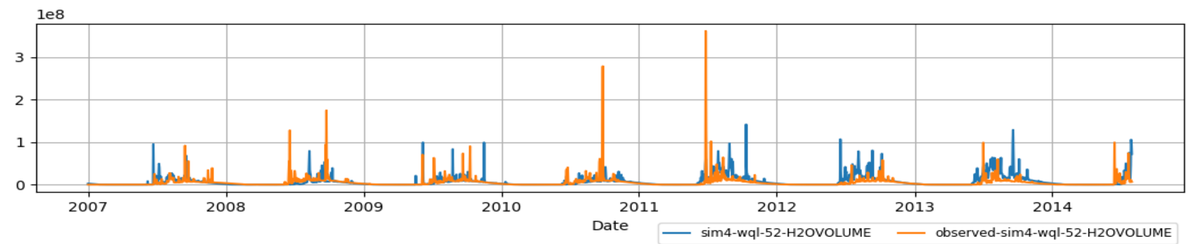


Figure 5 Discharge simulated and Observed from 2007 to 2014

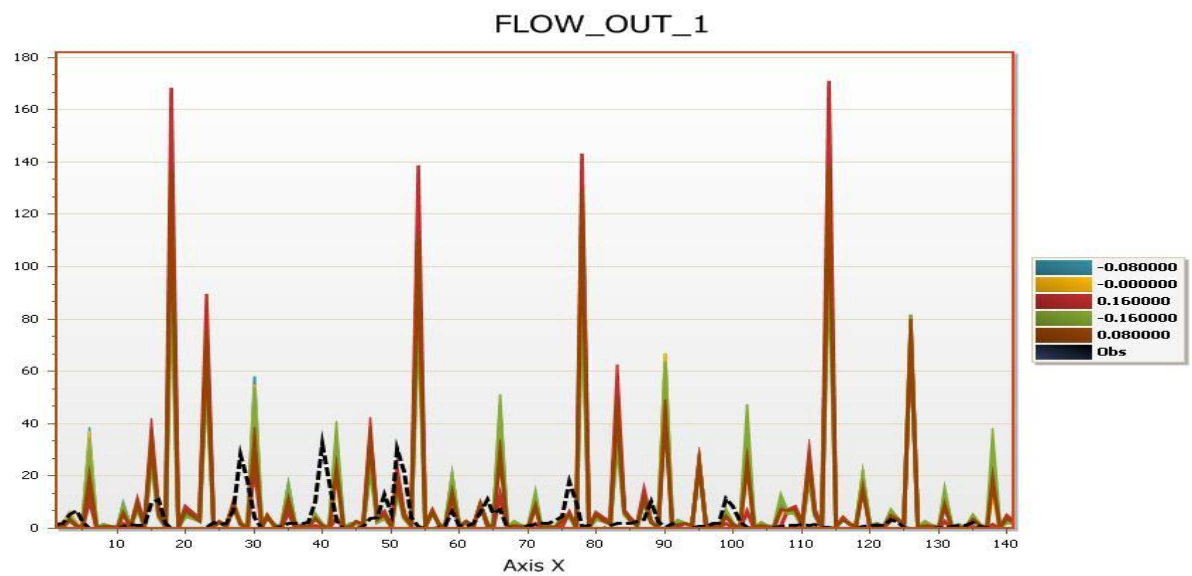


Figure 6 Flow Calibration

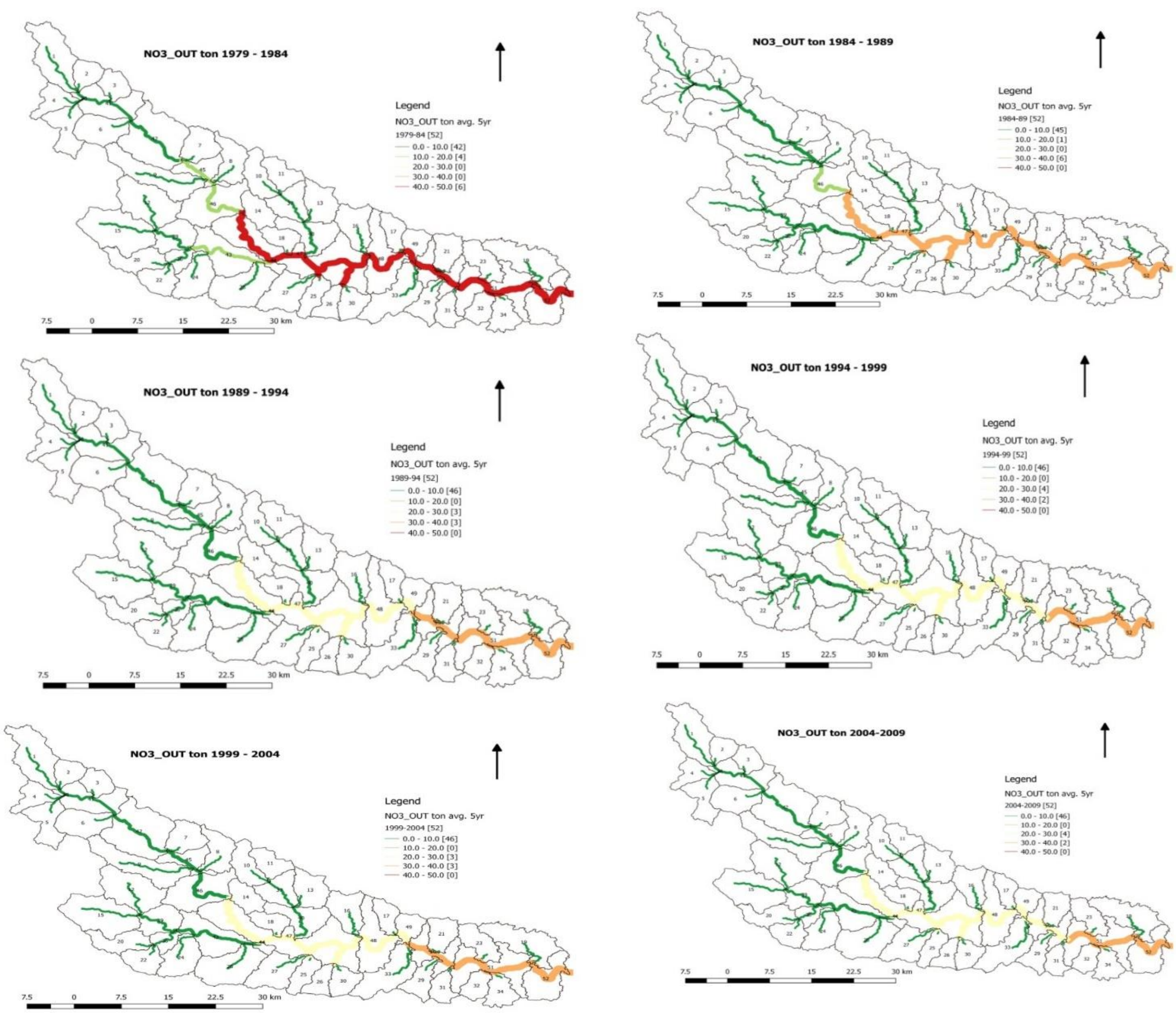
Model test results are more sensitive to the results like base flow alpha factors, groundwater delay time, cure number and threshold depth of water. In calibration, three variables such as P_factor, R_factor, and R^2 are computed for all types of objective function. Nash- Sutcliffe is the best fitness among the others. The values corresponding to these variables are 0.71, 1.35, 0.74 are respectively. This model is relatively good fit in the catchment area. The R^2 and NS coefficient are two important statically analysis for the result. According to Norusis (1999) when the R2 value is equal to 1, the model is considered to be good. When the R2 value is less than one the model would considered are not suitable. The study shows that the R2 value is 0.76 during the calibration period.

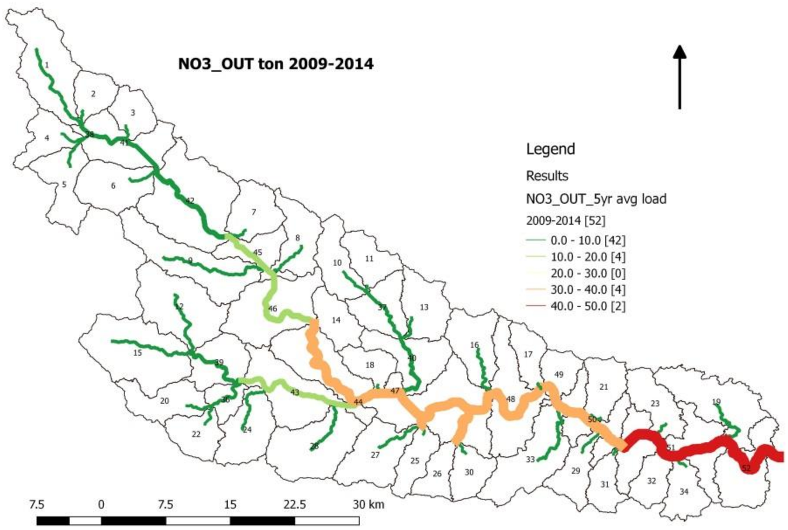
In this study, SUFI-2 will be used for model calibration. By using SUFI-2 can perform the uncertainty analysis and calibrate the model for more number of parameter. Most of the river originates from the intense storms during the rainy period. This statically analysis indicate that SWAT and SUFI-2 are a fair model for simulation and calibration for discharge by in river basin. The model gives relatively good result in Warana River basin.

3.9 Outcomes of SWAT

Warana River basin is analyzed by SWAT and validated by SWAT-CUP for the time period from 1979 to 2014. The average daily rate of water loss from reach by evaporation during time step (m3/s) is given by EVAP. The rate of evaporation loss varies in the year 2014. The min. value of the rate of water loss is 0.01 cms from sub-basin 14 in the month of July and the highest evaporation loss is from sub-basin 47 of 0.28 cms in the month of April 2014.

Nitrate and Total nitrogen transported with Warana river water out of reach during time step (kg N) given by NO3_OUT & TOT_N respectively. The min. 0.05 kg & 0.18 kg of NO3_OUT & TOT_N is transported from sub-basin no. 17 in the month of February 2014. The highest transport value 22370 kg & 2690000 kg (2690 tons) of NO3_OUT & TOT_N is seen in the month of July from 47 sub-basin of Warana River. The high quantity of transport of nitrate and total nitrogen is governed by surface runoff from agriculture area, the second zone of Warana basin villages namely Satave, Savarde, Kakhe, Kodoli, Warananagar and Chikurde. The Water intensive Industrial practice in Kodoli and Warananagar such as sugar factory, Milk Dairy and process dispose of partially treated wastewater increases nitrate concentration. It is also supported by the densely populated villages from the second zone of Warana River basin and dispose of as it is sewage in the Warana river. The same range of nitrate and total nitrogen is observed from subbasin 48 to 52 (end basin) of Warana River.





Results – Nitrate (Load) Avg. from 1979-2013

Similarly, total phosphorus transported with water out of reach during time step (kg P) is given by TOT_P. The nil amount of total P is transported from most of the sub-basins of Warana river basin and maximum amount is transported from sub-basin 47 to 52 in the range of 5,64,000 kg to 5,71,000 kg (564 to 571 tons) in the July of 2014. The disposal of nutrients into the Warana river is governed by intensive agricultural practice, partially treated sewage disposed and surface runoff includes the industrial wastewater wash off and forest and animal waste.

Table no. 5 agricultural management Plan for HRU 47

HRU	MON	DAY	CROP_FERT_DAY	OPERATION	PHUBASE	PHUACC	SOL_SW	BIO_MS	SOL_RSD	SOL_SUMNO3	SOL_SUMSOLP	YIELD	IRRAMT mm
47	2	49	FRST	PLANT	0.15	0	62.73	0	3918.79	4.64	83.24		600
47	8	213	FRST	HARV/KILL	0.73	0.64	221.68	7153.44	2780	0.09	82.54	5007.41	800

The agricultural management proposes plantation in February for all of the sub-basins in the Warana river basin. The fertilizer dose should be applied from February to May for respective sub-basins in Warana river basin. The crop harvesting is proposed from June to August for respective sub-basin in Warana river basin.

CONCLUSION

In Warana River basin, excess usage on an average 100 kg/hectare of urea fertilizer for cash crops, industrial waste and sewage from residential area leads to eutrophication and deterioration of water in Warana river. The variation in soil types, geological strata and varied rainfall intensity natural conditions stimulates water pollution.

Imposing regulatory measures to prevent the misuse of water and introducing rewards and punishment to encourage judicious use of water, will be helpful to conserve water. Finally, awareness and orientation of all the water users to change their lifestyle to conserve water can help the Warana river basin to tide over the water crisis and water pollution in the future.

REFERENCES

[1] Abbaspour, K. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., & Zobrist, J. (2007). Modelling hydrology and water quality in the pre-alpine / alpine Thur watershed using SWAT, 413–430.

[2] Alam, J., & Dutta, D. (2012). A process-based and distributed model for nutrient dynamics in river basin : Development, testing and applications. Ecological Modelling, 247, 112–124.

[3] Aranda, C. P., Valenzuela, C., Matamala, Y., Godoy, F. A., & Aranda, N. (2015). Sulphur-cycling bacteria and ciliated protozoans in a Beggiatoaceae mat covering organically enriched sediments beneath a salmon farm in a southern Chilean fjord. MPB, 100(1), 270–278.

[4] Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., (1998). Large-area hydrologic modelling and assessment. Part 1: Model development. J. Am. Water Resour. Assoc. 34 (1), 73-89.

[5] Artola, C. G., Pareja, B. L., & Garcia, P. G. (1995). Pergamon impact on hydrology and nutrient movements of developments in river basins draining into reservoirs, Water Resources 29(2), 601–609.

[6] Bhat, N. (2013) Life cycle assessment of sugarcane cultivation, M Tech Thesis, CTARA, IIT Bombay.

[7] Chen, D., Dahlgren, R. A., Lu, J. (2013). A modified load apportionment model for identifying point and diffuse source nutrient inputs to rivers from stream monitoring data. Journal of Hydrology, 501, 25–34.

[8] Edathoot A., (2012). A study of nitrate pollution in Warana basin and laboratory treatment studies of nitrates in drinking water, M Tech Thesis, CTARA, IIT Bombay.

[9] Eleventh Five-Year Plan (2007-2012) (Vol. II), Planning Commission, Government of India (2008), Oxford University Press, New Delhi.

[10] IRS(2015), Water Resource department, Gov. of Maharashtra, India

[11] IS 10500 (2012). Drinking Water Specification, Bureau of Indian Standards, 2, 1-11.

[12] Jessoe, K. (2013). Improved source, improved quality? Demand for drinking water quality in rural India. Journal of Environmental Economics and Management, 66, 460–475.

[13] Joy K., S. Paranjape (2011) Water resources planning and people's livelihoods in the Northern part of the Western Ghats. Live Diverse, 1-163.

[14] Khurana, M. P. S., & Aulakh, M. S. (2010). Influence of wastewater application and fertilizer use on the quality of irrigation water, soil and food crops : case studies from Northwestern India, (August), 19th World Congress of Soil Science, Soil Solutions for a Changing World 1 – 6 August 2010, Brisbane, Australia. 75–78.

[15] Kirubaharan (2012), Use of FOSS Platforms for Integrated Water Management Planning. M Tech Thesis, CTARA, IIT Bombay.

[16] Li, Y., Liu, Y., Zhao, L., Hastings, A., & Guo, H. (2015). Exploring change of internal nutrients cycling in a shallow lake : A dynamic nutrient driven phytoplankton model. Ecological Modelling, 313, 137–148.

[17] Sonawane, P.G., Munavali,G. R., Ranade, S.V. (2008) Feasibility of constructed wetland system septic tank effluent. Journal of IPHE, India 3, 32-36.

[18] Yang, X., Liu, Q., Fu, G., He, Y., Luo, X., & Zheng, Z. (2016). Spatiotemporal patterns and source attribution of nitrogen load in a river basin with complex pollution sources, Water Research 94, 187-199.

[19] Zeng, Q., Qin, L., & Li, X. (2015). Science of the Total Environment The potential impact of an inter-basin water transfer project on nutrients (nitrogen and phosphorous) and chlorophyll an in the receiving water system. Science of the Total Environment, 536, 675–686.