Study on the Effect of Surface Water Allocation for Hydropower in the Upper Ayeyarwaddy River Basin

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***Abstract*—**This paper presents the study on the effect of surface water allocation that links between the hydrologic and economic from water used in power production for the Upper Ayeyarwaddy River Basin. Water and green growth requires that water allocation should be constrained by the amount of water that is available at a specific time. Aquarius (a modeling system for river basin development planning model) software is used in this paper. Aquarius is a state-of-the-art computer model devoted to the temporal and spatial allocation of water among competing uses in a river basin. The required data for this study are collected from the department of meteorological, the electric power and irrigation. In this study, monthly discharges are collected from five stations. Reservoir and hydropower plant are considered as case study. A flow network is created in the network worksheet screen (NWS) using Aquarius in this paper. Water system components (WSC) palette and tools palette that make up a flow network are a series of nodes and links are processes in Aquarius software. Nodes represent the demand sites and links represent the linkage between river reaches. Model results show that reservoir are released the natural flows, outflows, storages and evaporations and hydropowers are generated turbine flows, hydropower generation, hydrogenation benefit. The maximum hydropower generation of hydropower is Yeywa hydropower (32%) and the minimum hydropower generation is Zawgyi II hydropower (2%). The purpose of this study is the hydrologic and economic linkages of surface water allocation for hydropower in the Upper Ayeyarwaddy River Basin.

***Keywords*—**Flow network, Links, Nodes, Water allocation, Water System Components (WSC).

I. Introduction

WATER shortage is one the real challenges facing many countries in the world. As water scarcity has increased globally, water allocation plans and agreements have increasing significance in resolving international, regional and local conflicts over access to water. In Myanmar, the process of population growth, urbanization and industrialization are occurring at an ever increasing phase at every year. According to report from Asian Development Bank, total water available water resources in Myanmar are around 89% for agriculture, 10% is for municipalities and 1% is for industries. Approximately 91% of the total water withdraw comes from surface water. The water allocation evaluates the hydrologic and economic linkages from water used by hydropower for the Upper Ayeyarwaddy River Basin. The Ayeyarwady River flows through the heartlands of Myanmar. It is Myanmar's largest river (about 2170 km long) and it is the most important commercial waterway. It originates at the confluence of the Mali Hka and N'Mai Hka rivers in Kachin State. Flow network are used to determine water allocation for hydropower in the Upper Ayeyarwady Basin.

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II. Study Area

The principal river of Myanmar is the Ayeyarwaddy. The Ayeyarwaddy River runs through the country from north to south and empties into the Andaman Sea. It lies between 20˚ 22' to 28˚ 31' north latitude and 94˚ 56' to 98˚ 45' east longitude. Upper Ayeyarwady River is 1310 km length and catchment area is 193.30 (000'sq-km). Annual surface water is 227.920 km^3.The study area is covered by Kachin State, Mandalay Division, south eastern part of Sagaing Division and western part of Shan State. The study area occupies 169917 km^2. The basin has eight hydropower plants such as Kinda, Sedawgyi, Yeywa, Thaphanzeik, Zawgyi II, Shweli I, Dapein I and Chibwenge. The location map of study area is shown in Figure 1.

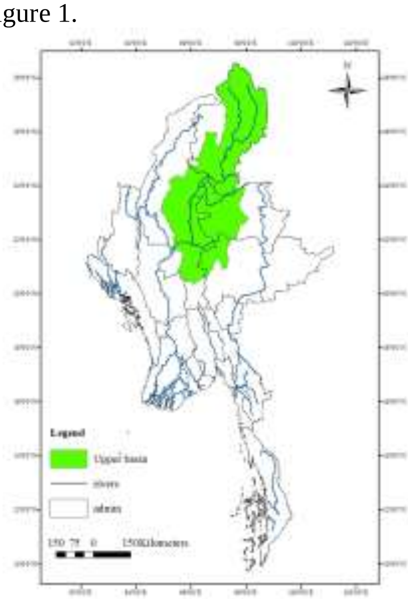

Fig. 1 Study Location

III. Data and Methodology

Water allocation is the sharing of water among users. Water managers face an increasing challenge in allocating available surface water flows among competing uses in a river basin. Over the years, a number of computer based tools that employ the allocation of water among competing uses have be developed. Among them, Aquarius (a modeling system for river basin development planning model) solves water allocation problems using an economical criterion that is based on demand functions.

A. Conventional Households by Source of Lighting for Society

This study is described that social factor is contributed to receive information for green growth. There are four types of lighting in this study such as electricity, solar system/energy, generator (private) and other. The proportion of households by main source of lighting in Kachin State, Mandalay Division, Sagaing Division and Shan State is considerable. Of the total of 1323191 households in Mandalay Division, 520838(40%) households had electricity, 107304(8%) had solar system/energy, 146520(11%) had generator (private) and 548529(41%) had others. In Shan state and Kachin state had 1169569 and 269365 households. The total households in Sagaing Division are about 1096857, with 265131(25%) of electricity, 130005(12%) of solar system/energy, 180883(16%) of generator (private) and 520838(47%) of others. This is illustrated in Table I.

TABLE I: Proportion of Households by Main Source of Lighting

State/Division	Electricity	Solar system/ energy	Generator (private)	Other
Mandalay	40%	8%	11%	41%
Shan	34%	26%	2%	38%
Kachin	31%	17%	13%	39%
Sagaing	25%	12%	16%	47%

B. Description of Aquarius Model

Aquarius was developed by Diaz and Brown (1997) to describe an analysis framework rather than a single dedicated model for water allocation. The water allocation problem solved by Aquarius, involving a set of exponential/linear/constant demand functions, requires a complex nonlinear objection function. The computational model developed here employs Aquarius to represent the hydropower in Upper Ayeyarwady River Basin as a network of 21 demand and supply nodes for surface water. Using a monthly time step to optimize the benefits derived in a single year, quantitative data describe the physical characteristics of these demand and supply nodes, including the spatial relationships among upstream uses, return flows, and downstream outcomes. Economic data describe the demand curves and social marginal benefit for allocations of water to various uses. The software Aquarius requires incoming water inputs as monthly data.

C. Model Input Data

The model's input data are divided into physical and economic data. The model's required input data are meteorological data, reservoir data, hydropower data and economic data. The brief methodology for preparation of the data is described as follows

- Physical Data: The physical data consist largely of the dimensions and operational characteristics of the system components such as maximum reservoir storage capacity and powerplant efficiency.

Economic Data: The economic data consist mainly of the demand functions of the various water uses competing for water within the river system. Monthly prices for energy are assumed equal for all months and for all power facilities.

IV. Model Application and Results

In order to apply Aquarius model to the upper Ayeyarwady basin, the major steps involved are data preparation, a flow network, physical data and economic data. The incoming water inputs data requires as monthly data. Model data for these reservoirs include the initial and final storage volumes, minimum and maximum storage capacities. Specific area storage and elevation-storage curves describe the monthly fluctuation in the volume of water stored. Aquarius facilitates the interpretation and analysis of all that information through readily accessible graphical output display formats.

A. Creating a Flow Network

The upper ayeyarwaddy River basin is represented by the flow network in Figure 2, in which the water flows from left to right. The basin comprises five water source subbasins such as Machanbaw, Myitkyina, Katha, Thebeikkyin and Sagaing. The natural flows in the system are regulated by eight reservoirs: Kinda, Sedawgyi, Yeywa, Thaphanzeik, ZawgyiII, ShweliI, DapeinI, and Chibwenge. Hydropower is generated using releases from these eight reservoirs. These powerplants operate directly connected to the reservoir. Additional nodes and links can be added to a network, but links can only be placed between existing nodes.

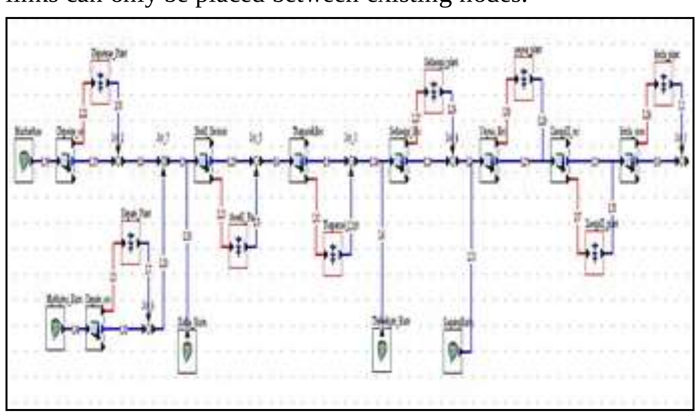

Fig. 2 Schematic Map of Aquarius Model for Reservoir & Hydropower Plant of Upper Ayeyarwady Basin

B. Natural Flows

In this study, the flow characteristics of the upper Ayeyarwaddy River basin are analysed based on 10 years (2005 – 2014) mean monthly flow at five stations, which was obtained from meteorological department. For the base model, the supply of water follows an average hydrologic regime as reflected in 10 years monthly discharge data. These flow data is used for estimating natural flows. Figure 3 is shown for natural flows of Sagaing, Thebeikkyin, Katha, Myitkyina and Machanbaw Basin by using Aquarius model. According to model result, the average monthly natural flows are 2673 MCM for Machanbaw, 7238 MCM for Myitkyina, 12006 MCM for Katha, 12286 MCM for Sagaing and 15248 MCM for Thebeikkyin Basin.

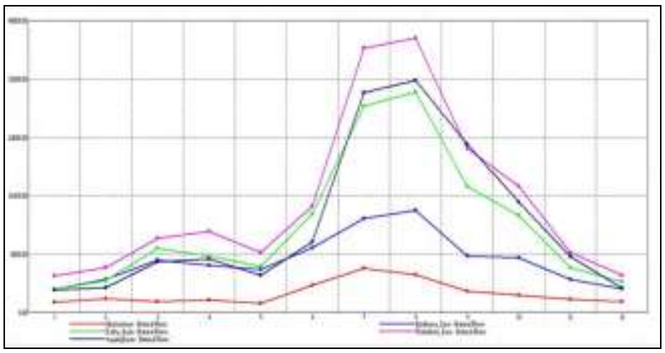

Fig. 3 Natural Flows for Sagaing, Thebeikkyin, Katha, Myitkyina and Machanbaw Subbasin

C. Reservoirs Water Use

Of course, Reservoirs play an important role during the process of allocating water in the basin. The modeled water demand is considered as storage reservoirs. For each reservoir AQUARIUS requires the corresponding physical characteristics (i.e., minimum and maximum volume, elevation vs storage and area vs storage functions), the operational characteristics (i.e., volumes at the initial and final) as well as the operational constraints. Elevation versus storage function is used by $E=c_1S^{d1}$ (as a power function). Surface area versus storage function is used by $A=c_2S^{d2}$ (as a power function). Initial and final storage, minimum and maximum storage are based on power plant operational constraint. Chipwinge reservoir regulates natural flows contributed by the Machanbaw subbasin. The flow of Myitkyina subbasin is also given to the Dapein I reservoir. The graphs in Figure 4 and 5 show the natural flows, outflows, storages and evaporations from the Chipwinge and Dapein I reservoir. The average inflow are about 2673 MCM and 7238 MCM in Chipwinge and Dapein I Regulated flows from the Machanbaw, Myitkyina and Katha subbasin enter Shweli I reservoir and then enter Thaphanzeik Reservoir. Figure 6 and 7 indicate the results of the water supply, water demand, storages and evaporation losses from the Shweli I and Thaphanzeik reservoir.

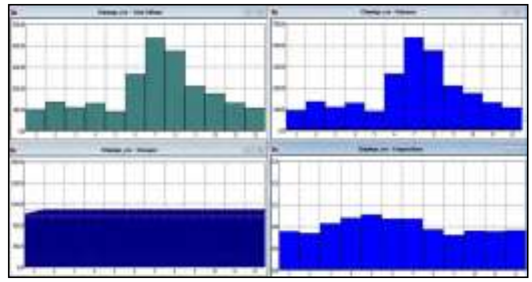

Fig. 4 Results of Aquarius model for Chipwinge Reservoir

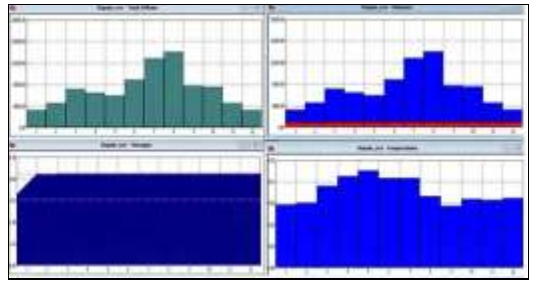

Fig. 5 Results of Aquarius model for Dapein I Reservoir

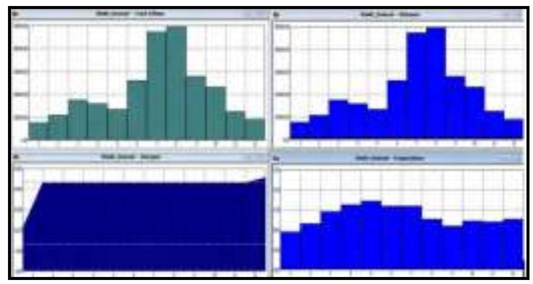

Fig. 6 Results of Aquarius model for Shweli I Reservoir

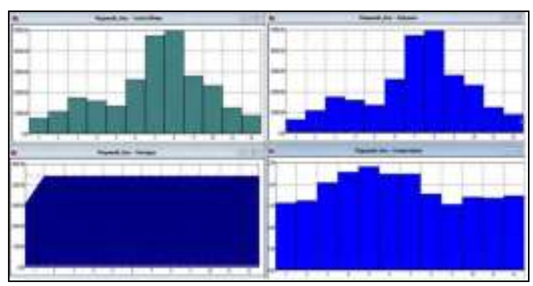

Fig. 7 Results of Aquarius model for Thaphanzeik Reservoir

The above three subbasin are found meeting the Thebeikkyin subbasin in the middle part and flow to the Sedawgyi reservoir. The results from the Sedawgyi reservoir display in Figure 8. The flows from the above four subbasin and Sagaing subbasin supply to Yeywa, Zawgyi II and Kinda reservoir. The output variables of inflows, releases, storages and evaporations from the Yeywa, Zawgyi II and Kinda reservoir are represented by Figure 9, 10 and 11. Evaporation losses represent a small amount of water when compared to the total inflows to the reservoirs. The maximum loss is less than 1%. The maximum average inflow is about 49338 MCM in Yeywa reservoir.

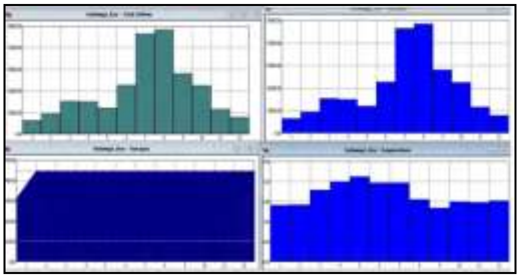

Fig. 8 Results of Aquarius model for Sedawgyi Reservoir

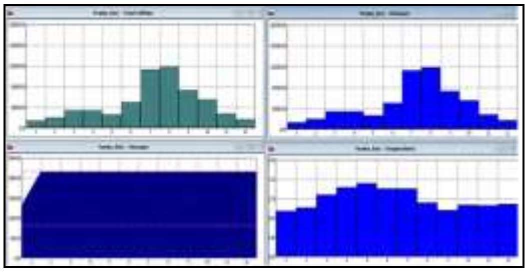

Fig. 9 Results of Aquarius model for Yeywa Reservoir

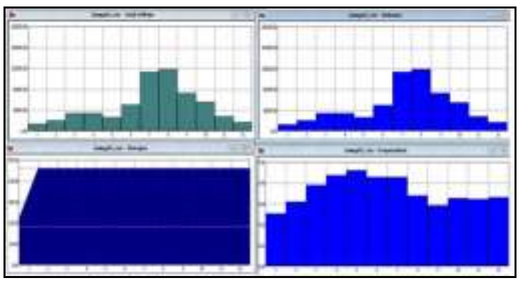

Fig. 10 Results of Aquarius model for Zawgyi II Reservoir

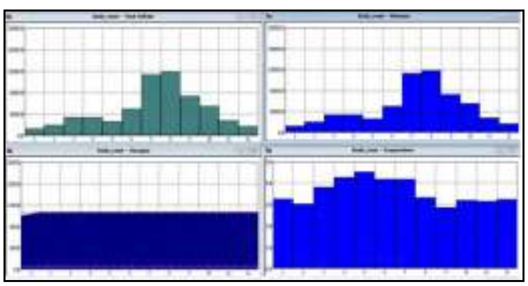

Fig. 11Results of Aquarius model for Kinda Reservoir

D.Hydropower Water Use

The foremost water use in the basin is power generation. Physical characteristics related to power plant such as installed capacity, design discharge, effective head and power production is collected from the electric power station. The generated electrical energy, P (KW) is approximated by P (KW) =9.8ηQH. The energy rate function (*erf*), which calculates the amount of energy (in kilowatt hours) generated by the plant per unit volume of water released through its turbines (in cubic meters) during a unit period of time (one hour), which is expressed in and *erf* (kWh m)=1/367ηH. Benefit from water used in power production is estimated using the above two equation. Plants operate directly connected to their reservoirs. The Chipwinge reservoir supplies water for Chipwinge powerplant. Dapein I reservoir outlet conveys water into Dapein I Hydropower. Figure 12 and 13 presented the results of turbine flows, hydropower generation, and hydrogenation benefit from Chipwinge and Dapein I Hydropower. The average monthly power plant flows are 105 MCM for Chipwinge and 1014 MCM for Dapein I. The average benefits of Chipwinge and Dapein I Hydropower are 12% and 19% respectively.

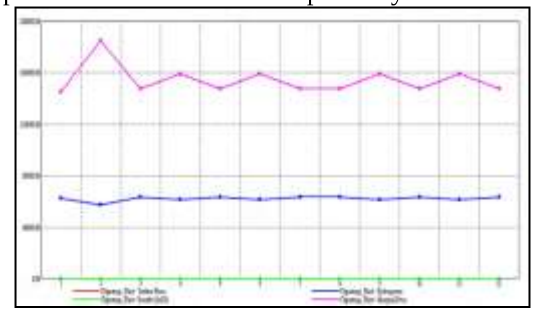

Fig. 12 Results of AQUARIUS model for Chipwinge Hydropower

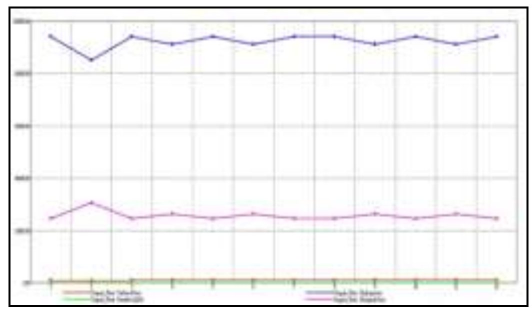

Fig. 13 Results of AQUARIUS model for Dapein I Hydropower

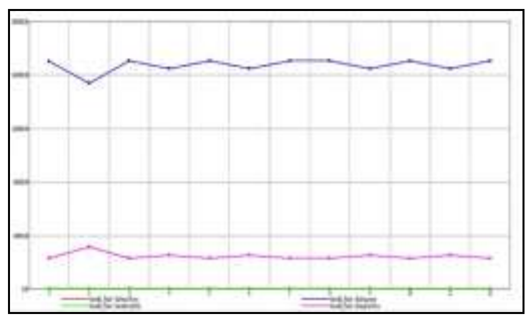

Fig. 14 Results of AQUARIUS model for Shweli I Hydropower

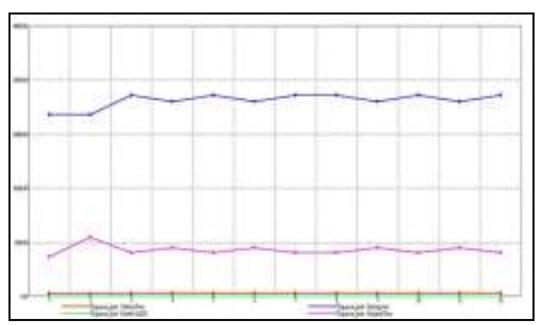

Fig. 15 Results of AQUARIUS model for Thaphanzeik Hydropower

Outflows from the Shweli I and Thaphanzeik reservoirs are fed into Shweli I and Thaphanzeik plant. The outcomes of analyses from the Shweli I and Thaphanzeik hydropower are illustrated by the graphs in Figure 14 and 15. The power productions of Shweli I plant are more than 5% of

Thaphanzeik plant (25%). The results generated by model showed that the average monthly power plant flows of Thaphanzeik and Shweli I are 497 MCM and 730 MCM.

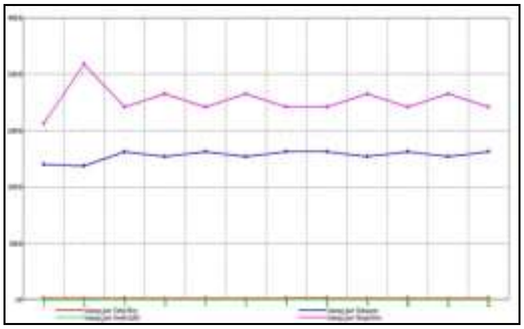

Fig. 16 Results of AQUARIUS model for Sedawgyi Hydropower

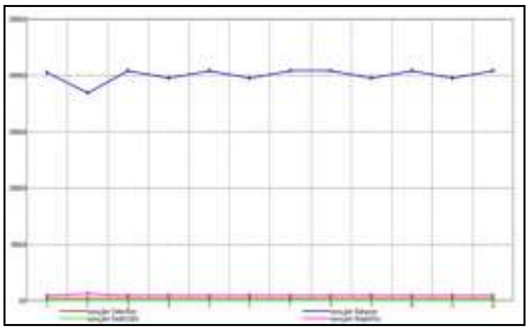

Fig. 17 Results of AQUARIUS model for Yeywa Hydropower

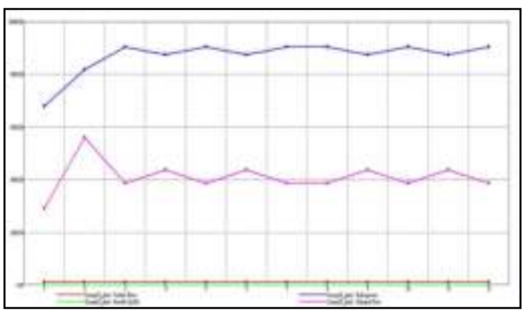

Fig.18 Results of AQUARIUS model for Zawgyi II Hydropower

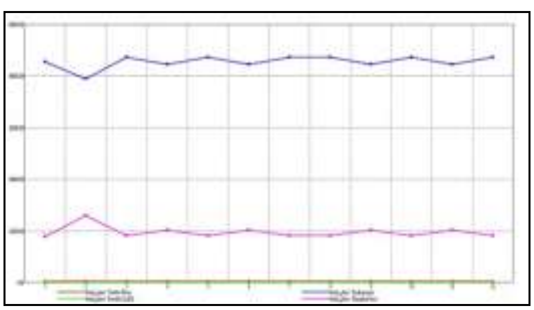

Fig. 19 Results of AQUARIUS model for Kinda Hydropower

There is releases water from Sedawgyi reservoir into Sedawgyi hydropower. The average powerplant flow is about 237 MCM in Sedawgyi Hydropower. The variation in power production and benefit from the Sedawgyi Hydropower describes in Figure 16. The average monthly power plant flow is about 237 MCM for Sedawgyi. Releases from the Yeywa , Zawgyi II and Kinda reservoir are used to generate power at Yeywa , Zawgyi II and Kinda Hydropower. According to model result, the average turbine flows are about 2209 MCM, 130 MCM and 294 MCM in yeywa, Zawgyi II and Kinda hydropower respectively. Figure 17, 18 and 19 represented the results from powerplant flows, hydropower, benefits and marginal prices from the Yeywa, Zawgyi II and Kinda Hydropower.

V.CONCLUSION

This study was undertaken to illustrate the water allocation of hydropower for the upper Ayeyarwady river basin with the application of Aquarius model. It is considered eight hydropowers and eight reservoirs for the upper Ayeyarwady river basin. The proportion of households using electricity, solar system/energy, generator (private) and other as the main source of lighting is represented for social factor. Aquarius model is generated that the water allocation and economic from water used in power production. For reservoirs water use, the average monthly powerplant flows are 130 MCM for ZawgyiII, 237 MCM for Sedawgyi, 497 MCM for Thapanseik, 294 MCM for Kinda, 105 MCM for Chipwinge, 1014MCM for Depain, 730 MCM for ShweliI and 2209 MCM for Yeywa. The percentages in power production are about 2, 3, 5, 8, 10, 15, 25 and 32% for these eight hydropowers. The maximum power production for Yeywa hydropower is about 32%. The minimum power production is Zawgyi II hydropower (2%).

To conclude above, there are eight reservoirs in this study. All of them, Yeywa is the biggest capacity and Zawgyi II is the smallest capacity. These values play a crucial role in water allocation mechanism. Within this case study, there is to investigate the surface water allocation for hydropower in upper Ayeyarwady river basin with the economic, environment and social factor.

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