PROBABLE MAXIMUM PRECIPITATION ESTIMATION USING STATISTICAL APPROACH

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By

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I hereby declare that all corrections and comments made by the supervisor(s) and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Kebarangkalian Hujan Maksimum (PMP) ditakrifkan sebagai kedalaman hujan yang paling besar pada masa dan tempoh tertentu di kawasan ribut atau kawasan tadahan air di bawah keadaan meteorologi. PMP untuk stesen di Malaysia oleh kaedah statistik Hershfield di awal kajian sebelum ini dianggarkan mengunakan faktor kekerapan 15 yang mana merupakan nilai yang paling tinggi di dunia. Nilai 15 sebagai faktor kekerapan didapati terlalu tinggi bagi sebuah negara yang lembap seperti Malaysia. Dalam kajian ini, data maksimum 1-hari hujan tahunan kira-kira 30 tahun untuk empat stesen yang terdiri daripada tiga stesen di timur dan satu di bahagian barat Semenanjung Malaysia, telah dianalisis dalam usaha untuk menganggarkan PMP untuk tempoh 1-hari berdasarkan faktor kekerapan yang sewajarnya. Stesen-stesen terletak di Setor JPS Kuala Terengganu, Terengganu, Stn. Pertanian Melor di Kota Bharu, Kelantan, Paya Besar di Kuantan, Pahang dan Ldg. Batu Untong di Kuala Langat, Selangor. Perbandingan anggaran PMP berdasarkan pendekatan statistik Hershfield (1965) telah dianalisis dengan nilai-nilai PMP yang dikira menggunakan kaedah Konvensional pendekatan statistik. Daripada kajian ini, didapati bahawa PMP yang diaggarkan meggunakan kaedah Hershfield boleh menghasilkan anggaran PMP yang munasabah dan sah untuk pengiraan reka bentuk berikutnya dan kaedah konvensional adalah setanding dengan kaedah Hershfield dan telah menghasilkan keputusan yang lebih konservatif kerana statistik boleh dianalisis dengan cepat. Kedua-dua kaedah yang dibincangkan telah terbukti berguna untuk anggaran PMP apabila diamalkan dengan teliti. Oleh itu, penggunaan pendekatan statistik boleh diterima untuk membuat pengiraan anggaran PMP. Berdasarkan data hujan sebenar stesen, didapati nilai tertinggi faktor kekerapan ialah 14 untuk Ldg. Batu Untong, 13 untuk Setor JPS Kuala Terengganu dan 12 untuk kedua-dua Stn. Pertanian Melor dan Paya Besar.

ABSTRACT

Probable Maximum Precipitation (PMP) is defined as the greatest depth of precipitation for a given time and duration over a given storm area or watershed area under meteorological conditions. The PMP for stations in Malaysia by Hershfield statistical method in earlier studies was estimated using frequency factor of 15 which is the highest value in the world. The value of 15 as frequency factor was found to be too high for a humid country like Malaysia. In this study, annual maximum 1-day rainfall data of about 30 years for four stations which consist of three stations on the eastern and one on western part of Peninsular Malaysia were analysed in an attempt to estimate PMP for 1-day duration based on an appropriate frequency factor. The stations are situated at Setor JPS Kuala Terengganu, Terengganu, Stn. Pertanian Melor at Kota Bharu, Kelantan, Paya Besar at Kuantan, Pahang and Ldg. Batu Untong at Kuala Langat, Selangor. Comparisons of the PMP estimate based on the statistical approach of Hershfield (1965) were analysed with the PMP values computed using the Conventional method of the statistical approach. From this study, it was found that PMP estimates by Hershfield method can produce reasonable PMP estimates and is valid for subsequent design calculations and conventional method is comparable to the Hershfield method and have produced more conservative results by performing quick statistical analysis. Both of the methods discussed have proven to be useful for PMP estimations when practice carefully. Hence, the use of statistical approach is regarded as acceptable for computation of PMP estimates. Based on the actual rainfall data of the stations, the highest value of the frequency factor was found to be 14 for Ldg. Batu Untong, 13 for Setor JPS Kuala Terengganu and 12 for both Stn. Pertanian Melor and Paya Besar.

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LIST OF ABBREVIATIONS

ACE	**A**ssociate **C**onsulting **E**ngineer
ARF	**A**rea **R**eduction **F**actor
ARI	**A**verage **R**ecurrence **I**nterval
DAD	**D**epth **A**rea **D**uration
DID	**D**epartment of **I**rrigation and **D**rainage
GIS	**G**eographical **I**nformation **S**ystems
PMF	**P**robable **M**aximum **F**lood
PMP	**P**robable **M**aximum **P**recipitation
WMO	**W**orld **M**eteorology **O**rganization

NOMENCLATURES

C_v	Coefficient of variation
D	Duration
i	Rainfall intensity
K_m	Maximum frequency factor
$P_{max,av}$	Average annual maximum daily rainfall
P	Accumulation of point rainfalls in inches
p	Convergence factor
S_n	Standard deviation
v	Velocity
W	Moisture factor
$\overline{X}_n$	Mean
X_m	Maximum observed rainfall
X_t	Annual maximum rainfall
$\overline{X}_{PMP}$	PMP for a given station for a specific duration

CHAPTER 1

INTRODUCTION

1.1 Background

The need for development of water resources is important in all states of Malaysia with a view to ensure sufficient potable water supplies and providing irrigation for hydro-power generation. As a result, large amounts of money are being spent every year in the construction of small and large water resources projects such as dam and storage reservoirs.

One of the most important problems in Hydrometeorology is the estimation of probable maximum precipitation (PMP) for different durations that are expected to occur over a point or an area. These estimates are of considerable importance to hydrologist for calculating the probable maximum flood (PMF) which is often used for the design of significant hydraulic structures such as spillways in large dam. The main objective of designing spillways using PMF is to avoid the overtopping of dams as a result of river flooding.

WMO (2009) defines PMP is the greatest depth of precipitation for a given duration meteorologically possible for a design watershed or a given storm area at a particular location at a particular time of a year, with no allowance made for long-term climatic trends. The most common method to develop PMP values was adopted in this study that is statistical method where the estimates of PMP are derived from frequency analysis of the annual maximum rainfall series for different durations. The statistical method is useful when there is insufficient meteorological data to apply storm maximization method (Sidek et al., 2007).

A statistical method for estimating PMP for small areas has been developed by Hershfield (1961, 1965) based on a general frequency equation given by Chow (1951). For PMP estimation practises in Malaysia, there is non-uniformity in the methods adopted throughout the country. Major studies of water resources projects such as dams were carried out by various agencies, thus the calculated PMP values are different from different studies. Most studies were conducted by maximising the largest recorded storm in the region and by transposing to the site area. There were also studies based on the Hershfield statistical approach considering the frequency factor of 15, which are the highest value in the world and not a reliable value climatic for Malaysian region (Marina, 2014).

1.2 Problem Statement

1.2.1 Extreme Rainfall

Malaysia has an equatorial climate with high temperature and high humidity of over 80% year round, except in the highlands. The country is considered to be one of the less vulnerable regions to natural disasters, it is expected that increasing trends in climate-related extremes may make the country more vulnerable to climate change and natural disasters. The geographic distribution of climate change vulnerability is not uniform over the entire country, for example, at the east coast of Peninsular Malaysia is more vulnerable to climate change compare to at the west (Rakhecha et al, 2006). Floods triggered by heavy rainfall has become almost an every year phenomena in the east coast states of Peninsular Malaysia.

Water shortage due to prolonged dry spells is also felt in the part of east coast region. It has been predicted that annual rainfall in the east coast of Malaysia will be more variable by the end of this century. It is anticipated that variability in inter-annual and inter-seasonal rainfall due to climate change will cause more hydrologic extremes in the east coast of Peninsular Malaysia and make the livelihood and infrastructure more vulnerable. All these studies analysed rainfall-related extremes based on only a few stations to infer the changes in climate. However, no study has been carried out so far that focused on the east coast of Peninsular Malaysia which is the most vulnerable climate change zone in Malaysia (Sidek et al., 2013).

Geographical Information System (GIS) maintains the spatial location of sampling points, and provides tools to relate the sampling data contained through a relational database. The GIS is used to analyse the spatial variation in the trends of rainfall and rainfall-related extremes. Implications from this study will help to understand possible changes in rainfall in order to take policy measures to adapt with the changing pattern of climate in the region.

1.2.2 Flooding

The probable maximum precipitation (PMP), which is a fundamental parameter in the design of a variety of hydrological structures, also has a key role in floodplain management, where it is made to correspond to the extreme potential risk of flooding at a given time and place. PMP is therefore very useful for hydrologists, to estimate the probable maximum flooding and thereby, for example, to design the most appropriate spillways to minimize the risk of overtopping a given hydraulic structure, such as a dam. In this way, the risks of loss of lives, damages and community impacts can be minimized and managed.

Floods and flash floods associated with extreme rain events are major hydrological disaster in the Peninsular Malaysia especially during northeast monsoon cold surge episodes (Azmi et al, 2013).

1.2.3 Climate Change

Climate change has altered not only the overall magnitude of rainfall but also its seasonal distribution and inter-annual variability worldwide. Such changes in semiarid regions, where water availability and timing are key factors controlling biogeochemical cycles, primary productivity and the phenology of growth and reproduction (Zul et al., 2014). The climate plays such a major part in our planet's environmental system that even minor changes have impacts that are large and complex.

Due to climate change, there will be many inter-related changes to weather. There will be more droughts, heat, waves, storms and floods. The stability of natural slopes and the associated risk will be very much effected by climate. Heavy rainfalls could bring disaster such as floods and landslides. Of course, the shortage of rainfall could also affect the water management system in such a way it could bring problems to the economic activities (Shukri et al.,2014). Therefore, there is a need to investigate the characteristic of rainfall of a country intensively and comprehensively. In Malaysia, the climatology and hydrology of rainfall have been intensively investigated in recent years.

1.3 Objectives

The objectives of this study are a follow :

i. To estimate probable maximum precipitation using Statistical method by Hershfield and Conventional method.
ii. To compare the estimation of probable maximum precipitation at four different locations using statistical approach.

1.4 Importance of Study

This final year project is carried out to give some benefit in Civil Engineering field. From the study, we will be able to determine the PMP estimation using statistical method. PMP estimates are important to hydrologist for calculating the probable maximum flood (PMF) for spillways on large earth and rock filled dam. The main purpose of designing spillways using the PMF is to avoid the overtopping of dams as a result of river flooding. Overtopping of a dam structure can result in damage to the dam wall or abutments through breaching. By using PMP estimation, the risk of loss of life, cost of rebuilding the dam, cost of the additional flood damage downstream and cost to the community due to the loss of water supply can thus be minimised.

1.5 Scope of Work

The aim of this study is to estimate and analyse the PMP estimation at four different rainfall stations which is in the state of Terengganu, Kelantan, Pahang and Selangor using the statistical method and determine the probable maximum precipitation of extreme storm at those rainfall station locations respectively. With this research, the amount of subjectivity in PMP estimations can be minimized, hence more uniform practices and consistent results for any location can be obtained.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Probable Maximum Precipitation

PMP is the theoretical maximum precipitation for a given duration under meteorological conditions. Such a precipitation is likely to happen over a watershed area, or a storm area of a given size, at a certain time of year. The objective of a probable maximum precipitation (PMP) estimates is to calculate the probable maximum flood (PMF) used in the design of a given project at a particular geographical location in a given watershed, and to further provide information that could assist in designing the size (dam height and reservoir storage capacity) of the given project and dimension of the flood-carrying structure (spillway and flood carrying tunnel) of the project (Sidek et al., 2007).

(WMO, 2009) mentioned that there are two general approaches to estimating PMP, one based on storm area (area surrounded by isohyets) and the other based on the specific watershed location (watershed area). The approach based on storm area (the indirect approach) focuses on the estimation of a group of PMPs with various durations and area in a wide region, and then provide a set of methods to convert them into the PMP in the design watershed for the purpose of PMF estimation in high-risk project (usually reservoirs and nuclear power stations).The approach based on watershed area (the direct approach) focuses on the direct estimation of PMP with a given duration according to the requirement of a specific project (usually the design of a reservoir) in the targeted watershed.

2.2 Conceptual Definition of Probable Maximum Precipitation

Probable maximum precipitation (PMP) is a theoretical concept that is widely used by hydrologists to estimate for probable maximum flood (PMF) that is can be used in planning, design and risk assessment of high-hazard hydrological structures such as flood control dams upstream of populated areas.

Prior to the 1950s, the concept of an upper limit to precipitation potential was known as maximum possible precipitation. The name was changed to PMP, reflecting the uncertainty surrounding any estimate of maximum precipitation (Casas et al., 2008). The 'probable maximum' concept began as 'maximum possible' because it was considered that maximum limits exist for all the elements that act together to produce rainfall, and that these limits could be defined by a study of the natural process.

2.3 Methods of Estimating Probable Maximum Precipitation

Various methods are available in estimating Probable Maximum Precipitation and is dependent with each other as the variables are considered inter-related. According to Yiau et al. (2011), the techniques that have been used are as follows :

i. The storm model approach

It is a logical method which the maximum values of variables used is assumed in the precipitation equation to extrapolate precipitation to its probable extreme. The rainfall intensity of storm model is mainly depends upon the geometrical basin factor (*K*), inflow velocity (*v*), moisture factor (*W*), and convergence factor (*p*) as shown in the equation below:

Rainfall intensity, $i = K \cdot v_{12} W_{12} \{1 - \frac{\Delta p_{12}}{\Delta p_{34}}, \frac{W_{34}}{W_{12}}\}$ (2.1)

There are mainly two types of storm models consist of upglide model and convergent model. The upglide model is typically for orographical rainfall while convergent model is for thunderstorm and tropical cyclone. This approach is selected to estimate the PMP when there is insufficient or unrepresentative storm data, rugged topography or a degree of rationalization and consistency is needed (Jonas, 2007). However, this model is not suit to be used for small areas due to difficulties of precision measuring of required factors (mentioned above) and express them in an appropriate way.

ii. The maximization and transposition of actual storm

It is the most convenient and acceptable form of obtaining the PMP. Transposition of storm is basically transforming the recorded storm characteristics from one or more areas to the given area (gauged location to ungauged location) while storm maximization includes adjustment on observed precipitation amount to its maximum moisture convergence (Putuhena et al, 2011). The rainfall depths which are expressed in isohyet maps or depth-area-duration (DAD) values are used together with representative dew point and maximum dew point to give the PMP values for the specified basin. This approach covers the deficiency of storm models in topographical intensification, spill over and variable storm efficiencies.

iii. The used of generalized data or maximized depth, duration and area data from storms, these are derived from thunderstorms or general storms

Typically, generalized approaches involve maximization and transposition of classes of storms over a wide region. It is used to obtain more reliable and consistent estimates of PMP and if there is lack of storm history or insufficient record of highly efficient storms. PMP estimations can be obtained based on a list of greatest recorded rainfall depths for various durations at rain gauges or point rainfalls as well as from the analysed DAD data. This is done by gather together all the rainfalls data from a very large area and standardized the rainfall depths (Hosseinzadeh et al., 2014).

iv. The use of empirical formulae determined from maximum depth, duration and area data or from theory

Commonly, empirical formulae represent local or world maximum values of precipitation in point values instead of areal accumulations (Chavan, 2015). Use of empirical formulae is likely to be the easiest way to estimate PMP. The currently available empirical formulae used to estimate PMP is originally derived from the world's highest gauge rainfalls and given the formulae as below:

$$P = 16.6D^{0.475} \tag{2.2}$$

where 16.6 is a constant, D is the duration in hours and P is the accumulation of point rainfalls in inches. Results of heavy rainfalls studies in other areas had indicated the notable changes in the constant of proportionality but constant for the exponent of D that approximates to 0.5 (Hansen et al., 1982). Thus, P varies as $\approx \sqrt{D}$ for the world's highest gauge rainfalls is only suit to be applied for specific duration while intense storms with long duration need exceptional conditions such as favourable topography. However, maximization and transposition of storms is always preferred if it is allowable and the original data is available with the appropriate adjustments instead of using the empirical formula.

v. **The use of empirical relationships between the variables in particular valleys or basins (only if detailed data are available)**

For a specific valley, the optimum wind velocity and surface dew point are the key factors in estimating maximum rainfalls due to their high consistency and amenable to statistical treatment and extrapolation. Therefore, a rainfall formula is directly relating the rainfall intensity over the valley to the wind velocity and the surface dew point with the constant derived from the intense storm history. This technique is applicable in mountainous areas with complex topography when there is insufficient of data and manpower to carry out storm model research (Collier, 1996).

2.4 Estimation of Probable Maximum Precipitation

2.4.1 Depth Area Duration Curves

Depth-Area-Duration (DAD) analyses have been computed to aid in the computation of probable maximum precipitation (PMP) estimates that influence the design and operation of structures such as dams, nuclear power plants, flood retaining structures, and levees. DADs require accurate, high-resolution precipitation depths in time and space, particularly in areas with the heaviest precipitation (Hendricks, 2015). Point rainfall cannot be used to represent areal rainfall as the area of interest increases. In natural occurrence of a storm, there is a storm centre where the rainfall is highest and the depth of storm decreases with distance from the storm centre. A typical DAD curve is shown in Figure 2.1.

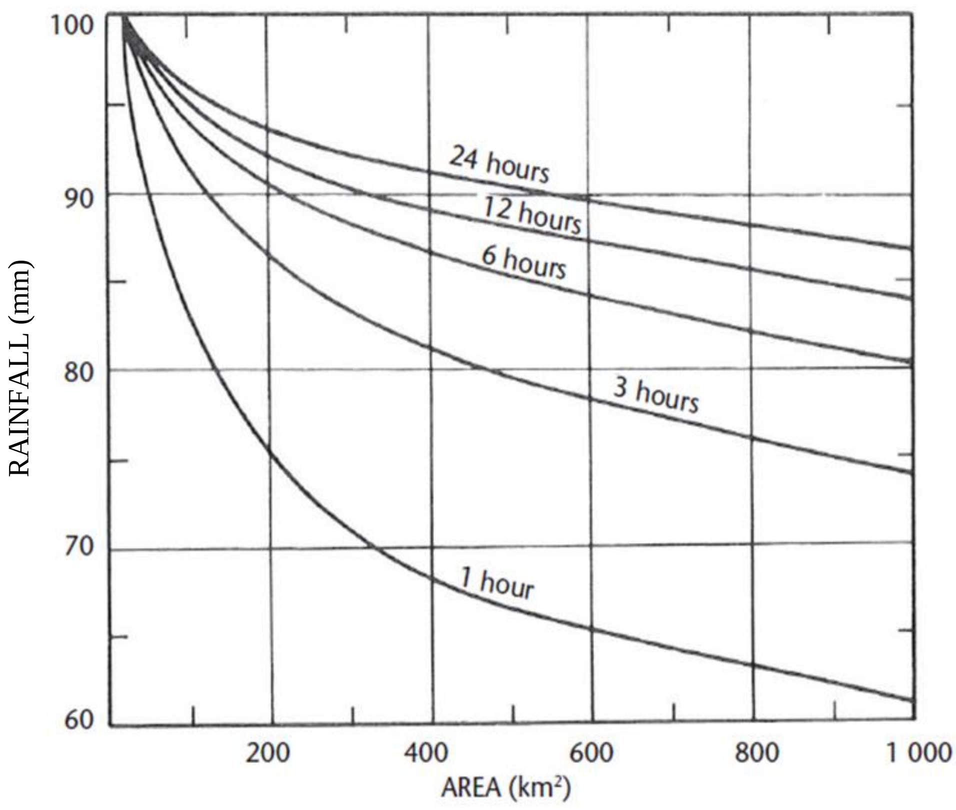

Figure 2.1 : Depth-Area-Duration Curves (US Weather Bureau) (WMO,2009)

The DAD curves show the maximum depth of precipitation occurring over various size of catchment area for various storm durations. The curves can be derived using the mass curve method or the isohyetal method. DAD curves are used in estimation of areal PMP.

2.4.2 Areal Reduction Factors

A variation of the DAD curves is the areal reduction factor (ARF) curves. In many hydrological studies, the interest is to estimate the extreme areal rainfall over a catchment (e.g the 20-, or 100-year ARI storm). Many do not have the resources to study areal distribution of design storm in detail and would merely depend on point rainfall records to estimate areal rainfall. However, these design rainfall estimates are derived based on point rainfall data and applying the estimates for large catchment will tend to