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Mitigation Measures of Flood and Drought for Ayeyarwady Basin

Minn Ko Ko Kyaw [a]*, Nilar Aye [b]

[a,b] *Department of Civil Engineering, Mandalay Technological University, Mandalay, The Republic of the Union of Myanmar*

[a]*Email: minnkokokyaw88@gmail.com*

[b]*Email: dnilaraye@gmail.com*

Abstract

This research represents about the mitigation measures of flood and drought for Ayeyarwady Basin. The objective of this study is to propose the mitigation effect of flood and drought in Ayeyarwady Basin. In this study, flood vulnerable areas for Ayeyarwady Basin are assessed by using Hydrologic Engineering Center's River Analysis System (HEC-RAS) model, GIS and Remote Sensing technique. Landuse classification map (2014 year) is extracted from Google Earth Engine based on land satellite LANDSAT-7 data and then Curve Number (CN) grid map is developed. Landuse classification in year 2014, the closed forest is found as about 48.9% and deciduous forest is about 26.3% of Ayeyarwady Basin. After delineating the flood plain area in HEC-RAS, the flood map for Ayeyarwady basin is developed by using Arc-GIS. The flood area by using 2014 landuse classification is 10414.18 km^2 and the flooded regions are part of Mandalay, Sagaing, Monywa, Pakokku, Magway, Yaynanchaung and Thayet. According to the landuse classification in 2000 year, closed forest is 62.8% and deciduous forest is 28.05%. The flooded area is about 7081.03 km^2. According to these scenarios, it is found that flooded area can be reduced about 32% due to forestation. For the spatial characterization of drought, Spatial interpolation (Spline) method in Geographic Information System (GIS) is used to generate drought severity maps. According to the drought severity map and severity values, Aunglan, Magway and Nyaungoo are the most severity regions and which are considered as pilot regions in this study. Two scenarios of rainwater harvesting are proposed to mitigate the drought severity area. In the first scenario, rainwater is collected from the roof top and stored in the storage tank.

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* Corresponding author.

The average maximum monthly collected rainwater per house hold for three types of roofing area are 4.423 m^3, 13.539 m^3 and 27.214 m^3 respectively. The second scenario is to recharge the rainwater volume directly over the different types of landuse area and soil group. As a result, the recharge volume for Aunglan, Magway and Nyaungoo regions are 530.85 Mm^3/year, 219.312 Mm^3/year and 224.863 Mm^3/year respectively. Finally, these scenarios are proposed to mitigate the effect of flood and drought in Ayeyarwady Basin.

Keywords: Drought, Flood, Mitigation Measures, Forestation, Rainwater Harvesting.

1. Introduction

Nowadays, most of the places in the world suffer climate change including Myanmar. Among them, flooding is one of the most importance problems in our country. Most of the flooding in the lower Ayeyarwady is caused by flooding in Chindwin and upper Ayeyarwady. In addition, Doakehtawady River, tributary of Ayeyarwady, also set off major floods. Floods, in consequence, can occur over a wide range of region especially in lower basin (Sagaing to Pyay). Myanmar is one of the vulnerability to climate change impacts in terms of extreme temperature, severe drought, cyclones, floods, heavy rainfall and less precipitation, landslides, earthquakes and tsunami [9]. In 2004, the flood has been occurred a result of intense rainfall in the upper portion of the Ayeyarwady River. Rainfall peak and water level peak are different since local rain is not affected in the study area. Most of the flood in the study area is mainly related to upstream rain effects [16].

According to Natural Disaster Risk Assessment country report, 50% of the total number of disasters in Myanmar was related to floods followed by storm (23%), earthquake (15%), and mass movement-wet (12%), whereas 73% of the total affected people by disasters were due to storm followed by floods [16]. Flood event occurred in 2011, which was caused damages in Magway and Mandalay in the central areas and Sagaing in the northern region. Flash floods hit Pakokku and collapsed a bridge. In Sagaing Division, more than 190,000 acres of the farmlands are flooded and 18,000 acres were destroyed. Similarly, Kalay and Kanbalu Township were severely affected by flooding. Overspills of Mone and Man creek affected 300 villages as well as town area in Pwintphyu, Saytotetayar and Ngape [16]. There is a rapid increasing of urbanization so that the landuse and landcover are simultaneously changing year after year. The flood or other natural hazard are occurred due to the effect of urbanization, deforestation and other human impact. So that the flooded area can be reduced as conserve forest and prevent the forest become extinct.

Drought is one of the major environmental disasters, which have been occurring in almost all climatic zones and damage to the environment and economies of several countries has been extensive. Drought has become one of the most important elements for water resources planning and management in Ayeyarwady basin especially in dry zone. Drought damages are more pronounced or prominent in areas where there is a direct threat to livelihoods. In drought management, making the transition from crisis to risk management is difficult because little has been done to understand and address the risks associated with drought.

Now in Myanmar, meteorological drought occurs when the seasonal rainfall received over an area less than 750 mm especially in dry zone. Drought causes problems in water resources and agricultural sector. Drought condition occurs during the dry season in the regions where the main cities include Magway, Chauk, Yenangyaung and Saytotetayar in Magway region and Kyaukpadaung and Myinchan in Mandalay region [9]. In 2014, water shortage in Nyaungoo and Kyaukpadaung and the reservoir was dried up in Mya Kan near Bagan. Water shortage is the most severe in Ayeyarwady, Sagaing, Yangon, Mandalay and Bago Regions and Mon, Rakhine and Shan States. Most of the wells were dried up due to the depletion of underground water supply because of late of monsoon onset and so the scarcity of drinking water problems occurred in Myanmar [9].

In this study, Geographic Information System (GIS) is used to generate the drought severity map for different time scales of Standardized Precipitation Index (SPI). SPI is calculated by the stand alone PC software which was used to calculate the drought severity. Spline spatial interpolation method is used to create the drought severity map based on the severity values for different rainfall stations in Ayeyarwady Basin. Central dry zone of the Ayeyarwady Basin has occurred high severity in which area is suffered water shortage in summer. In Myanmar, central dry zone is comprised of many township and region, among them, Aunglan, Magway and Nyaungoo regions are considered as three pilot regions. To reduce the actual impacts and losses during the next drought, it is necessary to be on alert-based preparedness under the light of mitigation activities and plans. Different mitigation strategies can be applied depending on the type of drought [6].

2. Location of the Study Area

The Ayeyarwady River is the largest river in Myanmar and it arises from the confluence of the May-Kha and Mali-Kha rivers. It is running through the centre of the country and the most important commercial waterway in Myanmar (about 1350 miles or 2170 km) long. In this study, research area is started from May-Kha and Mali-Kha and terminated in Pyay (outlet). Study area is about 363280 km^2 and lie between north latitude 20° 22' and 28° 31' and east longitude 94° 56' and 98° 45'. It is covered by Kachin State, Mandalay Division, Sagaing Division and Shan State and Bago Division. The location of study area is shown in figure 1.

3. Background of the Study

Firstly, the RAS background file is created to delineate the flood prone area by using HEC-GeoRAS. HEC-RAS 5.0.1 is used to develop the flood prone area and Arc-GIS helps to develop the flood map and drought severity map for Ayeyarwady basin. As seen in figure 2, TIN map is the basic data to extract the flood plain area and it can be converted from DEM (30 m) resolution map by 3D conversion tool in ArcGIS 10.1. After extracting TIN maps, RAS layers are created in RAS Geometry tool in HEC-Geo RAS. RAS layers are stream centerline, bank line, flow path centerlines, XS cut lines, land use area and manning's n values [1, 2, 13]. HEC-RAS is the hydraulic model which is used to calculate the water-surface profiles, steady-state, gradually-varied flow analysis. The data needed are geometry data and steady flow data. Geometry data are required for any of the analyses performed within HEC-RAS. The basic geometric data consists of establishing the connectivity of the river system, cross-section data, reach length, energy loss coefficient [1, 2]. In this study, river cross section data are obtained from Directorate of Water Resources and Improvement of River System (DWIR). Input cross section data at the upstream and downstream for each flow regime are assigned with Latitude and Longitude. Cross-section lines spacing are not equal and data are not available in every station which is used as the terrain data. Steady flow analysis consists of flow regime, boundary condition, and peak discharge information. Peak discharges are simulated by the HEC-HMS model. Flow regime is divided by 7 portions in Ayeyarwady River (main river). May Kha River is considered as main river and Chindwin, N Mai Kha, Ta Paing, Shwe Lei, Chaungmagyi and Dokehtawady are considered as tributary rivers. River slope is input data for boundary condition in HEC-RAS model which are taken from the basin characteristics in HEC-GeoHMS model.

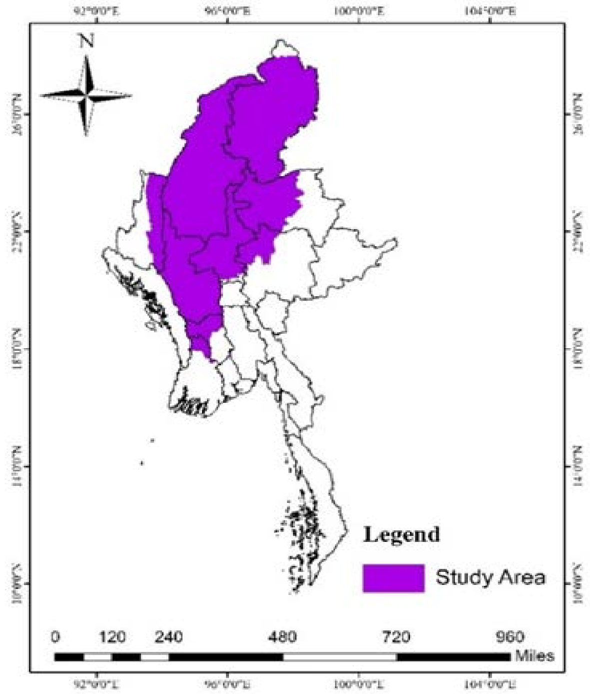


Figure 1: location of the study area

Drought severity map for Ayeyarwady basin can be extracted based on severity values for all rainfall stations by using Spline spatial interpolation method in ArcGIS 10.1. The drought severity map for 12-month scale SPI is shown in figure 3.

4. Materials and Methods

In this study, HEC-RAS model is chosen to delineate the flood prone area in Ayeyarwady Basin. To find the peak flow for ungauged stations, fifteen years daily rainfall data of Ayeyarwady Basin that approached the twenty-two rainfall stations during the period of 2001 to 2014 data were obtained from Department of Hydrology and Meteorology, Myanmar. The classification of soil map is obtained from Department of Agriculture and Irrigation, 2014 landuse map is extracted according to LANDSAT 7 data and six classes of landuse type are considered. And then, curve number (CN) grid map is developed for Ayeyarwady Basin. After preparations these data set, peak flow simulation is done by using HEC-HMS model which was used as the input flow data in HEC-RAS software to develop the flood prone area. River cross-section data are also one of the input parameter in hydraulic modelling which were taken from Directorate of Water Resources and Improvement of River System (DWIR). River geometry data, Manning's n values data are extracted in Arc-GIS and then flood prone area for Ayeyarwady Basin is carried out by using Arc-GIS and HEC-RAS. According to the landuse classification map, the forest area in 2000 year is more than the 2014 year. To know the flood reducing area in Ayeyarwady Basin, flood map was developed according to two scenarios. As a reference scenario, flood area is developed by using 2014 landuse classification and then flood area is developed by using 2000 year landuse classification for future scenario.

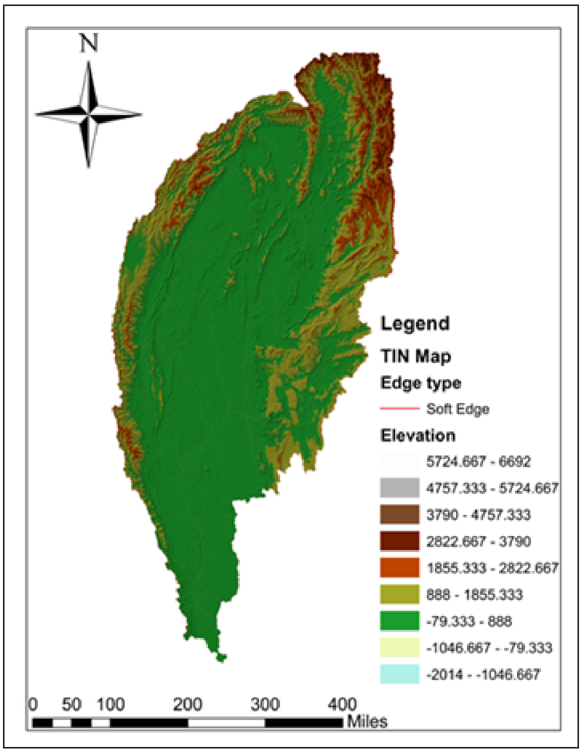


Figure 2: TIN map for Ayeyarwady Basin

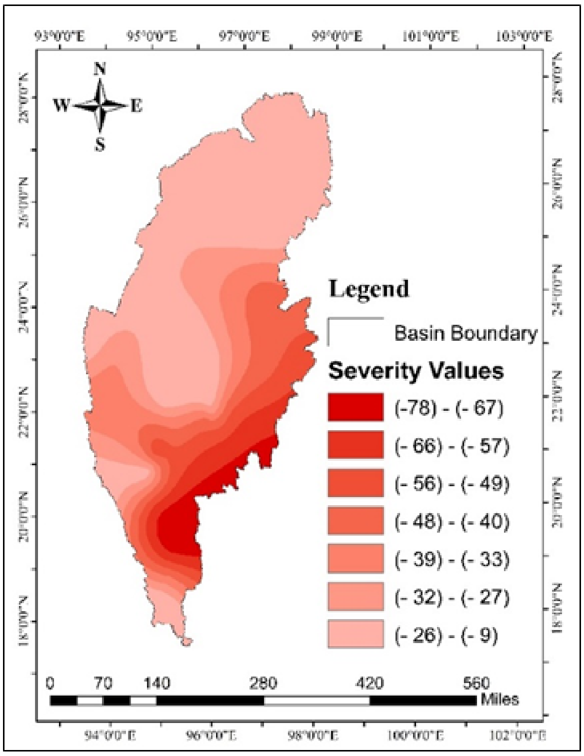


Figure 3. drought severity map for Ayeyarwady Basin

For the spatial characterization of drought, standardized precipitation index (SPI) is calculated by DrinC software and then spatial interpolation (Spline) method in Geographic Information System (GIS) is used to generate drought severity maps. According to SPI results and drought severity map, Aunglan (s= 68.96), Magway (s= 60.77) and Nyaungoo (s= 49.26) regions are the most severity regions which are termed as drought prone area. In case of drought mitigation in drought prone area, rainwater harvesting method is proposed to mitigate the drought event. The two scenarios of rainwater harvesting methods are consider in this study. The first scenario is to collect rainwater from the roof top and then conveying these water by using downspout pipe to the ground or underground storage tanks. Another scenario of rainwater harvesting is directly recharged to the ground from different types of landuse layers.

4.1. Rainwater Harvesting

There are many way to harvest the rain water. So, the rainwater can be harvested by the following ways. They are storing rain water for direct use, recharging ground water aquifers, from roof top run off and recharging ground water aquifers with runoff from ground area [11].

A. Collected Rainfall from Rooftop

Rainfall can be collected directly from the roof top. The rain water harvesting system consists of the basic components. They are catchment area, coarse mesh / leaf screen, gutter, downspout or conduit, first flushing device, filter, storage tank and recharge structure. The design catchment area is selected 37.16, 111.48 and 222.96 m^2 and the materials type of GI sheet, aluminum sheet, cement slabs and tiles are mostly found in pilot area. The amount of rainfall can be collected from the rooftop by using the following Equation (1).

$$\text{Collected Rainfall} = \text{Area} \times \text{Rainfall} \times \text{Coefficient} \tag{1}$$

The rain water collected on the roof top is transported down to storage facility through down spouts or conduits. Conduits can be of any material like PVC, GI or cast iron. The number of downspout pipe can be calculated by using the Equation (2).

$$\text{Number of downspout} = \frac{\text{Roof drainage area}}{\text{Maximum roof drainage area served per downspout}} \tag{2}$$

B. Rainwater Recharge Volume

Rainwater can be recharged directly to the ground from landuse classification layers. The ground cover types for three pilot area are classified by using LANDSAT 7 data which are residential, roads, trees, lawns and agriculture, water body and bareland. The area of the ground cover portions are shown in the following table 1. The recharge volume can be calculated by difference of precipitation volume and runoff volume. Runoff volume can be calculated by using the product of surface area, rainfall depth and runoff coefficient [10,15]. The average monthly rainfall for Aunglan, Magway and Nyaungoo regions are shown in figure 4. The average annual rainfall for Aunglan, Magway and Nyaungoo regions are 898.09 mm, 790.55 mm and 707.7 mm respectively. The maximum rainfall for these three regions are found in June and September. According to the soil classification map of Myanmar, four classes of hydrologic soil group are combined in Aunglan region. The soil groups of Aunglan region are group A (16.662%), B (45.672%), C (4.523%) and D (33.143%). Similarly, Magway[1] and Nyaungoo[2] regions have three type of soil group which are A (3.9%)[1] (7.96%)[2], B (20.42%)[1] (63.936%)[2] and D (75.69%)[1] (28.941%)[2]. The soil map and landuse map of these three pilot regions are shown in figures 5 and 6.

5. Results

Watershed delineation and basin characteristics are extracted by using Arc-GIS 10.1. Streamflow simulation results by using HEC-HMS are visualized as graphs, summary tables and time series tables for all hydrologic elements. After simulation of the peak flow values for all sub-basins, flood plain delineation and flood map for Ayeyarwady basin are developed by using HEC-RAS and Arc-GIS. The flooded regions are part of Mandalay, Sagaing, Monywa, Pakokku, Magway, Yaynanchaung and Thayet. The flood area using 2014 landuse classification is about 10414.18 km^2 and the flood area using 2000 landuse classification is about 7081.03 km^2. The flood area is reduced 32% in Ayeyarwady Basin by changing the landuse area. In case of drought, SPI, severity, intensity, duration, frequency and return periods for three pilot areas are calculated. Rainwater harvesting is the best way to mitigate the drought problem.

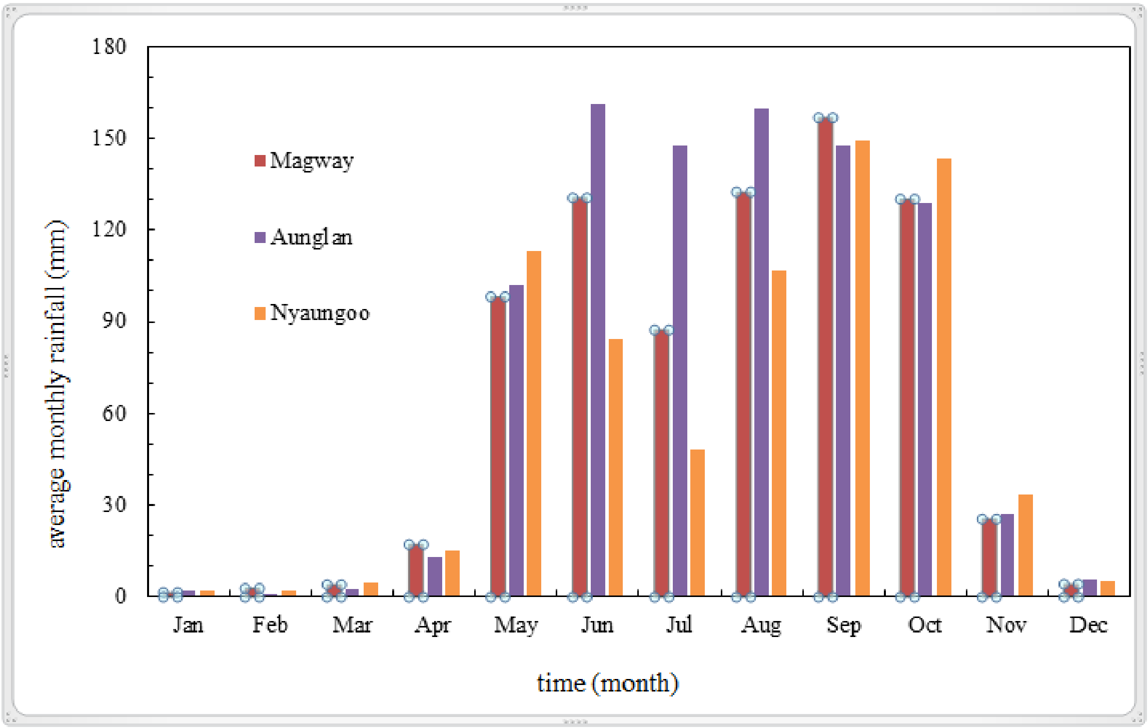
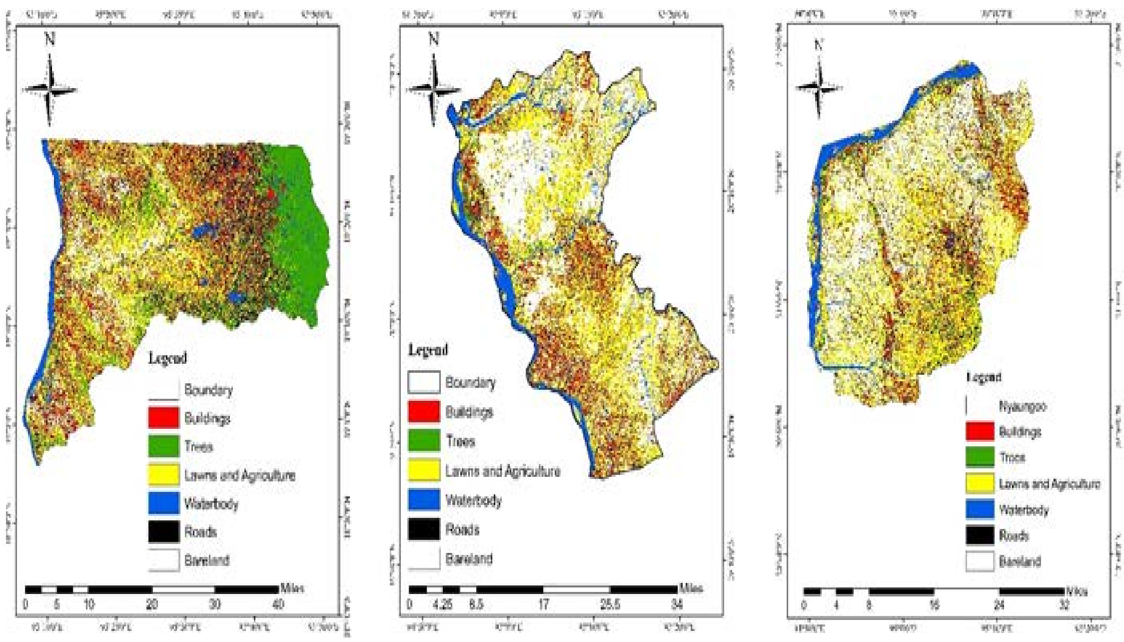


Figure 4: average monthly rainfall for Aunglan, Magway and Nyaungoo



(i) (ii) (iii)

Figure 5: landuse map for (i) Aunglan (ii) Magway and (iii) Nyaungoo

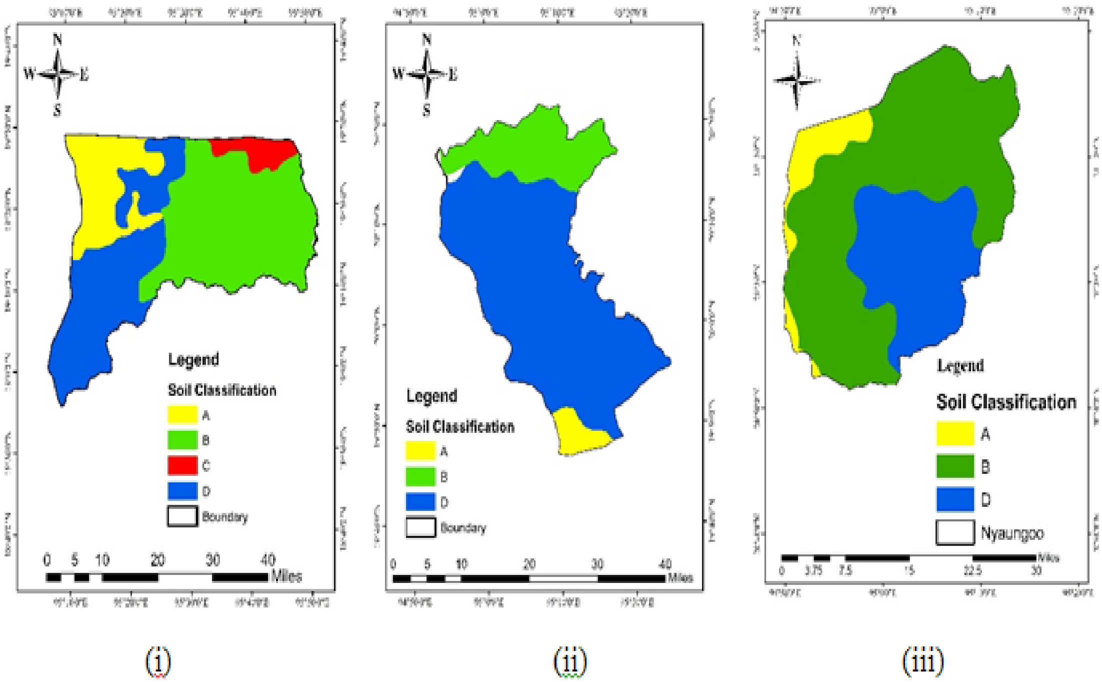


Figure 6: Soil map for (i) Aunglan, (ii) Magway and (iii) Nyaungoo

Table 1: landuse classification area of the Aunglan, Magway and Nyaungoo regions

City	Residential (km^2)	Trees (km^2)	Lawns and Agriculture (km^2)	Water Body (km^2)	Road (km^2)	Bareland (km^2)	Total (km^2)
Aunglan	464.416	528.582	937.701	231.594	427.845	259.496	2849.634
Magway	218.807	24.566	687.695	155.035	163.308	638.715	1888.126
Nyaungoo	151.302	32.976	605.939	110.309	175.296	495.528	1571.349

5.1. HEC-RAS Results

Flood map for Ayeyarwady basin is developed by using Arc-GIS. Firstly, flood plain delineation process is done in HEC-RAS modeling which is the input file to develop the flood map. The flood plain delineation of the Ayeyarwady Basin is shown in figure 8. The flood plain results in HEC-RAS as in a form of XYZ perseptive plot and then, water surface is delineated using the Arc-GIS. After the delineating process, flood map for the Ayeyarwady basin is developed. Flood palin delineation, water surface delineation and flood map of the Ayeyarwady basin is shown in figures 7, 8 and 9.

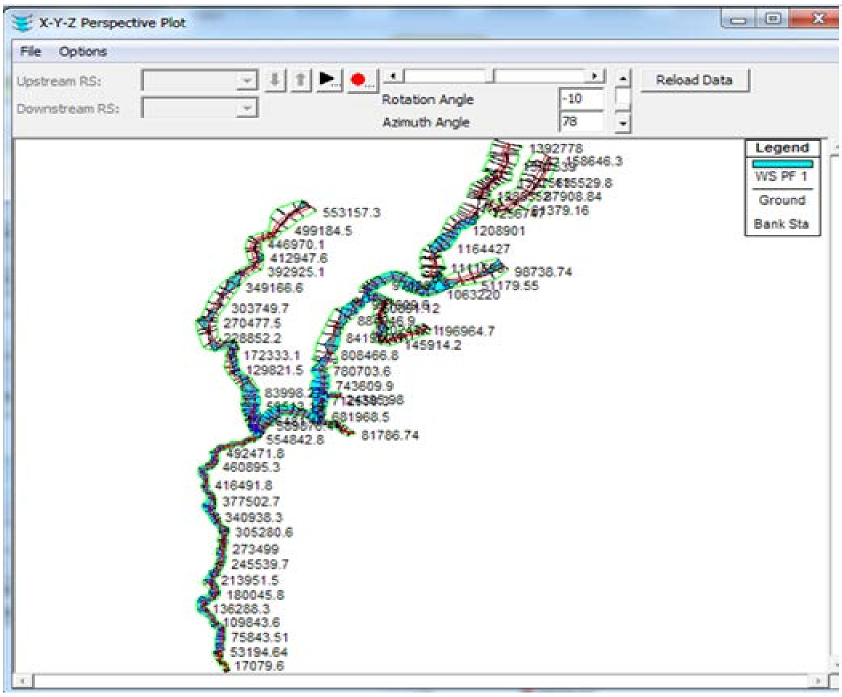
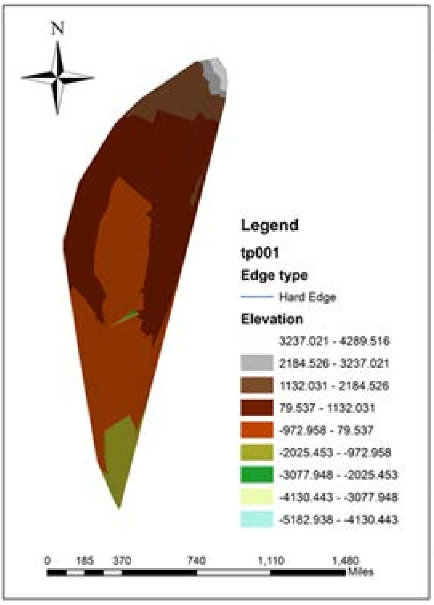


Figure 7: flood plain delineation in HEC-RAS



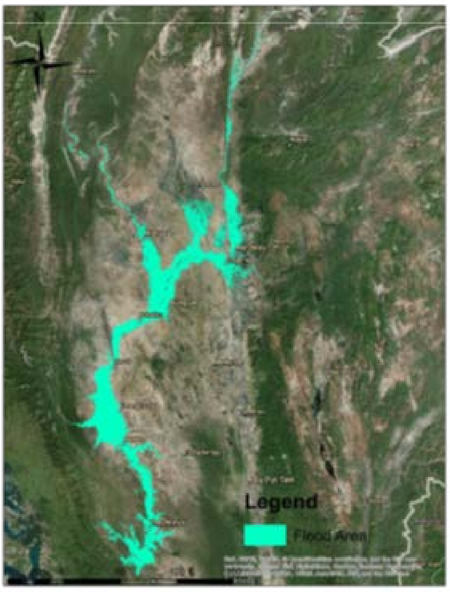


Figure 8: water surface delineation **Figure 9:** flood area using 2014 landuse

5.2. Flood Mitigation Measure

By using these landuse classification data (2014 map), extract the curve number grid map and simulate the peak flow in HEC-HMS for Ayeyarwady basin. In this study, five classes of land use area are considered which are water body, closed forest, deciduous forest agriculture and bareland. The closed forest and deciduous forest area are 48.9% and 26.3% of Ayeyarwady Basin in year 2014 landuse classification data. The flooded area is about

10414.18 km^2 by using the 2014 landuse map. According to the landuse classification in 2000 year, which was 62.8% for closed forest and 28.05% for deciduous forest. The flooded area is about 7081.03 km^2 using 2000 landuse map. The flooded area is decreased about 32% in Ayeyarwady basin due to forestation. The comparison of landuse classification maps are shown in figures 10 and 11 and changes in area percent is shown in the following table 2.

Table 2: Comparisons of area (%) and change in percentage for landuse classification (2014 and 2000) of Ayeyarwady Basin

Landuse Types	Landuse Area according to 2000 LU map (km^2)	Landuse Area according to 2014 LU map (km^2)	Differences	Change in Percent	Remarks
Water Body	3766.52	2582.19	1184.33	31.44	Decrease
Closed Forest	226257.68	176352.57	49905.11	22.06	Decrease
Deciduous Forest	101028.48	94792.32	6236.16	6.17	Decrease
Agriculture	3039.48	6032.43	2992.95	49.61	Increase
Bareland	26027.68	80361.9	54334.22	67.61	Increase

CN grid map was extracted by using the 2000 year landuse data but soil map and the lookup table remain the same. CN values are increased compare with the value by computing with year 2014 landuse data. Comparisons of curve number grid map are shown in figures 12 and 13. The more increase the CN values, the less the runoff values. The following table 3 shows the percent increase of stream flow results by HEC-HMS. As seen in figure 14, the flooded area is about 7081.03 km^2 and the comparisons of flood maps are shown in figure 15.

5.3. Drought Mitigation Measure

Rainwater harvesting method is the best way to mitigate the drought problems. In this study, selected design roof top area for Aunglan, Magway and Nyaungoo are 37.16, 11.48 and 222.97 m^2 respectively. The following tables 4 and 5 show the maximum amount of collected rainwater per month from the different type roof top in selected three pilot regions by using Equation 1. Four types of roofing materials are considered in this study, which are GI sheet, cement slab, tiles and aluminum sheet. The coefficient of roofing material are 0.9 for GI sheet, 0.65 for cement slab, 0.75 for tiles and 0.85 for aluminum sheet respectively [11]. In the calculation of collected rainfall from roof, 0.135 m^3 is not considered as the collection and disposal of the first flush of water from a roof. According to the local rainfall hydrograph shown in figure 5, the maximum monthly rainfall occurred in June and September. Then, storage tank design and the selection of the gutter and downspout pipes are also determined in this study. The total number of required downspout pipes are calculated by using Equation 2.

Table 3: Change in percentage of stream flow Results for subbasin (SB) by HEC-HMS

Name	Peak Flow (CN by 2000 LU Map) (m^3/sec)	Peak Flow (CN by 2014 LU Map) (m^3/sec)	Difference	Percent Increase (%)	Name	Peak Flow (CN by 2000 LU Map) (m^3/sec)	Peak Flow (CN by 2014 LU Map) (m^3/sec)	Difference	Percent Increase (%)
SB-1	10550.9	11442.4	891.5	8.45	SB-26	5945.3	6663.6	718.3	12.08
SB-2	8300.9	8504.2	203.3	2.45	SB-25	5452.6	6379	926.4	16.99
SB-4	9078.1	9408.6	330.5	3.64	SB-28	4909.4	5757	847.6	17.26
SB-3	8771	8789.3	18.3	0.21	SB-27	5405.8	6341	935.2	17.30
SB-7	7605.6	7875.9	270.3	3.55	SB-30	9470.6	10655.7	1185.1	12.51
SB-6	7409.4	7733.7	324.3	4.38	SB-29	2562.4	4449.5	1887.1	73.65
SB-5	6797.2	7149.9	352.7	5.19	SB-31	2205	2396.6	191.6	8.69
SB-47	1405.2	1433	27.8	1.98	SB-32	6018.4	6990.1	971.7	16.15
SB-8	835.5	1128.5	293	35.07	SB-35	6988	6988.9	0.9	0.01
SB-9	665.7	764.7	99	14.87	SB-36	8044.8	9498.8	1454	18.07
SB-39	1064.9	1194.3	129.4	12.15	SB-33	4150.1	5158.9	1008.8	24.31
SB-40	884.1	936.7	52.6	5.95	SB-34	4238.3	4997.2	758.9	17.91
SB-42	1217.5	1355.5	138	11.33	SB-37	4049.5	4230.4	180.9	4.47
SB-41	633.2	705.5	72.3	11.42	SB-13	1617.6	1640.4	22.8	1.41
SB-45	1354.2	1653.4	299.2	22.09	SB-15	2500	2500	0	0.00
SB-44	1344.5	1691.2	346.7	25.79	SB-14	2000	2000	0	0.00
SB-43	1217.1	1604.8	387.7	31.85	SB-17	569.4	1026.3	456.9	80.24
SB-46	92.5	117.8	25.3	27.35	SB-16	639.6	702.1	62.5	9.77
SB-10	271	303	32	11.81	SB-18	640.8	779	138.2	21.57
SB-12	44.4	57.6	13.2	29.73	SB-19	361.3	503	141.7	39.22
SB-38	2373.3	3044.9	671.6	28.30	SB-20	607.8	758.3	150.5	24.76
SB-11	529.8	567.3	37.5	7.08	SB-21	719.1	850.7	131.6	18.30
SB-23	5442.5	7784.9	2342.4	43.04	SB-22	1868.2	2218.7	350.5	18.76
SB-24	4656.5	4974.6	318.1	6.83	Outlet	117435.9	124193.6	6757.7	5.75

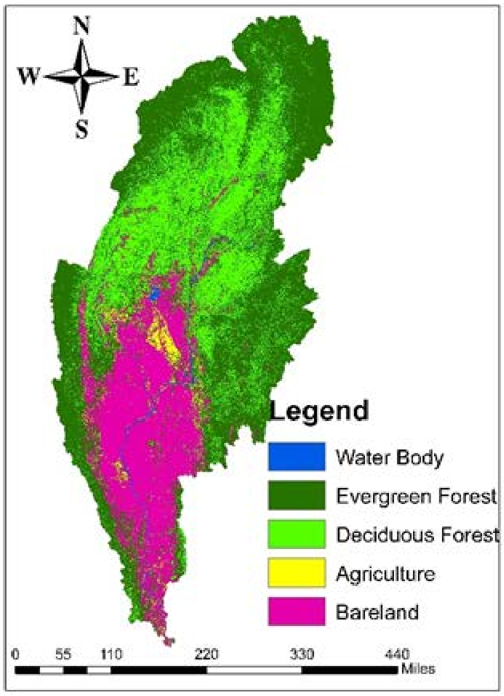


Figure 10: 2014 landuse classification map

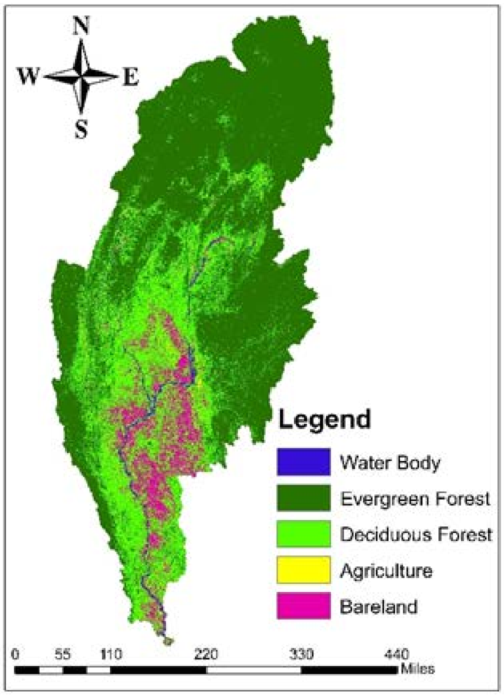


Figure 11: 2000 landuse classification map

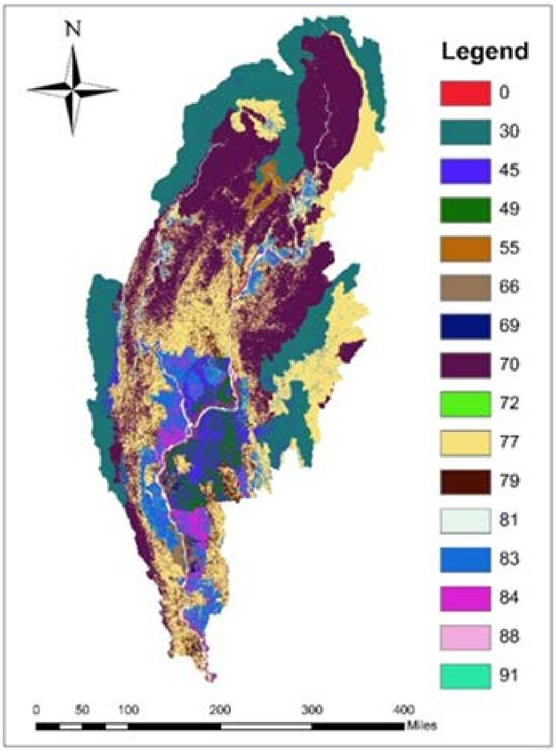


Figure 12: CN grid map by using 2014 landuse map

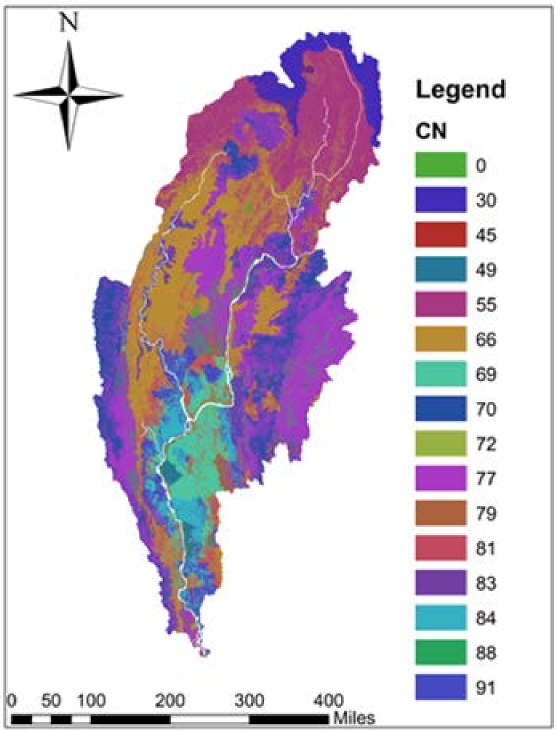


Figure 13: CN grid map by using 2000 landuse map

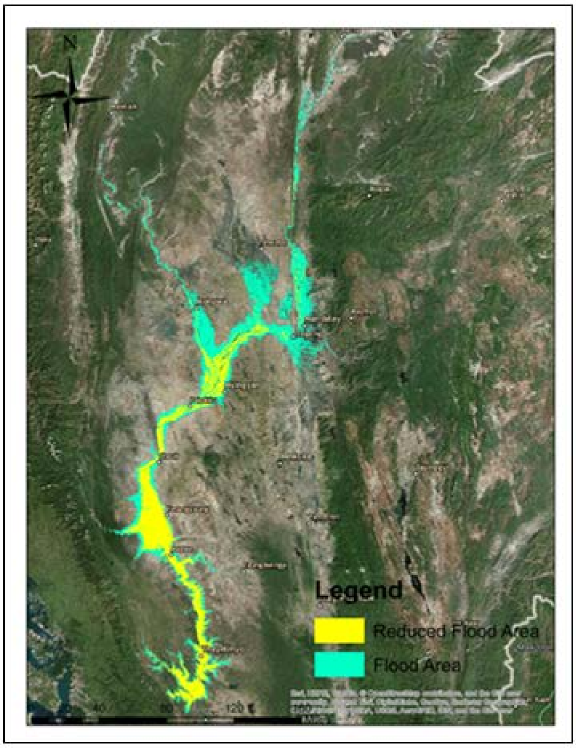


Figure 14: flood area using 2000 landuse **Figure 15:** flood area using 2000 and 2014 landuse

Table 4: Maximum water storage of different type of roof area and materials in Aunglan region

Roof Area (m^2)	Maximum Water Storage (m^3)			
	GI Sheet	Cement Slab	Tiles	Aluminium Sheet
37.16	5.258	3.760	4.359	4.958
111.48	16.043	11.549	13.346	15.144
222.97	32.220	23.233	26.828	30.423

According to the results, the average maximum monthly collected rainwater per household for 37.16 m^2 roof area is 4.423 m^3, 111.48 m^2 roof area is 13.539 m^3 and 222.97 m^2 roof area is 27.214 m^3. The typical tank design calculation is based on the results of average maximum monthly rainwater collected from different roofing materials. Free board 0.1 m is used to calculate the actual depth of storage tank. The following table 6 shows the typical tank dimension, and gutter size and the design of downspout size are shown in table 7. In the selection of gutter size and design, only K style gutter design is considered and selection of minimum downspout size are designed both square and rectangular type. Recharge volume is calculated by the difference of precipitation volume and runoff volume in that area. The runoff and recharge volume for different soil group are also calculated in this study. The runoff volume is calculated by the product of surface area, rainfall depth and runoff coefficient. The runoff coefficients for different soil group and ground cover are taken from USDA-NRCS Curve Number, 1986 which is seen in table 8 [10]. The results of the runoff volume for Aunglan, Magway and Nyaungoo regions are shown in the following tables 9, 10 and 11. Total runoff volume for Aunglan region is 2028.373 Mm^3 and total precipitation volume in that area is 2559.228 Mm^3. The recharge volume is 530.85 Mm^3 per year. Similarly, total runoff volume of Magway and Nyaungoo are 1273.339 Mm^3 and 887.209 Mm^3 and total precipitation volume are 1492.65 Mm^3 and1112.07 Mm^3. The recharge volumes are 219.312 Mm^3 and 224.863 Mm^3 per year.

Table 5: Maximum water storage of different type of roof area and materials in Magway and Nyaungoo regions

Roof Area (m^2)	Maximum Water Storage (m^3)							
	Magway				Nyaungoo			
	GI Sheet	Cement Slab	Tiles	Aluminium Sheet	GI Sheet	Cement Slab	Tiles	Aluminium Sheet
37.16	5.109	3.652	4.235	4.817	4.857	3.470	4.025	4.579
111.48	15.596	11.227	12.974	14.722	14.840	10.680	12.344	14.008
222.97	31.328	22.588	26.084	29.580	29.815	21.495	24.823	28.151

Table 6 : Typical Storage Tank Dimension for Different Roof Area

Roof Area (m^2)	Max Average Collected Rainfall (m^3)	Depth (m)	Area (m^2)	Length (m)	Width (m)	Capacity (m^3)	No[LxBxH]
37.16	4.423	1.20	3.69	2	2.00	5.2	1[2x2x1.3]
111.48	13.539	1.70	7.86	2.8	2.80	14.112	1[2.8x2.8x1.8]
222.97	27.214	2.00	6.80	2.6	2.60	14.196	2[2.6x2.6x2.1]

Table 7 : Typical Gutter Size and Minimum Downspout Size

Roof Area (m^2)	Gutter Size (mm) [in]	Number of downspout pipe	Minimum downspout size (mm [in.]) according to Gutter size	
			Rectangular	Square
37.16	100 mm [4 in.] K-style	1	50 x 75 [2 x 3]	75 x 75 [3 x 3]
111.48	100 mm [4 in.] K-style	3	50 x 75 [2 x 3]	75 x 75 [3 x 3]
	125 mm [5 in.] K-style	2	50 x 75 [2 x 3]	75 x 75 [3 x 3]
	150 mm [6 in.] K-style	1	75 x 100 [3 x 4]	100 x 100 [4 x 4]
222.97	150 mm [6 in.] K-style	2	75 x 100 [3 x 4]	100 x 100 [4 x 4]

Table 8 : Runoff coefficients for difference soil group and ground cover

Ground cover	Soil Group A	Soil Group B	Soil Group C	Soil Group D
100% impervious (parking lots, roof tops, paved sidewalks or pations)	0.98	0.98	0.98	0.98
Open space with grass cover < 50%	0.68	0.79	0.86	0.89
Open space with grass cover 50% to 75%	0.49	0.69	0.79	0.84
Open space with grass cover > 75%	0.39	0.61	0.74	0.80
Woods in fair hydroligic condition	0.36	0.60	0.73	0.79
Residential lot (1/4 acre)	0.61	0.75	0.83	0.87
Residential lot (1/2 acre)	0.54	0.70	0.80	0.85
Residential lot (1 acre)	0.51	0.68	0.79	0.84

6. Discussions and Conclusion

In this study, flood and drought mitigation measures are mainly considered in Ayeyarwady Basin. Firstly, peak flow values are simulated in HEC-HMS software which is the main input of the HEC-RAS to delineate the flood plain area. The main objective of this study is to reduce the flood area in Ayeyarwady basin. The curve number grid map is extracted by using the 2014 year landuse map, soil map and look up table then simulate the peak flow in rainfall- runoff model. The maximum peak flow at the outlet is 124193.6 m3/sec. After that, the main consideration of flood mitigation measure in research area is to reduce the flood area. So, reforestation is the best way to mitigate the flood problem. In year 2014, the closed forest is about 48.9% and deciduous forest is about 26.3% of the Ayeyarwady Basin so that total forest area is about 75.29. In the same way, the landuse classification in 2000 year was 62.8% for closed forest and 28.05% for deciduous forest of the Ayeyarwady

Basin. Curve number grid map is extracted again by using the 2000 year landuse map instead of 2014 landuse map without changing the soil map and lookup table.

Table 9 : Runoff volume calculation for different soil group and surface type in Aunglan region

Amount of Average Annual Rainfall in Aunglan =898.09 mm								
Surface Type	Soil Group - A		Soil Group - B		Soil Group - C		Soil Group - D	
	Area (km^2)	Runoff Volume (Mm^3)	Area (km^2)	Runoff Volume (Mm^3)	Area (km^2)	Runoff Volume (Mm^3)	Area (km^2)	Runoff Volume (Mm^3)
Water	91.591	80.612	194.189	170.910	16.281	14.329	162.122	142.687
Residential	13.559	4.384	383.312	206.549	62.529	40.994	68.905	48.887
Road	175.368	61.423	358.131	196.196	17.141	11.392	386.720	277.847
Trees	40.415	36.296	113.369	101.815	9.050	8.128	68.694	61.694
Agriculture	68.032	59.877	214.189	188.514	23.484	20.669	121.960	107.340
Bareland	85.663	52.314	37.769	26.797	0.339	0.262	135.690	108.457
Total	474.627	294.905	1300.958	890.781	128.825	95.774	944.091	746.912

Table 10 : Runoff volume calculation for different soil group and surface type in Magway region

Amount of Average Annual Rainfall in Magway =790.55 mm						
Surface Type	Soil Group - A		Soil Group - B		Soil Group - D	
	Area (km^2)	Runoff Volume (Mm^3)	Area (km^2)	Runoff Volume (Mm^3)	Area (km^2)	Runoff Volume (Mm^3)
Water	15.175	11.757	31.360	24.295	172.184	133.397
Residential	0.356	0.101	2.526	1.198	21.677	13.538
Road	27.121	8.362	144.927	69.889	515.398	325.956
Trees	8.236	6.511	38.913	30.763	107.525	85.003
Agriculture	10.967	8.497	25.374	19.658	126.912	98.323
Bareland	11.553	6.211	142.263	88.848	484.707	341.033
Total	73.408	41.438	385.363	234.651	1428.403	997.251

Table 11 : Runoff volume calculation for different soil group and surface type in Nyaungoo region

Amount of Average Annual Rainfall in Nyaungoo =707.7 mm						
Surface Type	Soil Group - A		Soil Group - B		Soil Group - D	
	Area (km^2)	Runoff Volume (Mm^3)	Area (km^2)	Runoff Volume (Mm^3)	Area (km^2)	Runoff Volume (Mm^3)
Water	10.063	6.979	77.757	53.930	63.455	44.010
Residential	5.268	1.342	10.753	4.566	16.941	9.471
Road	29.328	8.095	361.969	156.265	214.448	121.415
Trees	36.389	25.753	61.619	43.609	12.261	8.677
Agriculture	11.457	7.946	102.112	70.821	61.663	42.767
Bareland	18.971	9.130	390.553	218.357	85.853	54.076
Total	111.476	59.245	1004.764	547.548	454.619	280.416

The peak flow value at the outlet is 117435.9 m^3/sec. The stream flow value is reduced about 6757.7 m^3/sec. After simulation the peak flow value for all subbasin in Ayeyarwady Basin, flood maps are developed in hydraulic model by using the results of stream flow. The flooded regions are more evidenced in part of Mandalay, Sagaing, Monywa, Pakokku, Magway, Yaynanchaung and Thayet. The forest area in year 2000 is more than the area in year 2014. After passing more than a decade, the forest are depleted 22.1% for evergreen forest and 6.2 % for deciduous forest. Due to deforestation, the bareland area and agriculture area are wider about 68% and 49.6 % in Ayeyarwady Basin. According to the results, the flood area developed by using 2014 landuse is about 10414.18 km^2 and by using 2000 landuse is about 7081.03 km^2. The flood area about 3333.15 km^2 (32%) can be reduced by reforestation as the year 2000. Drought mitigation is also considered in this study and drought severity map is firstly extracted by using Arc-GIS. According to the drought severity map, the region of Aunglan, Magway and Nyaungoo have the high severity value than those of other regions as seen in figure 2. The regional area of Aunglan, Magway and Nyaungoo are 2849.634, 1888.126 and 1571.349 km^2 respectively. In this study, two methods of rainwater harvesting are considered. The first way is collected rainwater from the roof top and the second method is the rainwater recharged directly to the ground. The design roof area for three pilot area as 37.16, 111.48 and 222.97 m^2 and four type of roofing materials are considered. The average maximum collected rainwater per household for 37.16 m^2 roof area is 4.423 m^3, 111.48 m^2 roof area is 13.539 m^3 and 222.97 m^2 roof area is 27.214 m^3 respectively. Again, the rainwater is recharged from pervious area and runoff volume are determined according to the soil group in selected regions. The soil groups in Aunglan region are group A, B, C and D, Nyaungoo and Magway regions have soil group of A, B and D. The calculated runoff volume in Aunglan region is 294.905 Mm^3/year in soil group A, 890.781 Mm^3/year in soil group B, 95.774 Mm^3/year in soil group C and 746.912 Mm^3/year in soil group D respectively. Total runoff volume for Aunglan area is 2028.373 Mm^3/year and total precipitation volume in that area is 2559.228 Mm^3/year. So, the recharge volume in Aunglan is 530.85 Mm^3/year. Similarly, total runoff volume of Magway region is 41.438 Mm^3/year in soil group A, 234.651Mm^3/year in soil group B and 997.251Mm^3/year in soil group D. Same as the runoff volume in Nyaungoo region is 59.245 Mm^3/year in soil group A, 547.548 Mm^3/year in soil group B and 280.416 Mm^3/year in soil group D. So, the total runoff volume in Magway and Nyaungoo are 12173.339 Mm^3/year and 887.207 Mm^3/year. The precipitation volumes are 1492.65 Mm^3/year in Magway region and 1112.07 Mm^3/year separately. After that the recharge volume in Magway region is 219.312 Mm^3/year and 224.836 in Nyaungoo region respectively. As a conclusion, reforestation is considered for flood mitigation measure and rainwater harvesting method is considered for drought mitigation measure. This study will help to reduce the flood area and drought mitigation as rainwater harvesting for Ayeyarwady Basin.

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