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Revisiting the Flood Mitigation Measures Based on Lesson Learnt From the Recent Flood Damages of Iranaimadu Irrigation Scheme - Case Study

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Abstract—Floods represent one of the main natural disasters, affecting many states over a year, environment and natural resources, and leading to large economic losses, social and health problems. Monsoon floods or natural disaster occur seasonally. Sri Lanka has adopted for monsoon climate with wet, intermediate, dry zone climate changes with a mean annual rainfall of 800-1200 mm. The recent flood caused in the Northern Province is one of the worst disasters. Our project area Iranaimadu Irrigation Scheme is situated under dry zone. The catchment area of Iranaimadu reservoir is 587.92 km2 and stores water for the irrigation requirements in downstream areas. Every year Iranaimadu upstream and downstream affected by flood. The main cause of the very worse flood situation in 2018 is improper management of Iranaimadu reservoir. There is no daily runoff model, and proper flood mapping and flood prone zone identifying model. This study proposes a better operational procedure to mitigate and forecasting the flood of Iranaimadu Irrigation schemes through operational study; rainfall runoff model of the reservoir and identify the flood prone areas around the downstream and upstream of Iranaimadu using flood mapping.

Index Terms— Iranamadu, flood mitigation, Kanakarayan river basin, flood mapping

1 Introduction

OUR study area mostly affected by flood and drought by every year. Here we analysis the monsoonal floods which occur between 2010 and 2018. Our project area Iranaimadu reservoir is situated in dry zone of Mullaitivu District of Northern Province Sri Lanka. The Iranaimadu reservoir with catchment area of 587.92 km2 run through Vavuniya and Mullaitivu Districts, stores 147 million meter cubes of water for the irrigation requirements of 8,900 hectares of irrigable land in Kilinochchi District and having the capacity of providing domestic water supply demand of around 8 million meter cube for the Kilinochchi and Jaffna Districts. It has two irrigation canals which are Right Bank canal and Left Bank canal to distribute water to the downstream areas. Iranaimadu reservoir receives inflow from its own basin via Kanagarayan Aru River.

Heavy thunderstorms have hit northern Sri Lanka between 21st and 22nd of December 2018. The flood which caused by the climate change has mostly affected the lower reaches of the Kanakarayan Aru river basin. Due to this heavy flood, livestock damaged, paddy fields ready for cultivation and residential areas inundated and road networks damaged. These damages of flooding caused by improper Iranaimadu reservoir management due to non-availability any study of rainfall runoff model, and proper flood mapping and flood prone zone identifying model.

The management process of a reservoirs should ensure the safety of the dam, safety of peoples, minimal impact of live stokes and properties, retention of possible water storage of the reservoir.

The study about the flood is important to provide a clear idea about the flood periods and provide information to local residents in adapting and mitigateary measures towards floods and provide an idea about maintaining drainage infrastructures.

The information collected from local residents and the study using the flood action plan emphasizes social and environmental issues and the flooding problems experienced by local residence shows that, by implementing a comprehensive flood mitigation awareness is very essential to minimise the damage to the society and to the economic infrastructures.

This research carried out with the historical data collected from government departments' such as catchment characteristic maps, land use data, rainfall data, depth-area-capacity, population data…etc.

Using the above historic data, the Iranaimadu flood mitigation analysis is carried with the

- ARC MAP software to draw the flood mapping to find the flood affecting areas.

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- SWAT (Soil Water Assessment Tool) model to Daily rainfall - runoff model to carry out the flood mitigation effectively.

Using the above two software, the efficient reservoir management concepts of Iranaimadu reservoir is developed

2 Literature Review

2.1 Review Stage

For weather research and forecasting, researchers (Ratnayake, Sachindra and Nandalal, 2010) developed a weather model with a hydrologic model and a hydraulic model for predicting floods. WRF 3.0 weather model was configured and used to predict rainfall over the basin 24 hours into future. The predictions were compared with observed point rainfall data. Hydrologic model was developed using the HEC-HMS 3.3 (Hydrologic Engineering Centre-Hydrologic Modelling System). River discharges of sub basin were ingested to the HEC-RAS 4.0 (Hydrologic Engineering Centre-River Analysis System) hydraulic model for water profile computations along the Nilwala main river. Output of HEC-RAS was exported to ArcGIS 9.2 where it was two dimensionally visualized as a flood map.

In this research they have prepared the flood mapping using GIS and Hydrologic Engineering Centres River Analysis System (HEC-RAS). Due to this flood human life losses and with significant amount of property damages were experienced in 2012 flood. The researchers have prepared their flood model using digitization of topographical data and preparation of digital elevation model using ArcGIS, simulation of flood lows of different return periods using a hydraulic model (HEC-RAS), and preparation of flood risk maps by integrating the results of above ArcGIS and HEC-RAS(Html, 2016).

They prepared to predict flood levels at downstream locations based on observed water levels at upstream locations. Strategies for reducing flood losses by flood protection and management include modifying susceptibility to flood damage (Actions taken before a flood), modifying flood waters, and modifying the impact of flooding (during and after flood). Forecasting based on mathematical modelling allows experts to convert information on the past-to-present rainfall into a river flow forecast (Nandalal, 2009).

A cascade modelling approach comprised by meteorological, hydrological and hydrodynamics models is implemented. Natural flows with urban infrastructure and planning of the models were developed. The models shown land use changes have significantly increased the observed flood impacts during flood. In their analysis the importance of land use planning was measured to reduce flood risk (Aslam, 2018).

In a rapidly urbanizing area like Benin City, proper land use policies, regulations, building, and development by-laws are very necessary to check the excesses of developers and to monitor the nature of urban development (Cirella, Iyalomhe and Adekola, 2019).

2.2 Problem Statement

These are the statements with high impact on the Iranaimadu reservoir operation and be improved.

- The flooding caused by improper Iranaimadu reservoir management.
- There is no developed rainfall runoff model.
- Identify flood mapping and flood prone zoning not available
- The instrumentation (precipitation and river gauges) and monitoring facilities needs to be established in the catchment area in order to provide real time data to the control room.
- There was no organized preparedness to face flood incidents - Standard Operational Procedures (SOP) need to be updated, trailed by all relevant parties especially Disaster Management Unit and Irrigation Department.
- Flood and drainage infrastructure with poor operation and maintenance.

This research proposes a better operational procedure to mitigate and forecasting the flood of Iranaimadu irrigation reservoir through operational study; rainfall runoff model of the reservoir and identify the flood prone areas around the downstream and upstream of Iranaimadu using flood mapping.

3 Methodology

The methodology of this research focused on the following six major steps.

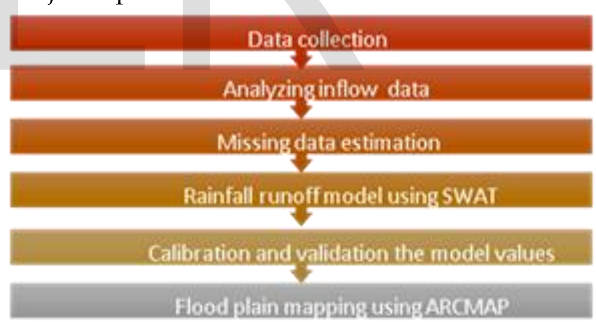

Figure 1 –Methodology procedure

Step 1 Data Collection

The following historic data were collected from respective authorize

- Rainfall data of Iranaimadu, Muthayankaddu, Vavunikkulam, Mankulam and Vavuniya rain gauges collected from Irrigation Department.
- Iranaimadu catchment data such as rainfall, temperature, soil, land use data, tank height-area-capacity and digital elevation maps.

Step 2 Analyzing Inflow Data

To analysis the reservoir capacity variant with rainfall around the catchment areas, a rainfall runoff model developed using SWAT software and to identify the flood prone areas,

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the flood mapping model developed using ARC MAP software. The Iranaimadu reservoir capacity always calculated by the water level elevation. The rainfall data used for preparation of inflow in the tank.

In the Iranaimadu reservoir there is no proper inflow measuring device. Hence, water balance method was used to find the inflow of the reservoir. Here we used reservoir water storage varying data and water discharge data to find the inflow of the reservoir.

Variable Storage and Muskingum Routing method are the two types of routing method in SWAT. In the present study, Variable Storage Routing method was used. For a given segment of reach, the storage routing is based on the following continuity equation.

$$V_{in} - V_{out} = \Delta V_{stored} + \text{Evaporation} \quad \ldots(1)$$

Where Vin is the inflow volume (m3), Vout is the outflow volume (m3) and ΔVstored is the change in storage volume during the time step (m3).

Step 3 Missing data estimation

There were few missing and outlier rainfall data. Incorrect measurements, damage or fault in a rain gauge during a period, ecological system, malfunction instrument and relocation of stations may be the reasons for this data laps.

Theisen polygon method is among many methods, popularly used to estimate the missing rainfall data. Theisen polygon method calculation are accuracy than other methods. The rain gauge stations in Iranaimadu, Muthayankaddu, Vavunikkulam, Mankulam, Vavuniya (figure 2.) were selected to find missing data.

Figure 2 – Rain gauge stations

The rain gauge station weights are determined in proportion to their representative areas defined by a polygon as in figure 3 and 4.

Figure 3 –Theisen polygons

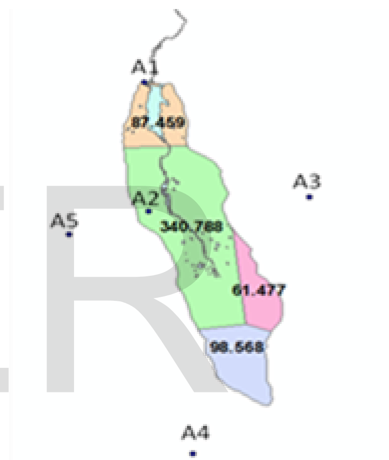

Figure 4 – Theisen polygon area

Equation (2) and (3) were used to find the minimum number of rain gauges.

$$N = \left(\frac{Cv}{E}\right)^2 \quad .... (2)$$

$$Cv = \frac{100 \times \sigma}{\bar{P}} \quad .... (3)$$

Where,
N-minimum required number of rain gauge stations,
$\bar{P}$-average annual precipitation,
E-allowable percentage error,
Cv-coefficient of variation of the rainfall

Based on this calculation the optimum number of stations necessary to find the missing data is coming as 3. Hence 5 stations selected for the calculation of the missing data calculation of Mankulam station for the 2010 period. After Find the missing rainfall data screening test, double mass test and outlier test of 5 rain gauges station was carried out.

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Step 4 Rainfall Runoff Model Using SWAT

SWAT and HEC-HMS used to carry out the runoff over the basins. In this research SWAT software was been selected to carry out the rainfall runoff model with the data of inflow of the reservoir and rainfall. The main reason to select SWAT model was to consider different land uses pattern, soil type within basin, digital elevation and temperature. SWAT simulates runoff, sediment, nutrient and bacteria transports. It simulates the daily, monthly and annually runoff but HEC-HMS simulates hourly based events. Most suitable model with high precision.

3.1 Automatic Watershed Delineator

The watershed delineation is that the lines drawn on a map to identify the boundary of the watershed. These are typically drawn on topographic maps using information from contour lines. Contour lines are lines of equal elevation, so any point along a given contour line is the same elevation.

3.2 Topography Map-Digital Elevation Map

Digital Elevation Model (DEM) as in figure 5. is the digital representation of land surface elevation with respect to any reference datum. DEMs are used to determine certain attributes such as elevation at any point, slope and aspect.

Figure 5 – Digital elevation map

3.3 Flow Direction- Dem Based

Flow direction determines which direction water will flow in a given cell (figure 6.). Based on the direction of the steepest descent in each cell, we can measure flow direction. Flow direction is calculated for every central pixel of input blocks of 3 by 3 pixels, each time comparing the value of the central pixel with the value of its 8 neighbours.

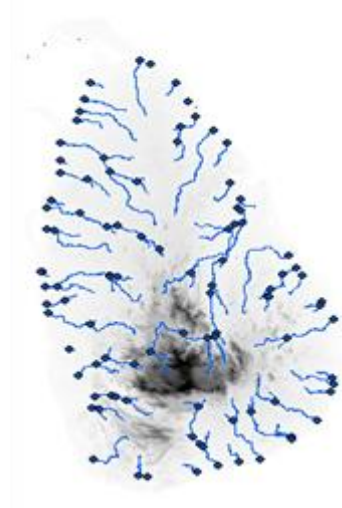

Figure 6 – Flow direction

3.4 Stream Network

This is most useful input to the Watershed tool to quickly create watersheds based on stream junctions. It can also be useful for attaching related attribute information to individual segments of a stream. The Stream Link tool allows to assign unique values to each of the links in a raster linear network. First the outlet of the reservoir to be create then according to the outlet point the basin can be created as in figure 7.

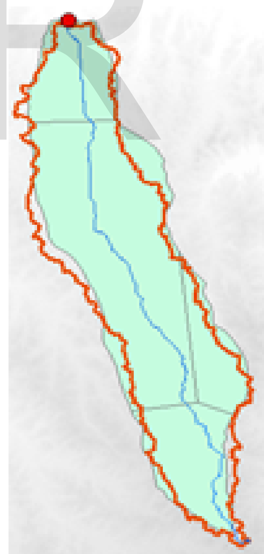

Figure 7 – Outlet point and basin

3.5 Hydrological Response Unit (HRU)

The way a catchment reacts when it is subjected to a rainfall event is called hydrological response. Total-hydrological response is composed of the surface and subsurface flow. Partial - hydrological response results from the surface flow or subsurface flow. Land use / land cover map measuring current conditions and how they are changing can be easily achieved through land cover mapping, a process that quantifies current land resources into a series of thematic categories, such as forest, water and paved surfaces.

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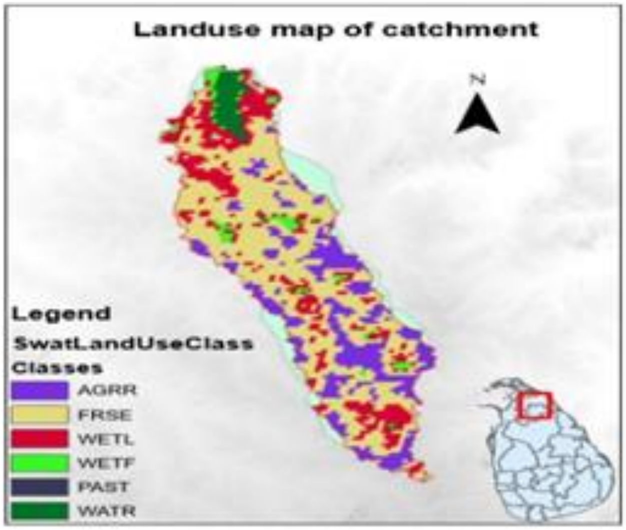

Figure 8 – Land cover map

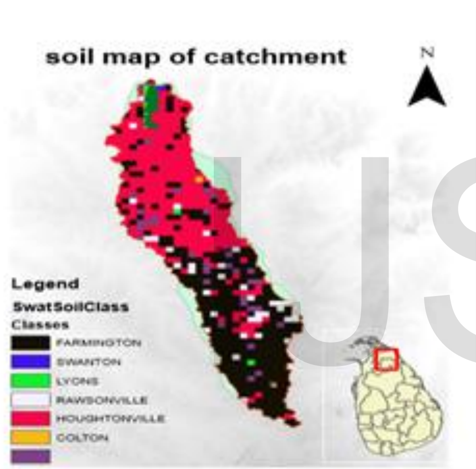

Figure 9 –Soil map

3.5 Hydrological Response Unit (HRU)

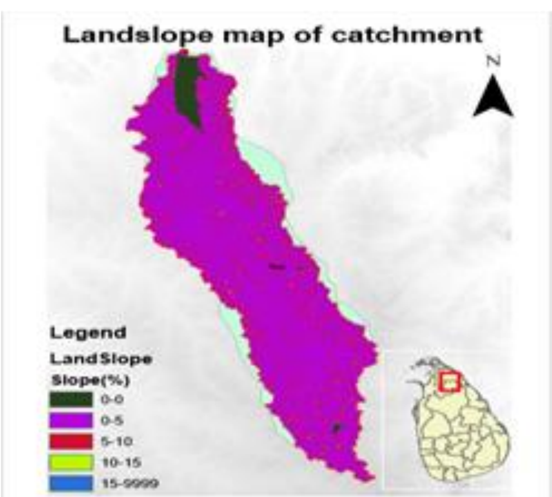

Figure 10 –Land slope map

3.6 Watershed and Topographic Report

Here we analysis the Iranaimadu reservoir catchment elevation and according to the elevation below area. Our study area elevation varying with 19m to 130m from the mean sea level. If we take the 36m from MSL 4.83% of catchment land area under an elevation and 4.40% of catchment land under a watershed as given in figure 11.

Statistics: All elevations reported in meters

Min. Elevation: 19
Max. Elevation: 130
Mean. Elevation: 69.47[illegible]
Std. Deviation: 21.17[illegible]

Elevation	% Area Below Elevation	% Area Watershed
19	0	0
20	.01	0.01
21	.01	0.01
22	.02	0.02
23	.02	0.02
24	.02	0.02
25	.03	0.03
26	.03	0.03
27	.04	0.03
28	.04	0.04
29	.04	0.04
30	.05	0.06
31	3.87	3.83
32	3.93	4.06
33	4.02	4.08
34	4.18	4.16
35	4.43	4.26
36	4.83	4.40
37	5.37	4.54

Figure 11 Watershed and topographic report

3.7 HRU Analysis Report

		Area [ha]	Area[acres]
Watershed		55862.1696	138038.2142
Number of Subbasins: 1			
		Area [ha]	Area[acres]
LANDUSE:			
	Agricultural Land-Row Crops --> AGRR	11467.8573	28337.6489
	Forest-Evergreen --> FRSE	30678.3445	75807.7231
	Wetlands-Mixed --> WETL	10813.8178	26721.4844
	Wetlands-Forested --> WETF	1867.5916	4614.9123
	Pasture --> PAST	21.1690	52.3098
	Water --> WATR	1013.3893	2504.1357
SOILS:			
		2949.5184	7288.4074
	COLTON	88.1345	217.7847
	FARMINGTON	25112.2486	62053.6219
	HOUGHTONVILLE	24529.2615	60613.0317
	LYONS	177.0025	437.3821
	RAWSONVILLE	2925.2054	7228.3288
	SWANTON	80.7987	199.6576
SLOPE:			
	0-0	1505.4124	3719.9492
	0-5	44013.5839	108759.7664
	10-15	327.3866	808.9886
	15-9999	15.0908	37.2901
	5-10	10000.6960	24712.2198

Figure 12– HRU analysis report

3.8 Land Use Pattern for Iranaimadu Catchment Area

It is found through this process the land use pattern of Iranaimadu catchment area is mostly forest evergreen.

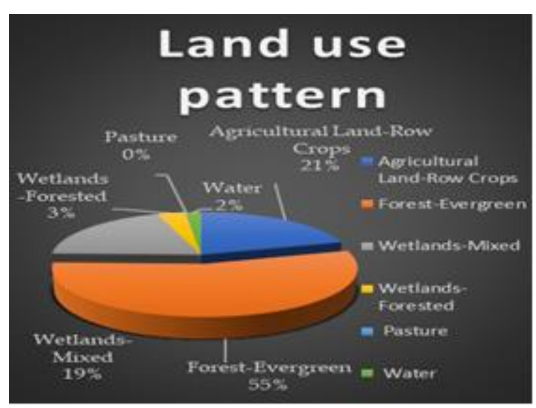

Figure 13 – Land Use Pattern

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3.9 Soil Pattern for Iranaimadu Catchment Area

Major part of the catchment soil type is Farmington.

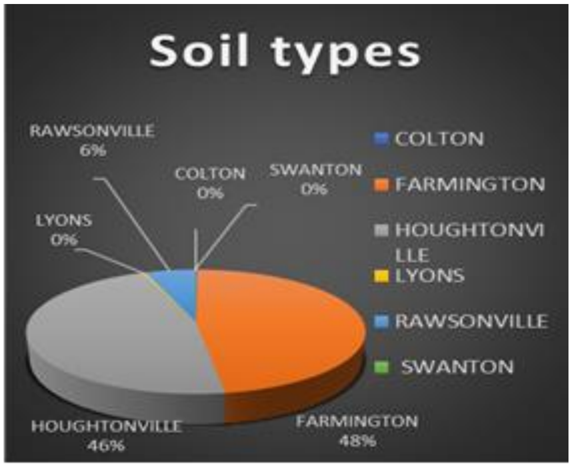

Figure 14 – Soil Type

3.10 Weather Data Definition

SWAT requires daily precipitation, maximum / minimum air temperature, solar radiation, wind speed and relative humidity. Values for all these parameters may be read from records of historic observed data or they may be generated. In our project we used input data rainfall data and temperature date.

3.10.1. Generated Weather Data

We have to generate 2010 period rainfall data of Mankulam station. The locations of rain gauge stations within the study area at Iranaimadu, Vaunikulam, Vauniya, Muthiyankaddu and Mankulam are given in table 1 and figure 2.

Table 1 – Gauges Location

Rain gauge station	Longitude	Latitude
Iranaimadu	162807.25	459622.81
Vaunikulam	152081.03	432437.36
Vauniya	169883.63	393444.86
Muthiyankaddu	186554.86	439125.49
Mankulam	163473.71	436612.32

When the precipitation values mentioned by the p1, p2, p3, p4 …. And the neighboring M stations are mention by the M1, M2, M3…. and the normal annual precipitation mentioned by n1, n2, n3………. Then by using the below equations we can find the precipitation values.

If the normal annual precipitation values at various stations are within about 10% of the normal annual precipitation at station x, then a simple arithmetic average procedure is followed to estimate Px, thus

$$Px = \frac{p1+p2+p3.....+pm}{M}$$

If the normal precipitation varies considerably, then Px is estimated by weighing the precipitation at the various stations by the ratios of normal annual precipitation. This method known as the normal ratio method, Gives Px as

$$Px = \frac{Nx}{M}\left[\frac{P1}{N1}+\frac{P2}{N2}+\cdots+\frac{Pm}{Nm}\right.$$

In the table 2, (Ni-Nm) define the difference in the average of normal precipitation and Nm define the normal precipitation of particular station.

Normal annual precipitation helps to find the missing data of the Mankulam rainguage station.

The variance of total normal annual precipitation vary considerably greater than 10 % as in table 2. Hence normal ratio method is used to estimate the missing rainfall for this study.

Table 2 – Variance of Total Annual Rainfall

Station	Normal annual precipitation (2010-2018)	percentage $\frac{Ni-Nm}{Nm}x100$
Mankulam	12290.60	0
Vavunikkulam	13764.75	11.99
Muthayankaddu	15776.10	28.36
Vavuniya	14374.60	16.96
Iranaimadu	14807.20	20.48

The variance of total normal annual precipitation vary considerably greater than 10 % as in table 2. Hence normal ratio method is used to estimate the missing rainfall for this study.

Step 5 Calibration

Calibration is the setting or correcting a measuring device or base level, usually by adjusting it to match or conform to a dependably known and unvarying measure. Calibration refers to the act of evaluating and adjusting the precision and accuracy of measurement equipment. Instrument calibration is intended to eliminate or reduce bias in an instrument's readings over a range for all continuous values.

Inflow to the Irnaimadu reservoir from the catchment (figure 15.) and SWAT output (figure 16) at the catchment mouth are compared and adjusted by trial and error method to find a good match.

Comparing the predicted results with the data used for calibration an error below 0.02 observed. It is blow the allowable error percentage.

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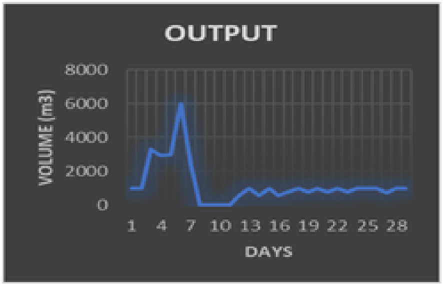

Figure 15 – SWAT Output

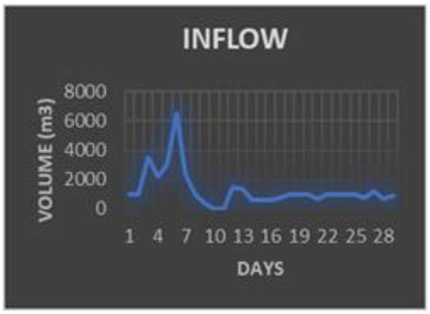

Figure 16 – Inflow of the Irnaimadu Reservoir

Step 6 Validation

Validate is the process to prove that something is based on truth or fact or is acceptable. Process validation is defined as the collection and evaluation of data, from the process design stage through commercial production, which establishes scientific evidence that a process is capable of consistently delivering quality product.

After the calibration process the pattern of the SWAT output (figure 18) and rainfall values (figure 17) are checked with next two consecutive years (2017-2018) for validation of the model. There is no change in the parameters during this validation. It shows that model constructed can predict well for future operations.

Figure 17 –Rainfall Values with Days

Figure 18 – SWAT Output with Days

Step 7 Flood Plain Mapping Using ArcMAP

ArcMap is the main component of Esri's ArcGIS suite of geospatial processing programs and is used primarily to view, edit, create and analyse geospatial data. ArcMap allows the user to explore data within a data set, symbolize features accordingly and create maps. The geoprocessing tools that are available in the ArcMap are used for this study.

ArcGIS pro has many capabilities beyond ArcMap including better 3D visualization. Use the ArcMap software to draw the flood mapping to find the flood affecting areas. In the ArcMap we input Land use map and Digital elevation of downstream and catchment. The amount of exceeded water from the reservoir was obtained from the SWAT model. Then using the ArcMAP the flood plain areas were found.

4 Results and Discussion

SWAT based rainfall runoff model used to simulate the daily, monthly and annually runoff of a catchment. Rainfall runoff model was constructed by using watershed delineator, hydrological response unit, land use, soil map of the catchment. Land use pattern was used to identify the various crops into the catchment and also the topographic map used to find the elevation of the catchment.

During the calibration process an error below 0.02 was observed. Calculated results error value are less than the allowable error percentage. Calibration process there is no change in the parameters hence directly validated the proceeding two years (2017-2018) data.

The flood plain maps can differentiate the affected areas. With the help of the maps from figure 20 to 24, which are generated from this research, can encourage to the professional emergency responders (Police, District Administers, Irrigation Authorities and Disaster Management Personals) to take immediate consideration on vulnerable areas and assets in the flood plain.

This will help to shift the people from high risk areas to safe areas well in advance. Flood maps improves the better planning and prioritization of effort to better mitigate from floods by the irrigation authorities.

In figure 19 and 20 the catchment and downstream based on the elevation is analysed. The lowest catchment elevation from the mean sea level is 19.0 m.

This research identified the catchment flood affect areas according to the elevation varying and area changing percentage and given in figure 21 and 22.

In the figure 21, the red colour identifies the flood affected area when the reservoir water level elevation rises up to 40 m above mean sea level. This red colour areas will be affected every year by flood.

Figure 22 defines the flood affect pattern when reservoir water level rises up 45m from mean sea level.

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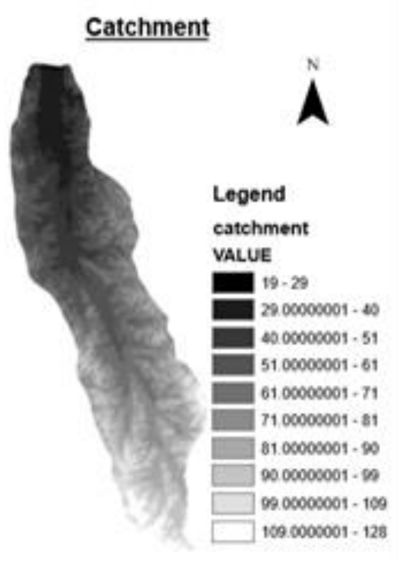

Figure 19 –Catchment Elevation of Iranaimadu

Figure 22 – Flood affect area when reservoir water elevation at 45 m

Iranaimadu reservoir at the full supply level 148MCM inundation will increased. In the above map shows red areas mostly affect by the flood. Blue colour is Iranaimadu reservoir water body. Blow we can analysis the when elevation changing flood affect downstream.

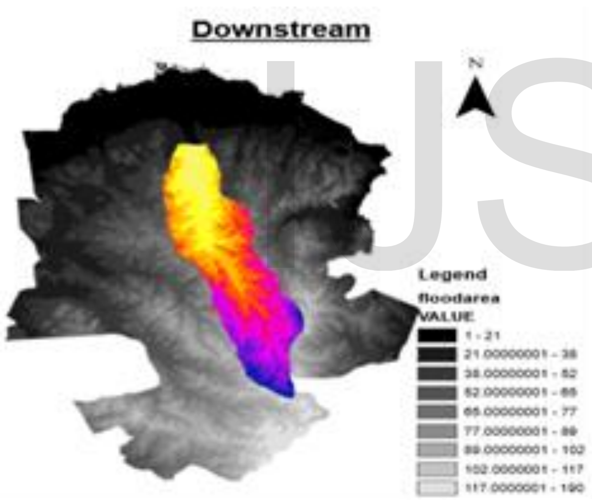

Figure 20 –Downstream and Upstream

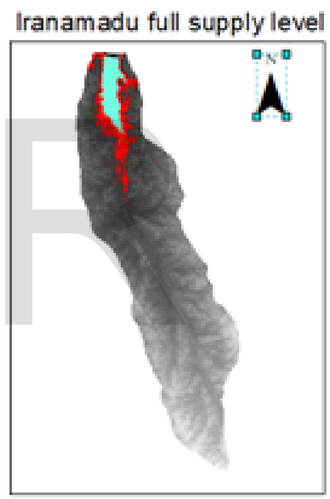

Figure 23 –Iranamadu Full Supply Level Flood Affect Pattern

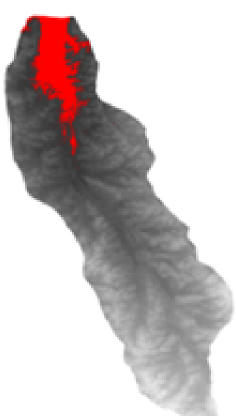

Figure 21 – Flood affect area when reservoir water elevation at 40 m

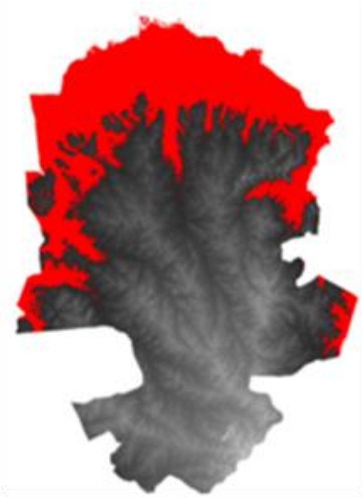

Figure 24 - Flood affect area of downstream water elevation at 38 m

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This figure 24 shows the flood affect area (red colour) of downstream of Iranaimadu reservoir when water elevation raises to 38 m.

Using these data we can give early warning and evacuate people from the flood plain areas.

5 Conclusion

SWAT model for the catchment is producing good simulation results for daily, monthly and yearly runoff values as for the other water balance components. The evaluation of the model performance is carried out with the recommended calibration error.

These performances can be enhanced furthermore using more accurate input data especially for the soil, land use and DEM data that will be estimated in this study with global data. The integration of climatic data such as rainfall data, temperature data also helps to compute accurate rainfall-runoff correlation.

With the help of observed runoff data of the catchment especially recent flash flood incident, model validation is done.

Finally, we developed rainfall runoff model of Iranaimadu reservoir. From the model we can get more benefits such as water resource planning for future and useful for the operational process.

The flood prone areas around the downstream, upstream and catchment of Iranaimadu are identified using flood mapping. From the flood mapping we can provide early warning to people and eliminate the construction of water path. It will be more beneficial to the authorities to mitigate any possible flood within, around and downstream of Iranaimadu catchment.

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