Modification of basic hydrology formulation based on an approach of the rational method at field measurement

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Abstract. The rational method was a simple technique for estimating the design discharge of a small watershed and can be used in a probabilistic approach. The main parameter in the rational method formula was the C coefficient. The rational method was the primary method for determining the peak discharge from surface runoff flow. At the end of the dry season and the beginning of the rainy season, it placed an automatic water level recorder and automatic rain gauges for the initial water level. This field research aimed to correct a simple hydrological formulation with field measurements and build a numerical rainfall modelling based on rainfall simulation, infiltration, land use, and flow parameters according to the relationship model of precipitation. The hypothesis in this study, the basic formulation of hydrology, is simple: it requires experience to fit the theoretical hydrological formula so simply (simplicity). The theory needs to be simplified because it is an experience of field necessary to explain.

keywords: model, precipitation, probabilistic approach, runoff flow

1. Introduction

The rational method was simply a method to determine peak discharge from runoff—time of concentration equivalence with the duration in the drainage area. The rational method could estimate peak flow and indicate the land-use change to know the hydrology effect. The rational method will provide a ratio between inflow and outflow under conditions of specific rainfall duration, proportional to the time of concentration in the watershed. Weaknesses in this previous study are that this rational method's results are tough to use in determining storage detention time without making a hydrograph unit graph. The shape of the hydrograph unit depends on the temporal variation of rainfall and the specific characteristics of the catchment.

Another difficulty is that one type of hydrograph unit form is challenging to use as a reference for all catchment types. The main parameter in the formula of the rational method is the coefficient C [1]. The rational method is a simple technique for estimating the design discharge of a small watershed [2] in a probabilistic approach. The application of the rational method is a simple formula related to the production of potential watershed runoff, the average rainfall intensity for a certain length of time (time of concentration), and watershed drainage area [2]. The main parameters in this rational method formula Method produced from each modelling calibrate using the daily discharge recorded at the automatic water level recording. The interpretation of streamflow variations adapted to catchment
Characteristics is the main topic in hydrological research for catchment development or streamflow management. [3]. Catchment characteristics depend on the volume of runoff. A runoff coefficient value of 0.20 according to the conditions and composition of soil types and land use in the study area. In small areas (about 100-200 acres or 40-80 ha), estimating drainage channels in cities [4]. Remarks on applying a more straightforward method for calculating peak flow at catchment areas. Peak flow is related to the spatial-temporal distribution and intensity of rainfall, time of concentration, and curve number. One catchment characteristic is the time, water to reach the catchment outlet. The rational method calculates peak flow using rainfall intensity, runoff coefficient, and catchment area. There is also a relationship between runoff coefficient and curve number but does not consider peak flow in other previous studies. Therefore, alternately peak flow for water catchments that do not use rational methods and information about rainfall, time of concentration, and curve number can determine the relationship between runoff coefficient, precipitation, and curve number [5]. Stated that the runoff hydrograph at the outlet of the urban catchment area depends on variations in rainfall, the process of rainfall-runoff in the catchment area, and the hydrograph routing of the pipe.[6] With computers, complex models can simulate complete runoff hydrographs and generate flow rates and hydraulic gradients at various nodes of the sewer network. However, the authors adopt the previous research method, water level monitoring, and manual rain gauges.

This field research aimed to correct a simple hydrological formulation with field measurements and build a numerical rainfall modelling based on rainfall simulation, infiltration, land use, and flow parameters according to the relationship model of precipitation. Analysis of rain characteristics includes rainfall intensity, excess rainfall, and rain area. This proposed research aims to apply this research with minor catchment conditions with existing watershed parameters. Contribute to rational methods, a correction number used in the ungauged catchment with typical rainfall height and land use/land cover. A review of previous research to obtain a novelty in this study modified the theoretical formula based on field measurements with a rational method approach assumed by infiltration parameters, land use, rain, and flow.

The research focuses on the hydrological cycle based on data measurement in the field. It estimates the runoff coefficient based on the modified rational method, which extends the rational method. Furthermore, on the following page is table 1 of the originality of this research (state of the art). The theoretical formula of the rational method determination of peak discharge estimation (\( Q_p \)) using the rational method began in the 1880s. Although the rational method is considered simple, this method is still effective for estimating peak discharge in small watersheds. The runoff coefficient (\( C \)) is the main parameter for the rational method, and there are various ways to assess the runoff coefficient. [7]. Research Hypothesis, hydrological formulas are so simple that they require theoretical hydrological formulas. Hydrological formulas are so simplified that field measurements are needed to correct the formulas.

2. Materials and Method

2.1 Research Area

The research area in this study is an intermittent river, Kali Lanang, in the Kediri area. The location of Kediri Regency, which is flowed by several rivers or natural channels throughout the year, flows in. One of them is Kali Lanang. In the rainy season, the area around the river has the potential to experience flooding and inundation. The research location is in the region Kediri Regency, East Java Province, Latitude coordinates: -7°57’55.08” and Longitude: 12°1’37.92” with an area of 1,386.05 kilometers square.

Based on the topography, Kediri Regency includes 4 (four) groups based on the location, namely altitude above 0 meters - 100 meters above sea level. Stretches an area of 32.45%, a size above 100 meters - 500 meters above sea level stretches an area of 53.83%, an altitude above 500 meters - 1,000 meters above sea level stretches an area of 9.98%. A measurement above 1,000 meters above sea level
pushes an area of 3.73%—the location of Kediri Regency, which is flowed by several rivers or natural channels throughout the year.

The catchment area of the Lanang river is 92,276 square kilometers, and the size of the river is 40.37 km, so that the width of the watershed to calculations. The width of the river equals 2,285 kilometers.

![Figure 1. Kali Lanang catchment area](image)

Research begins with an initial survey to observe and justify the type of river. The catchment delineation is also defined by topographic divides between two or more adjacent catchment basins, flow direction, flow accumulation, and pointing sampling points spatial data from the map. The method of determining the location of the automatic water level recorder placement is by using the site survey method according to the manual of the hydrology—Horton method for determination infiltration rate.

2.2 Data collection

Overlay process performed using ArcGIS. This study contains administrative boundary digital data, digital rainfall data, digital topographic map data, RTRW digital map data, flood hazard maps, Kediri Regency soil type maps, and field observations. At the GIS stage, it is the stage to review whether the data previously has errors or not. If the information has errors, then it needs to be re-digitized. If the data is correct, then it can be continued to the following process. After going through the editing process, an overlay process or merging of some data is carried out to get the analysis results. The watershed analysis is carried out based on the results obtained from the overlay results (Figure 2).

3. Results and discussion

3.1 Data Processing

Based on data processing results using GIS, the following soil types for the Lanang watershed area. The soil types in this watershed are soil types with the suborder VITRANDS. The water retention at 1500kPa for air-dried soils is less than 15%, and for non-drained soils, less than 30%. Ustivitrans has a unique moisture regime. Typic Ustivitrands is another Ustivitrands. (Keys to soil taxonomy) Arenic Eutrudepts: another part of Eutrudepts that has a texture class (fine earth fraction) of coarse sand, sand, fine sand, loamy coarse sand, loamy sand, or fine loamy sand in a horizon layer with a depth of 50 cm of mineral soil surface. Another soil type is typic Eutrudepts. The geological characteristics of the Kediri Regency area classify into several parts according to the development and planning agencies of Kediri Regency, the western part of the Brantas River, which is the hilly slopes of Mount Wilis and Mount Klotok, most of which are infertile areas. The Central part is a very fertile lowland crossing the Brantas River from south to north, dividing the Kediri Regency area. The eastern part of the Brantas River is a barren hill that stretches from Mount Argowayang in the north and Mount Kelud in the south. This data processing is shown in Figure 3.
Field survey

Literature review

Data Collection

Start

Brantas Watershed Map

SHP Indonesian river stream

Topography map

Soil Map

Landuse map

Plotting data and digitize

River stream direction

Soil type determination

Land use determination

Infiltration Rate Horton Method (Mahendra, 2012)

Hydrological soil group

Runoff curve number (CN) catchment

Estimation Direct runoff Difference (%) Zelelew, (2017)

Cross-validation method (Zhang, 2021)

End

Figure 2. Flow chart
Based on the topography, Kediri Regency divides into 4 (four) groups based on the area, namely the altitude above 0 meters - 100 meters above sea level stretching an area of 32.45%, altitude above 100 meters - 500 meters above sea level stretching an area of 53.83%, altitude above 500 meters - 1,000 meters above sea level stretches 9.98%, and altitudes above 1,000 meters above sea level stretch for 3.73%. The contour map of the Lanang catchment is shown in the following Figure 4.

The pattern of land use as agricultural land for food crops (paddy fields) according to data from the Development and Planning Agency of Kediri Regency is as follows, having an area of 47,786 hectares or about 34.48% of the total area. Then the land for fields/fields is 27,199 Ha (± 19.62%), the land use designation for the yard has an area of 4,316 Ha (±3.11%). In comparison, the land-use allocation for community forest is 187 Ha (± 0.13 %), plantation land use is 8,536 Ha (±6.16%), and other dryland uses are with a total area of 50,581 Ha (±36.5%). From the results of map data processing with GIS, land use in the Lanang watershed has settlements or villages/hamlets by 32%, from land use that the rice fields are 28% and industrial forest plantations are 11%. From the land-use of dry land with shrubs 1% and water bodies 0%. The land-use map resulting from GIS processing is shown in the following Figure 5.
Figure 5. Land use in the Kali lanang catchment area

3.2 The formula of rational method theoretical

The determination of peak discharge estimation \((Q_p)\) using the rational method began in the 1880s. Although the rational method is considered simple, this method is still effective for estimating peak discharge in small watersheds. The runoff coefficient \((C)\) is the main parameter for the rational method, and there are various ways to estimate the runoff coefficient.

The rational method theory formula given is \[ Q = F.C.I.A \] (1)

Where:
- \(q\) = peak discharge \([L^3/T]\)
- \(F\) = unit conversion factor
- \(C\) = dimensionless runoff coefficient
- \(i\) = rainfall intensity for the duration equal to catchment concentration-time \([L/T]\)
- \(A\) = catchment area \([L^2]\)

Testing on this formula results in the product of rain intensity and catchment area unit \([L^3/T])\) so that the rate of inflow catchment is given \(iA\) with a steady rate duration. Where the outflow is \(q\), and the unit is consistent where \(F = 1\). The runoff coefficient \(C\) is expressed in terms of the ratio between inflow and outflow \([7]\).

The rational method was initially developed to estimate peak discharge as an initial assumption for the design of drainage channels and culverts. Furthermore, the rational method used has the formula\([7]\) \[ Q_{PR} = mOCI A \] (2)

Where \(C\) is the runoff coefficient (non-dimensional) while \(I\) is the average rainfall intensity (mm/hour or inch/hour) and \(A\) is the drainage area (in hectares or acres). At the same time, \(m_0\) is the dimensional correction factor where the value is \(1/360 = 0.00278\) in SI units or \(1.008\) in Imperial units.

3.3 Calibration with the Nash method and the RSME method

The placement of the automatic water level recorder is generally the placement of the probe\([8]\). The water level should meet the following criteria.

1. The location of the hydrometric station on a river segment with a parallel flow pattern shows no significant difference in flow velocity along with the flow view.
2. The installation of the water gauge is chosen at a location with a relatively regular and stable cross-section of the river channel. It is not easy for deposition to occur due to sedimentation or silt due to erosion.
3. The relationship between water level and discharge with sufficient sensitivity, small changes in discharge can be seen in changes in water level.
4. There is no plant disturbance and the influence of "backwater".
5. The location of the hydrometric station should be accessible for observers to visit at any time and under any circumstances.

Water level measurement determines the water level (or flow depth) of a river at a hydrometric station located at a specific time. The definition of time, in this case, is related to the period of measuring/recording the water level. Measurements are carried out at certain hours or continuously. A measuring board can be used within the first, often referred to as a manual measuring tool. Meanwhile, for constant data collection, an automatic water level recorder is used. Water level data can be achieved by reading the water level position on a scaled guess board at the time of measurement or reading the resulting water level fluctuation graph recording by an automatic water level recorder.

Rainfall is the most critical component in analysing hydrology. Rain will transform into river flow through surface, interflow, subsurface runoff, or even groundwater flow. The used empirical formula is to calculate rain intensity in determining the peak of debit with Rational Modification method and Mononobe formula as in rain intensity. Average rain in catchment one of the methods to calculate rain average in a watershed is using the Polygon Thiessen method. This method uses when on one station area the observation of average rainfall is not distributed evenly. The average rainfall was calculated by considering the influence of each observation station. The minimal of used observation station is three stations [11]

3.4 Cross-validation method
Cross-validation, sometimes called rotation estimation or out-of-sample testing, is a validation technique for assessing how statistical analysis results are generalized to independent data sets. This method has previously been applied for rainfall validation. The mean absolute error (MAE) is used to calculate the average error; The mean relative error (MRE) calculates the relative error for comparison at different stations. The coefficient of determination (R²) is used to measure how well two observations are with each other, indicating the proportion of variance in the dependent variable explained by linear regression and the predictor variable [13]

3.5 Evaluate the accuracy of the results with R², NS, percent bias (PBIAS)
R², NS, and percent bias (PBIAS) are used to evaluate the accuracy of the results. NS is determined by the relative magnitude of residual variance compared to the measured data, which indicates how well the plot of observed versus simulated data fits on a 1:1 line. PBIAS measures the mean tendency of the simulated values to be greater or lesser than the observed values. These three parameters are sufficient to evaluate the performance of hydrological modelling results and have been widely used for model evaluation. The formula for R² shown in Equation The formula for NS and PBIAS is as follows [13] Coefficient into the rational methods theoretical, specifically the number C with a correction in the ungauged catchment, which has a certain typical rainfall height and land use/land cover. Review of previous research to obtain a novelty in this study, namely modification of the theoretical formula based on field measurements with a rational method approach influenced by infiltration parameters, land use, rainfall, and flow.

4. Conclusion
The research aims upon the hydrological cycle, founded on data measurement in the field and an attempt to estimate the runoff coefficient based on the modified rational method, which is an extension of the rational method. The expected contribution of this research is to be able to apply this research with small catchment conditions with existing watershed parameters and comparison with similar catchment which has same area and type.

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