Estimation of River Discharge at Ungauged Catchment using GIS Map Correlation Method as Applied in Sta. Lucia River in Mauban, Quezon, Philippines

Monjardin, Cris Edward F., Uy, Francis Aldrine A., Tan, Fibor J.
School of Civil, Environmental and Geological Engineering, Mapua Institute of Technology, Manila, Philippines

cefmonjardin@mapua.edu.ph, faauy@mapua.edu.ph, fjt@mapua.edu.ph

Abstract. This paper presents use of GIS Map Correlation Method, a novel method of Prediction of Ungauged Basin, which is used to estimate the river flow at an ungauged catchment. The PUB Method used here intends to reduce the time and costs of data gathering procedure since it will just rely on a reference calibrated watershed that has almost the same characteristics in terms of slope, curve number, land cover, climatic condition, and average basin elevation. Furthermore, this utilized a set of modelling software which used digital elevation models (DEM), rainfall and discharge data. The researchers estimated the river flow of Sta. Lucia River in Quezon province, which is the ungauged catchment. The researchers assessed 11 gauged catchments and determined which basin could be correlated to Sta. Lucia. After finding the most correlated basin, the researchers used the data considering adjusted parameters of the gauged catchment. In evaluating the accuracy of the method, the researchers simulated a rainfall event in the said catchment and compared the actual discharge and the generated discharge from HEC-HMS. The researchers found out that method showed a good fit in the compared results, proving GMC Method is effective for use in the calibration of ungauged catchments.

1. Introduction

Daily stream flow is essential before designing such structures because it is the one that can determine if a certain area or watershed is feasible or not for the project. Daily stream flow can be obtained easily from gaged catchments, however to those ungauged catchments, gathering stream flow information is still a challenge in hydrology [9]. This study will basically focus on the determination of stream flow from ungauged basins using PUB (Prediction at Ungage Basin) Method which is said to be more
accurate than The basin of Sta. Lucia which covers Mauban has a total land area of 10,059 ha. Sta. Lucia River covers Mauban Municipality in the Province of Quezon, the area is an ideal watershed where it is not yet overpopulated by people and many parts of it are still full of vegetation. And in the vicinity, it can be seen that large area is available for use if ever we want to put up a hydropower plant or reservoir.

Phil-LiDAR 1 is the project of DOST given to the SUC’s and HEI’s in the Philippines, and Mapua Institute of Technology is one of the selected schools and actually the only private HEI. This project gave opportunity to the researchers to acquire lots of data.

The study will predict the water availability of a certain ungage catchment using PUB Methods which were widely used in other countries but still not here in the Philippines. PUB Methods don’t require expensive equipment and data, most of the data that will be using here were all free such as Google Earth, which is a free satellite image by Google so it will really be much easier to conduct the study since all the data need are available. Determination of water availability is very important since not all the watersheds in the country are accessible; some are located in remote areas which are difficult to reach. It will be much better if there are certain studies that can predict the hydrograph without even going on the place itself because it can save time and money, since people don’t need to travel just to study the watershed and money since people don’t need to buy expensive equipment to validate the model as all that is needed is to rely on the previous available data [10]. This study can also help water industries that wants to put up a hydropower plant or a reservoir on a certain watershed.

Water availability is one of the major concerns of the people related to water engineering, and these industries have many projects in mind but they can’t pursue it since they don’t have the data about the watershed.[6] Nowadays, the government is getting very strict when it comes to the environment, industries can’t easily do a project without consent or permit. Many of the approved projects by the government were in the remote areas since it can’t affect many people in that location but the problem is they don’t have any data about that place. Water availability is one of the major things they need to know before the industries can conduct a certain project, and through PUB methods, without even going on the site and those expensive equipment the researcher can easily determine the hydrograph of a certain watershed.

Equipment and accessibility are one of the major things people need to consider when studying a certain watershed [8]. But since there is no such budget and time some become less interested in planning projects to the watersheds. With the use of PUB Method to determine water availability, many industries and even the Phil-Lidar 1 of DOST will benefit from it, since it won’t be needing any other expensive equipment just to calibrate a certain watershed model.

Determination of water availability has seen a great impact in many studies [3]. It is very convenient if this can be utilized using PUB methods in determining such parameters. The industries and government can save time and money since they won’t be needing expensive equipment; all they need to do is to apply and understand the proposed method. PUB Method was already widely used in other countries, it’s a big step for the Philippines if it also start using this because this is really a good thing to many future environmental projects.

1.1. Objectives
The main objective of this study is to use PUB Method in determining the water availability of ungauged catchments such as the Sta. Lucia Watershed. Specifically, the project seeks to:

a. Determine the water availability of ungauged catchments.

b. Come up with own PUB Method (GMC Method)

c. Suggest a method to Mapua Phil-Lidar 1 to calibrate their model at ungage catchment

It is expected that this study would help many industries and government agencies in solving environmental issues. Water availability is one of the main concerns of everyone who are into water industry since it is the main requirement before a project can be established or not, and for the government agencies it is very helpful in terms of disaster preparedness.

Also, with the said methodology not only the cost will be lessened but also the safety of the people who will be conducting a study or project won’t be a problem because they don’t need to visit the site every time they can even rely on the image provided by Google Earth or if they want a clearer image they can ask an orthophoto in NAMRIA (National Mapping and Resource Information Authority).

Since most of the projects must be done on the upstream and as everyone already knows what the situations are there, many of the said areas are being occupied by New People’s Army and other Rebel groups.

Moreover, with the goal of determining water availability using PUB (Prediction at Ungaged Basin) Method it would be a good solution to the problems. The Philippines is encountering nowadays in the environment, having a model of a watershed is very important to predict the ever changing behavior of the environment.[11] Government agencies and water industries will be the ones who would be benefiting a lot from this study.

2. Methodology

The objective of this study is to estimate the water availability of a certain watershed without the use of rain gage and stream gages. Arc GIS and HEC HMS are the primary programs to use in the estimation since it will involve the study of maps, specifically land cover maps and the hydrologic cycle in the area. PUB Methods will be used to determine the flow hydrograph of Sta. Lucia, Quezon. Most of the data to be used here came from Phil-Lidar 1 and from open sources, then these data will be processed. Next thing is study the characteristics of the watershed and compare it to others then decide what PUB Method will be used. With the use of PUB Method the researcher can predict the hydrograph of an ungaaged basin that can be used to calibrate the said river.[1] Calibration is done using HEC-HMS’ optimization function. After calibration, next thing to do is to validate the accuracy of the model, this will determine the effectiveness of PUB Method used. Once the model is validated, it will now be the output of the study. Finally, an ungage basin calibrated using PUB Method without the use of modern technologies is produced.

Actual flow data will be gathered on site to test if the calibrated model using PUB Method is effective. If the actual data is almost similar to the simulated what the researcher can say that this PUB Method is efficient. The calibration and validation will be done with the help of HEC-HMS. To predict the flow at ungage basins is a challenge to many hydrologists and water resources engineers, so coming up with a certain method and proving its effectiveness is a milestone for them.[9] There were already
many studies from different countries about this PUB Methods but still no one conducted it here in the Philippines; it will be a good thing that with this paper the Philippines won’t be left behind in terms of this kind research study.

Figure 1. Flow chart for GMC Method.

In this PUB Method as illustrated in Figure 1, the researcher will make use of the other calibrated gaged basin model. The calibrated basin models’ properties will be compared to the property of the ungage catchment using land cover maps for land use, slope map for contours and soil maps for soil types. Using Pearson’s r correlation, the researcher will compare all the properties of the basins then identify which is/are the most correlated catchment that can be used to calibrate the ungage basin. Using these criteria, it will be the basis that can tell if a certain gage basin/s is correlated to an ungage basin. After identifying which is/are the most correlated basin, make use of that catchment as reference to calibrate the model. And, when the calibration is done, test the accuracy of the model using Nash-Sutcliffe test for goodness of fit.

3. Results and Discussion

In the study, the researcher considered 11 watersheds to know which among those basins is the most correlated one to Sta. Lucia Basin. These 11 watersheds were Lian, Maragondon, Canas, Ilang-Ilang, Binabang Molino, Bolbok, Rosario-Lobo, Catanauan, Pandanan, Vinas and Kilbay Catabangan. These watersheds were all located in Region IV-A “CALABARZON” where the Mapua Phil-Lidar 1 conducting their study. On the other hand, parameters considered in the correlation were the following: land cover, slope, curve number and average basin. These parameters are the ones that might affect the river flow in a certain basin, therefore if the researcher can identify all these parameters and compare to each river basin they can easily identify which river basin is most correlated to Sta. Lucia River.

Figure 2. Digital Elevation Model.
3.1. Slope

First parameter to be considered is slope since this determines how fast the water inside the watershed will flow, the steeper the slope the faster the travel will be. The researcher utilize the data they have specifically their SAR-DEM that has a cell size of 10m by 10m which is very efficient for watershed modelling. Using this DEM, the researcher created slope maps that helps to identify which river basin is the most correlated to Sta. Lucia. Region IV-A is mountainous that is why slope inside each watershed is very significant for the watershed’s behaviour and must be considered.

![Slope Map](image)

**Figure 3.** Slope Map.

All percentages were given above and compared with respect to Sta. Lucia. Out of the 12 watersheds, two showed significant relationship with Sta. Lucia that was Catanauan which gave an average percent error of 14.13%, and the other was Rosario-Lobo which showed 8.72% percent error. Since the two said watersheds is the most correlated with respect to Sta. Lucia; they will be prioritized for comparison to the next parameters that will be considered.

3.2. Curve Number

Curve number is a parameter that mainly determines the infiltration rate of a certain watershed. Curve numbers are dependent to what type of soil is present in the watershed. Determining the curve number of the watersheds is not that difficult because such data were already gathered by other researchers and shared online at PhilGIS.org there is already an available shape file for the entire Philippines indicating different types of soil a certain area has. There is also another data made by other researchers as well that gives the curve number for every type of soil. This data were very helpful in different kinds of study like this one. With the help of Arc GIS, the researcher easily created a Soil Map to determine the correlation of the watersheds to Rosario-Lobo.

As reflected in the calculation above, other watersheds show a significant difference with Sta. Lucia that it goes beyond 100%. Only Rosario-Lobo gives a percent difference below 100%. That’s why, one can easily say that in terms of curve numbers Rosario-Lobo is the most correlated basin to Sta. Lucia.

3.3. Land Cover
Land cover is one of the important parameters that must be considered when comparing watersheds. Land cover determines the land use of different areas inside the watershed. This must be considered because land use plays an important role to what will be the response of a watershed when rainfall occurs. Many studies show that as land cover of a certain area changes, it shows significant effect to its river flow. The data used in here came from Philgis.org a reliable source resources which is very helpful to different studies. The researcher downloaded the shapefile from Philgis. This shapefile contains digitized boundary for different types of land use of the whole Philippines.

By figures, Sta. Lucia is mostly brushland which is 89.61% of the watershed area, and 9.93% of it is cultivated area. Comparing Sta. Lucia to other watershed, Rosario-Lobo shows a significant similarity with Sta. Lucia having 81.35% of the total watershed area as brushland and 10.04% of it is cultivated area. Therefore, the researcher found out that among the 11 watershed Rosario-Lobo shows significant similarity in terms of its land cover to Sta. Lucia.

### 3.4. Average Basin elevation

| River Basin | Average Basin Elevation | % difference with Sta. Lucia as Reference Gage |
|-------------|-------------------------|-----------------------------------------------|
| Sta Lucia   | 128.8861601             | 0                                             |
| Maragondon  | 248.476991              | 92.78795396                                   |
The average basin elevation of the 11 watersheds were also computed and compared with Sta. Lucia. Considering its % difference, there were four basins that can be compared to Sta. Lucia which were Ilang-Ilang with 1.41% difference, Kilbay-Catabangan with 19.57% difference, Bolbok with 21.7% difference and Rosario-Lobo with 40.22% difference. With the figures shown those four were the ones close to Sta. Lucia in terms of average Mean Sea Level.

Considering the four most important parameters of a watershed the researcher found out that among the 11 watersheds the most correlated one to Sta. Lucia is Rosario-Lobo. Rosario-Lobo showed a significant homogeneity with Sta. Lucia in terms of its slope profile, curve number, land cover and average basin elevation. With this, the researcher can use the data gathered in Rosario-Lobo, which is a gaged basin to calibrate the watershed model at ungaged site which is Sta. Lucia.

![Figure 6. Calibration of Sta. Lucia using data from Rosario-Lobo.](image)

To validate the accuracy of the data, the researcher gathered actual flow rate in the river during an event (Rainfall). The simulated hydrograph by HMS must coincide with the actual hydrograph gathered from the river.

The efficiency of the model with respect to the actual flow were tested using the three formulas used for determination of goodness of fit (Nash Sutcliffe, Percent Bias and RMSE-observation Standard Deviation Ratio). The results were significant, in the calculation above Nash-Sutcliffe had 0.5 which is satisfactory, Percent Bias was 2.16% which is Very good and RSR was 0.71 which is satisfactory. All values were above the minimum requirements therefore the researcher can conclude that the model simulation has a good fit with respect to the actual data.
Test for goodness of fit was made using the following equation: Nash-Sutcliffe, Pbias and Root Mean Square Error.

The efficiency of the model with respect to the actual flow were tested using the three formulas used for determination of goodness of fit (Nash Sutcliffe, Percent Bias and RMSE-observation Standard Deviation Ratio). The results were significant, in the calculation above Nash-Sutcliffe had 0.5 which is satisfactory, Percent Bias was 2.16% which is Very good and RSR was 0.71 which is satisfactory. All values were above the minimum requirements therefore the researcher can conclude that the model simulation has a good fit with respect to the actual data.

4. Conclusion

In this study the researcher came up with a method that will help in the calibration of the watersheds that don’t have its own rain gages and automatic water level sensors, it is called GIS Map Correlation (GMC) Method that uses base maps and digital elevation models such as SAR and LiDAR data to compare the physical/geographical characteristics of the watersheds and determine which were correlated to each other.

Sta. Lucia Watershed Model was calibrated using the data from Rosario-Lobo basin, this method can be used as long as there is an available data, specifically the DEMs which is one of the important parameters that needs to be considered. This method can help Mapua Phil-LiDar 1 to accomplish their project Flood Hazard Modeling of Region IVA.

To check the efficiency of the model calibrated with the use of GMC method, the researcher gathered actual discharge data. This data was compared with the simulated discharge of the HMS model. For the actual discharge, the peak flow was 0.3 m$^3$/s while the simulated peak discharge was 0.3 m$^3$/s.

The researcher test the goodness of fit of the model using Nash-Sutcliffe, PBIAS and RSR. The results were the following Nash-Sutcliffe had 0.5 which is satisfactory, Percent Bias was 2.16% which is Very good and RSR was 0.71 which is satisfactory. Having those values indicate that the simulated data had a good fit with respect to the actual data.

5. Recommendation

The research was all about watershed models, in the study the researcher consider five parameters to determine which watershed is most correlated to Sta. Lucia and the result is Rosario-Lobo. Sta. Lucia watershed model were already established using the data gathered from a gaged basin which is the Rosario-Lobo since the two watershed were correlated to each other. For the duration of the study, the Philippines is experiencing El niño which became a challenged for the researcher in gathering data. The researcher is recommending that the model’s accuracy in forecasting discharge flow must be checked further, checking the reliability of the model will increase the proof that it can be used for Disaster Management programs. Checking the accuracy of the model will just give an idea how effective it is. Since all the data used in this study specifically the parameters used, came from other study done in the past therefore it may not be up to date considering the recent condition therefore the researcher is recommending that data must be updated so accurate correlation can be done.

6. Acknowledgement
This material was inspired by the work done by University of the Philippines – Diliman Phil-LiDAR 1 Program. The authors are thankful to the people behind it, to the Department of Science and Technology - Philippine Council for Industry, Energy and Emerging Technology Research and Development (DOST-PCIEERD) and to Mapúa Institute of Technology Phil-LiDAR 1 Project for all the support to this research.

References

[1] Kentel, E., (2009). Estimation of River Flow by Artificial Neural Networks and Identification of input vectors susceptible to producing unreliable flow estimates. Journal of Hydrology, 375 (2009) 481–488.

[2] Kentel, E. and Ergen, K. (2015). An Integrated Map Correlation Method and Multiple-Source sites Drainage-Area Ratio Method for Estimating Streamflows at Ungauged Catchments: A Case Study of the Western Black Sea Region, Turkey. Journal of Environmental Management, 166 (2016) 309e320.

[3] Yoshida, K. and Ishikawa, T. (2014). Flood Hydrograph Estimation Using An Adjoint Shallow-Water Model. Journal of Hydro-environment Research 9 (2015) 429e440.

[4] Mutie S.M., Mati B, Home P., Gadain H. and Gathenya J. (2006). Evaluating Land Use Change Effects On River Flow Using Usgs Geospatial Stream Flow Model In Mara River Basin, Kenya. Center for Remote Sensing of Land Surfaces, Bonn, 28-30 September 2006.

[5] Getachew, H. and Melesse, A. (2012). The Impact of Land Use Change on the Hydrology of the Angereb Watershed, Ethiopia. International Journal of Water Sciences.

[6] Mazvimavi, D. (2003). Estimation of Flow Characteristics of Ungauged Catchments Case Study in Zimbabwe. Ph.D. Thesis, Wageningen University.

[7] Granato, G. (2012). Estimating Basin Lagtime and Hydrograph-Timing Indexes Used to Characterize Stormflows for Runoff-Quality Analysis. U.S. Geological Survey, Reston, Virginia.

[8] Cooper, R. (2002). Determining Surface Water Availability in Oregon. State of Oregon, Water Resources Department.

[9] Archfield, S. A. and Vogel, R. M. (2010). Map Correlation Method: Selection of a Reference Streamgage to Estimate Daily Streamflow at Ungauged Catchments. Water resources research, vol. 46, w10513.

[10] Gamble, C. (1989) Techniques For Simulating Flood Hydrographs And Estimating Flood Volumes For Ungaged Basins In East And West Tennessee. U.S. Geological Survey Water-Resources Investigations Report 89-4076.

[11] Gamble, C. (1989) Techniques For Simulating Flood Hydrographs And Estimating Flood Volumes For Ungaged Basins In East And West Tennessee. U.S. Geological Survey Water-Resources Investigations Report 89-4076.