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Spatial Interpolation of Dialy Rainfall in Cambodia using Inverse Distance Weighting

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Abstract: *Rainfall is an important parameter in Hydrology. It significantly contributes to hydrological modelling of the regional scale. Limitation of rain gages and miss recording rainfall data may force Cambodia to face the difficulties of watershed management and study. This report identifies the performance of a rainfall interpolation method called Inverse Distance Weighting and do the map of its spatial distribution. By using FORTRAN programing language, the interpolation method is formulated and conducted in daily time step 168 stations distributed around the country for each 25 km^2 (5 km×5 km) grid in an area of 181 035 km^2 of Cambodia. The data record in daily time step is practical for 29 years period from 1985 to 2013. The result shows that the variety of rainfall changes significantly from 1000 mm to nearly 4000 mm (3900mm) with an annual average rainfall equal to 1447 mm, the maximum rainfall value 1861 mm and the minimum rainfall value 1120mm. The performance of IDW is somewhat acceptable. 56 most records stations are selected for partial cross validation of IDW performance of the three month period from 1st August to 31st October 2000, the most severe flood time. Root Mean Square Error evolves from a small error of 0.5 mm to a high error of 34.3mm. For all of cases, this study illustrates that the IDW will be sufficient for Cambodia whenever the data distribution of the point observation is dense enough in the whole country. Therefore, there must be a small scale study for dense rain gage area. Furthermore, others methods such as Geostatistical method might be recommended for interpolation and study its performance in this case of the sparse rainfall stations.*

Keywords: *Inverse Distance Weighting (IDW); Interpolation of rainfall; Spatial Interpolation; Daily rainfall data; Annual Rainfall change.*

1. INTRODUCTION

Hydrological and water quality applications, must be given data on the very important rainfall distribution and records (Ly, Charles, & Degré., 2011). These point data present the position of station with given coordinates. Observation with the daily time step provide a better investigation on extreme event. To initiate the required investigated maps, for instance, it must take time in gathering the rain observation data as much as possible (Ahrens., 2005). Mathematically, an input of a single rain gauge alone result a great uncertainties regarding runoff estimation (Faurès et al., 1995 and Chaubey et al., 1999 as cited in Ly et al., 2011). Therefore, increasing the density of monitoring network is the best method to improve the quality of spatial rainfall estimation. Spatial Interpolation of the point data are better leaded by the rain gauge given by the spatial grid spacing and cell support (Ahrens., 2005), as in this study interpolation is done for 25 square kilometer grid.

Furthermore, data from rain gauges which are sparse does not always provide enough spatial representation of rainfall. Therefore, the necessity of interpolation remains stable in order to estimate the total rainfall over a certain area. Rainfall has been interpolated using average values ranging from daily, monthly or annual aggregation levels. However, quit a number of interpolation methods have been proposed for rainfall estimation (Tao, Chocat, Liu, & Xin, 2009).

There are also many technical studies and research in this field have been proposed to compensate those loosen variable. Mair & Fares (2011) mentioned the two terms of interpolation method, Traditional method (Thiessen Polygon, Inverse Distance Weighting) and Geostatistical interpolation methods (Linear regression, Ordinary Kriging (OK), and Simple Kriging with varying Local means (SKLm) were used to estimate wet and dry season rainfall. Moreover, (Ly et al., 2011) defined this methode as Deterministic and Geostatistical method which he included Kriging for External Drift, KED and Universal Kriging (UNK) which is great contribution to the trend surface for the Kriging process. Besides this, Tao et al (2009) also applied ordinary Kinging, Kriging with external drift and co- Kriging, other techniques based on splines or genetic algorithms.

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Furthermore, an interesting method, Inverse distance weighting (IDW), assign weights to neighboring observed values based on the distance to interpolation location and the interpolated value is the weighted value of the observation. IDW are used in many precipitation mapping method (Ahrens, 2005). There were not much different between Geostatistical and IDW method (Ly et al., 2011).
Elevation data have also been merged with rain gauge data to improve rainfall estimation by using other geostatistical methods (Hevesi et al. 1992; Christel and Reed 1999; Goovaerts, 2000; Sarangi et al. 2005; Carrera-Hernandez and Gaskin, 2007 as cited in Mair & Fares, 2011). Others have estimated rainfall through a linear regression of rainfall versus elevation, whereas elevation is derived from the grid cell from a digital elevation model (DEM) (Daly et al. 1994). On the other hand, several studies have found that geostatistics produced better estimates of precipitation than traditional methods(Goovaerts, 2000)
Mair & Fares (2011) has mentioned that Goovaerts (2000) compared the rainfall prediction performances of two types of interpolation methods: (1) methods that use only rainfall data from 36 stations [Thiessen polygon, IDW, and ordinary kriging (OK)]; and (2) methods that combine rainfall data with elevation [linear regression, SKlm, KED, Collocated ordinary Cokriging (CCK)]. The largest prediction errors were obtained for the Thiessen polygon and IDW methods. Mair, and Fares (2011) has put his result that the SKlm method produced the smallest error in most months and yielded the best prediction overall. However, OK produced smaller errors than all other methods when the correlation between rainfall and elevation was less than 0.75. (Goovaerts, 2000)propose to more ways of secondary information be studied to assess whether they can further improve rainfall interpolation.
Anyway, Ly et al. (2011) found out that contribution of elevation in Kriging External Drift (KED) and Ordinary CoKriging (OCK) did not provide more accuracy for interpolation of the daily rainfall. Ordinary Kriging (OK) and IDW were considered to be the best method when the result in smallest RMSE in all case. Furthermore, Wagner, Fiener, Wilken, Kumar, & Schneider (2012) mentioned that IDW can be referred to as regression-inverse distance weighting which can be applied using elevation as a covariate, this term use elevation as some geostatistical methods.
Therefore, Spatial interpolation is generally carried out by estimating a regionalized value at un-sampled points from a weight of observed regionalized values(Ly et al., 2011). Many description of interpolation method use to estimate rainfall depth to the un-sample data rainfall location is described subsequently. Those are included Deterministic Algorithms (Thiessen polygons, Inverse Distance Weighting (IDW)), And Geostatistics Algorithms (Linear Regression, Kriging with an External Drift, Ordinary Kriging (OK), Ordinary CoKringing, Simple Kriging with varying Local Means (SKLm).
In previous study, the Inverse Distance Weighting interpolation (IDW) method is applied. The interpolated valued is derived from the weight average of the observation when IDW assigns weights to neighboring observed values depend on the distance to the interpolation location (Ahrens, 2005). IDW is applied in many precipitation mapping methods (Ahrens, 2005; Drešković & Đug, 2012; Garcia, Peters-Lidard, & Goodrich, 2008; Goovaerts, 2000; Ly et al., 2011; Mair & Fares, 2011; Tao et al., 2009).
The inverse Distance Weighting (IDW) algorithm is a moving average interpolator that is usually applied to a highly variable data. When there a dense of observed data the IDW recommended to be used (Childs, 2011). In addition, Tobler (1970) stated his first law of geography that everything is related to everything else, but near things are more related than distant things (Miller, 2004) and it is so the same way of inverse distance weighting.
For illustrational purposes, most of the interpolation method using Inverse Distance Weighting normally in a scale not more than 5000 km^2 and especially with the dense data (Degré et al., 2013; Ly et al., 2011; Mair & Fares., 2011) in which the result show that using IDW archive somewhat good performance.
Anyway, those algorithm of each methods for interpolation does require the validation or cross validation using the historical data (Lanza, 2001). Cross validation is determined by estimate the series daily time step for the selected period at one gauge by using all other rain gauges (Wagner et al., 2012). To evaluate the efficiency of the model, Wagner (2012) proposed Nash-Sutcliffe Efficiency (NSE), Root Mean Square Error (RMSE). Vicente-Serrano, Saz-Sánchez, & Cuadrat (2003) mentioned that the problem is that RMSE determine the model validity that places a lot of weight on high errors, whereas he also focus on Mean Absolute Error (MAE) that is less sensitive to extreme values.

2. METHODOLOGY

2.1 Study Area

In this study, the study area is Cambodia country with the total area 181 035 km^2. The recorded data are organized reference to the daily time step. The recorded data are collected from the station which is technically transferred or recorded from rain gauges.The existing rain gages of 168 stations around the country are chosen to be interpolated for the whole area of the country, including either mountainous regions or lower land area. The data location varied in different provinces and cities except, Kep, and Mundul Kiri provinces as shown in the **Fig.1**.
Rainfall records are secondary data provided from Ministry of Water Resources and Meteorological of Cambodia (MoWRAM). Most of the stations locate around the Tunle Sap Lake and distribute along the upper Mekong River to the

lower Mekong as well as Bassac River. The interpolation method is used to compute the rainfall distribution in each grid 25 km^2- regular grid (5 km×5 km) of the total area. In **Fig.1** represent the data availability and the data location in each provinces in the period 29 years from 1985 to 2013. The most records more than 20 years has only 93 stations and the most records of the station are only from some provinces such as the coastal area Sihanouk Ville Koh Kong, and Kompot, the low land area start from Pusat, Kompong Chhnang, Kompong Speu Takeo, and along the Mekong delta such as Stung Treng, Kompong Thom, Phnom Penh, Prey Veng.

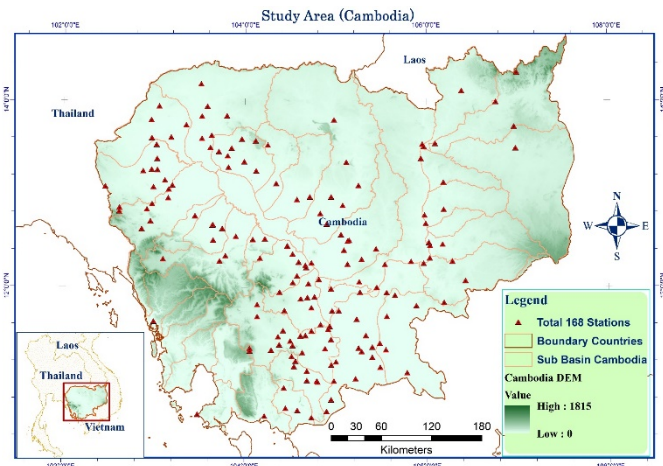

Fig.1. Study area identify the whole area of Cambodia

In preprocessing, the data was provided in the different set between the name and the code of the stations. The purpose is to arrange the data as a set with the pair of coordinates and existing observed value of each stations.

2.2 Interpolation Method

Rainfall estimation and mapping are done by interpolation using the rainfall record. In this study, the data both 5 minutes and hourly time step are converted to the daily time step. The Spatial Interpolation is generally carried out by estimating a regionalized value at un-sampled points from a weight of observed regionalized values.

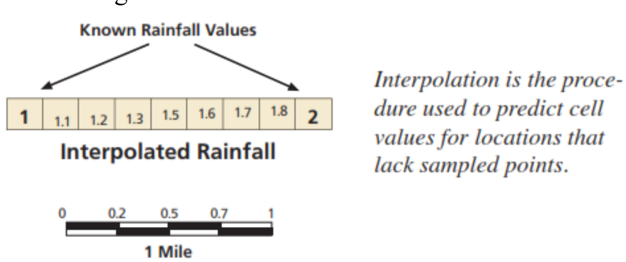

Fig.2. Concepts of the interpolation, image source: Childs, (2011)

As shown in (**Eq.1**), a general formula for spatial interpolation is as follows (S. Ly, C. Charles, and A. Degré, 2011):

$$Z_g = \sum_{i=1}^{ns} \lambda_i Zs_i \qquad \text{(Eq. 1)}$$

Where Zg is the interpolated value at point g when Zs_i is the observed value at point i and ns is the total number of the observed points (rainfall stations) then the weight λi is the weight contributing to the interpolation. In this study, this weight is calculated by inverse distance weighting.

Inverse Distance Weighting Algorithm

The weight **λ** in Inverse Distance Weighting (IDW) method which is formed based on the functions of the inverse distances and it is defined by the opposite of the distance and normalized so that their sum equals one (Degré et al., 2013). The weights decrease as the distance increases. In this study, inverse square distance is formed to obtain the value at all grids for the whole study area.
Inverse Distance Weighting, the weight can be computed by:

$$\lambda_i = \frac{\frac{1}{|D_i|^d}}{\sum_{i=1}^{ns} \frac{1}{|D_i|^d}} \qquad \text{(Eq. 2)}$$

Where Di is the distance between sample and un-sampled points. The d parameter is specified as a geometric form for the weight while other specifications are possible. This specification implies that if the power d is larger than 1, call distance-decay effect will be more than proportional to an increase in length between two point, and vice versa. Thus, small power d tends to give estimated values as averages of Zs in the neighborhood, while large power d tends to give larger weights to the nearest points and increasingly down-weights points further away (Lu & Wong, 2008 as cited in Ly et al., 2011). However, parameter d is chosen equal to the value of 2 for daily and monthly time steps as mentioned above as Inverse square Distance.
Other important parameter for interpolation in IDW is the present of the point coordinate of both observed and interpolated point. To get the weight and the interpolated point in (**Eq.1**) and (**Eq.2**) respectively be executed, the distance D_i is the distance between observed and the interpolated points and is formed by the square root of the sum square of the minus coordinate **x** and **y** of the two points. It is formed by:

$$D_i = \sqrt{(xs_i - xg_i)^2 + (ys_i - yg_i)^2} \qquad \text{(Eq. 3)}$$

Where xs, ys is the coordinate of observed station, and xg, yg is the coordinate of the interpolated point.

In computation, these algorithm is written in Fortran 90 programming language (offering from my adviser) in order to interpolate all of observed data in daily time step. The program, then read in daily data for 365 or 366 time (365 days or 366 days per year). On the other hand, in the daily rainfall, there must be missing of records in a periods and those data are noted as -999.9 to guide the program for not being computed on that day. The total rainfall per year will be then plot in ArcGIS for the post processing.

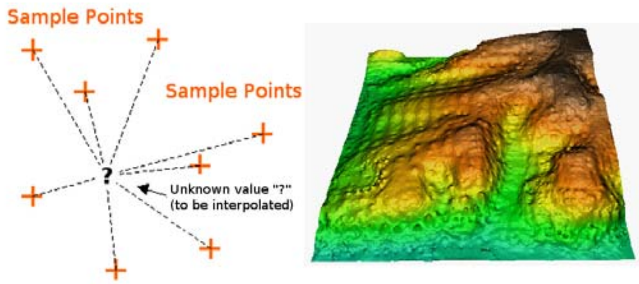

Fig.3. The concept of Inverse distance weighting, image Source: Mitas & Mitasova, (1999)

However, the data from observed point is sometime missing recording and the flow algorithm is process by the following

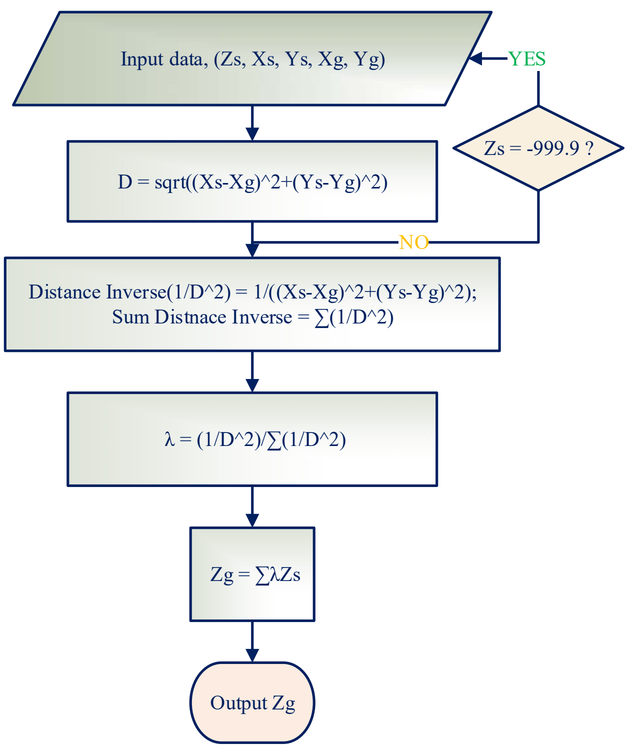

Fig.4. Flow chart of the simplified procedure of IDW computation.

Partial-Validation

The Root Mean Square method in **(Eq. 0.3)** is used as the error criterion for comparison of the model-predicted result (IDW) with the observed valued. The smaller the RMSE, the better the prediction capability or it has RMSE close to zero (Ly et al., 2011; Mair & Fares, 2011; Wagner et al., 2012). In this study, the performance of the interpolation method is evaluated by the removing one station and re-estimate using the remaining stations; for instances, the other 167 stations. Root Mean Square Error formula using to identify error criteria of the rainfall estimation is formed by the following:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{1}^{n}(Z_{si}{}^{*} - Z_{si})^2}$$

Where *Zsi** is the interpolated value of at the rain gage, *Zsi* is the observed value at the same rain gage and *n* is the sample size, in this study *n* is the total day of data series

3. RESULTS AND DISCUSSION

3.1. Result of the Interpolation by IDW

3.1.1 Annual Rainfall Change

In the result, the total 29 years, annual mean rainfall equal to 1447 mm as shown in **Table 1** with the average maximum rainfall of 3815 mm and minimum rainfall of 1058.

Table 1**.** The annual mean rainfall in (mm)s of Cambodia, interpolate using Inverse Distance Weighting methods and 168 stations available around the country.

Method	**Average**	**Min**	**Max**	**Max RMSE (mm)**	**Min RMSE (mm)**
IDW	1447	1058	3815	0.5	34.3

The annual rainfall change from 1985 to 2013 which is the result from Inverse Distance Weighting in **Fig.5** show that the rainfall varies significantly from below 900 mm to more than 3400 mm almost every year. While the average annual rainfall in **Fig.4** varies between 1000 mm to 4000 mm during the 29 years period. It has been shown that the most extremely rainfall changes occur noticeably along the coastal area almost every year with highest rainfall only in 2013, in Koh Kong province and Sihanouk Ville.
The lower rainfall in (mm) currently appears in 2004, 2005, and 2006 respectively given from below 900 mm to not more than 1600 mm nearly the whole area of Cambodia except some part of the northeastern part of Ratanak Kiri and some of Kratie province of the country. While in 1995, 1996, 1999, 2001, 2002, 2005, and 2012, this north eastern part of the

country as well as along the Mekong River experienced the rainfall of more than 2400 mm. However, during 2002 and 2004, it is apparently given a sight with a lowest rainfall cover significantly the north western part along the Tonle Sap Lake to the lower Mekong of the country.
The rainfall view for the year 2004 to 2006 show that the northeastern part of the province experienced about 2400 mm to 2800 mm rainfall throughout, and in 2005 is the higher one.

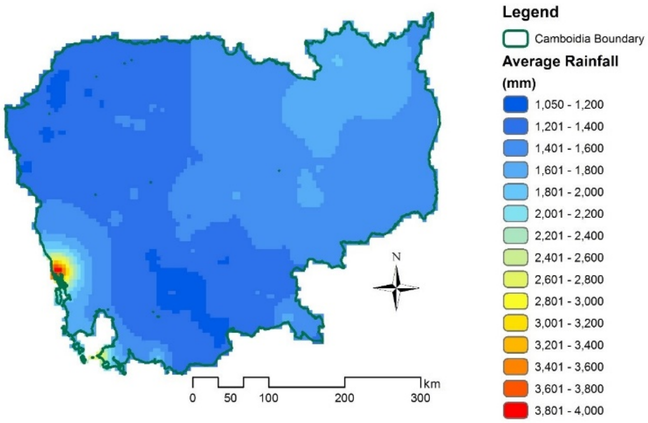

Fig.4. Annual mean rainfall of the 29 years period using the Inverse Distance weighting.

However, the above mentions refer to using this method could not assure the effective result. However, the performance in the large scale like this can be somewhat an artificial result for analytical review. And in the same view, the result given rainfall distribution large intensity of coastal area about 2600mm.

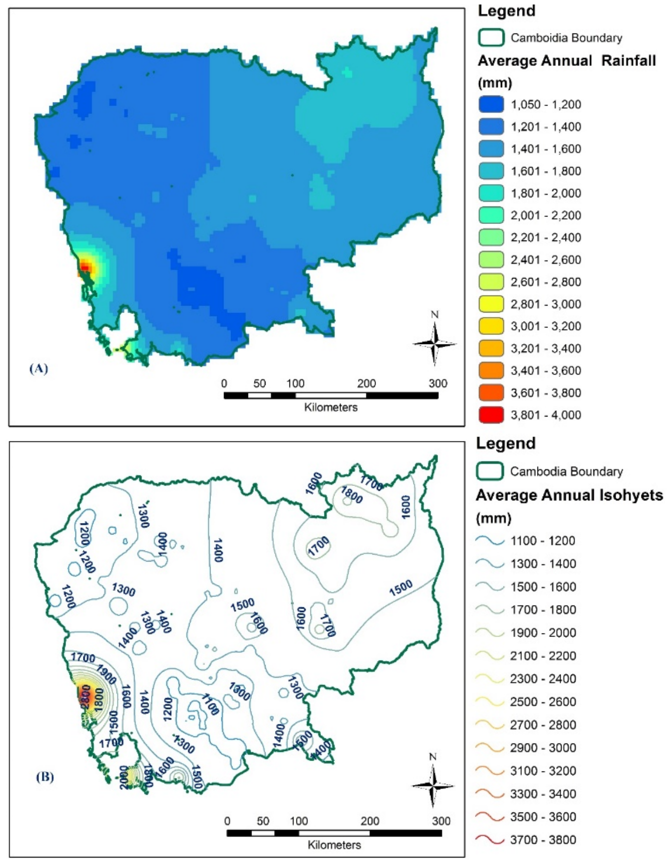

Fig.5. (A) Isohyets of Annual Mean rainfall; (B) Annual Mean rainfall of 29 years, by IDW.

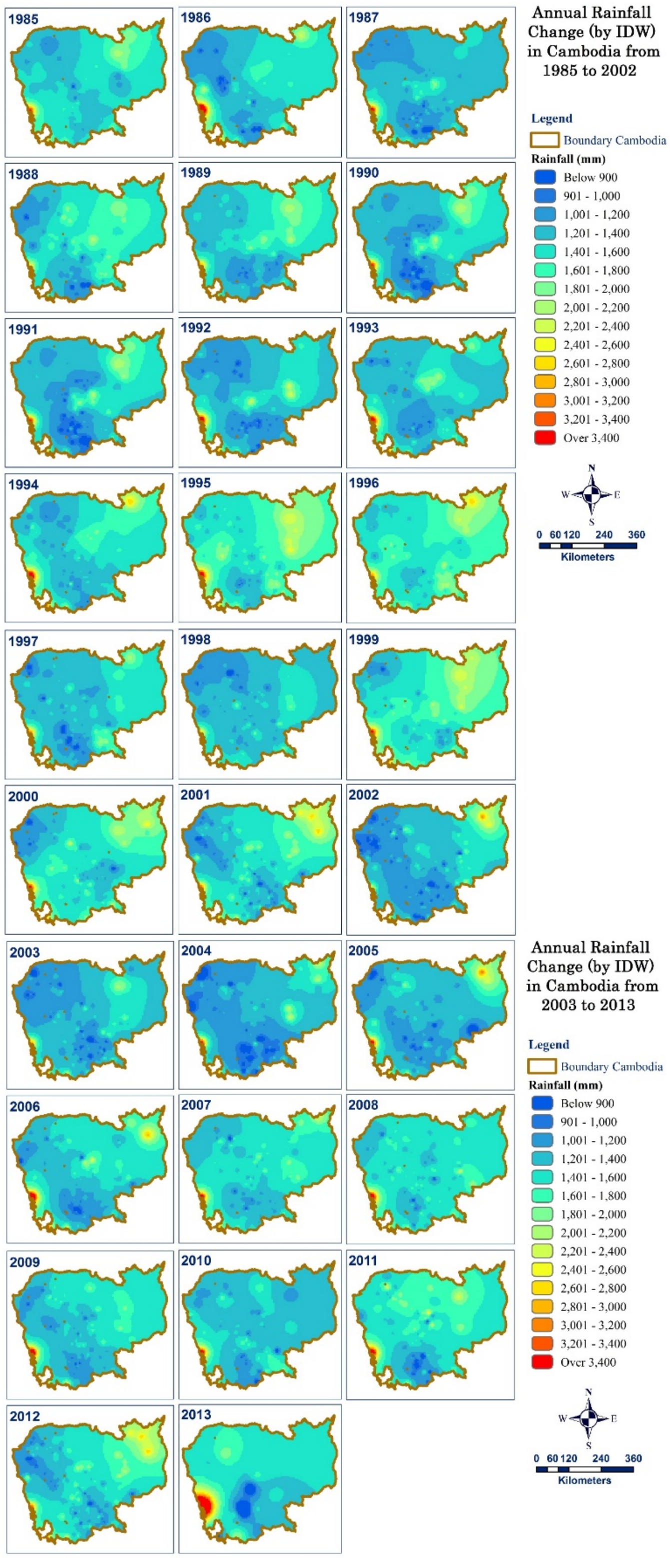

Fig.6. Rainfall change during 9 year period from 1985 to 2013, by IDW

Model Performance

In this report, Root Mean Square illustrates error of the model with 56 validated stations which are selected based on most of the stations has most priority recorded periods (more than 20 years). As the flood most apparently occur between September to October, the severe flood of 2000 appear to be the worst one (Chea & Sharp, 2015) somewhat in **Fig.6** can view similarly account to the rainfall cover mostly more than 2000mm (method by IDW). So, the selected period is done from 1st August to 31st October 2000 reference to the data homogeneity); however, there are only 138 stations among 168 stations itself have rainfall record. The Root Mean Square Error is applied to see the efficiency rainfall during this period.

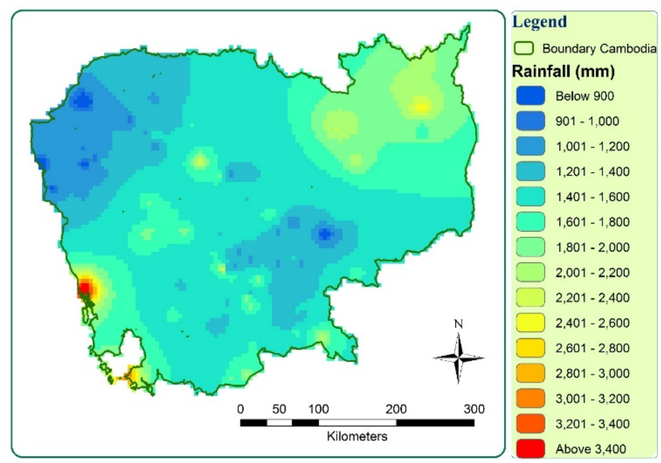

Fig.7. Rainfall characteristic in Cambodia in year 2000, by IDW.

Among the 56 rainfall station, the total observed rainfall varies from 348 mm to 1568mm. Accidentally, the RMSE is definitely large of 34.3mm at station **Beoung Khnar**, but appear to be lower 0.5 mm at Station **Dounkeo** in **Fig.10** and **Fig.12** respectively. However, in this report, the result of RMSE shows an extent of standard deviation.

Station **Dounkeo** located at a site where most of the recorded station. This result is in a most accurate one. However, it can be seen that Station **Beoung Khnar** is given in a high error which result from an alternative aspect of the lowest one of RMSE.

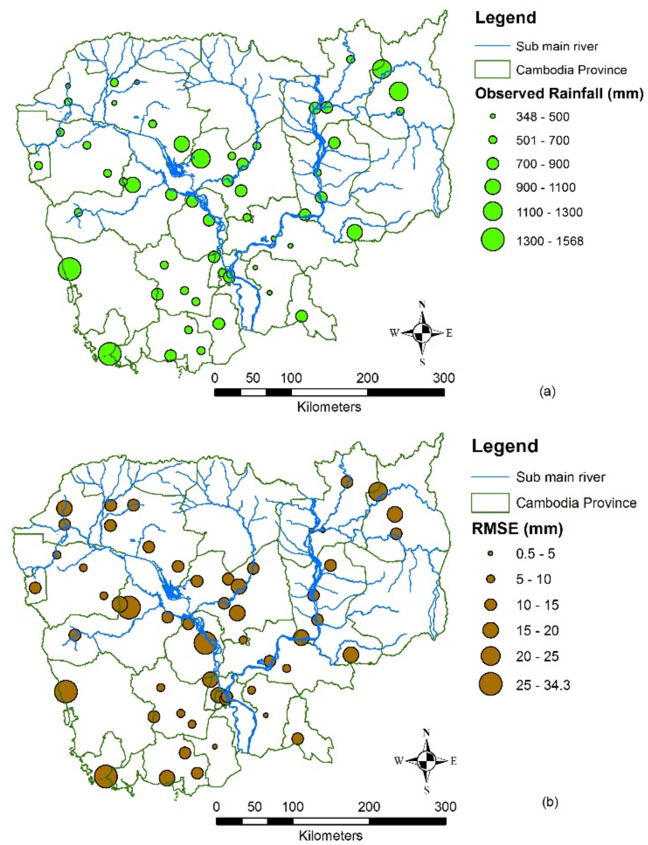

Fig.8. The selected in validated criteria error of 56 stations for series of selected period of Raining Season (from 01 August to 31 Oct 2000). (a) The Total Observed Rainfall, (b) Root Mean Square Error. The background is the Sub Basin Cambodia.

The station itself located far different distance from other stations.

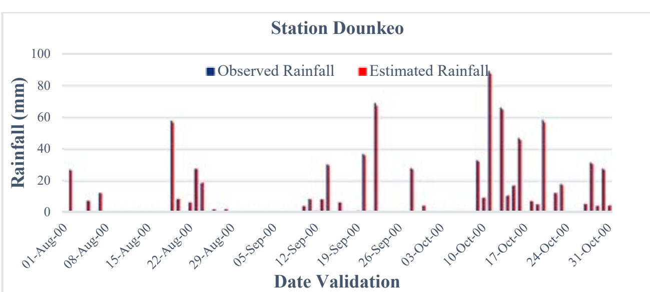

Fig.9. Station **Dounkeo** which is the most accuracy of interpolation among other 56 stations

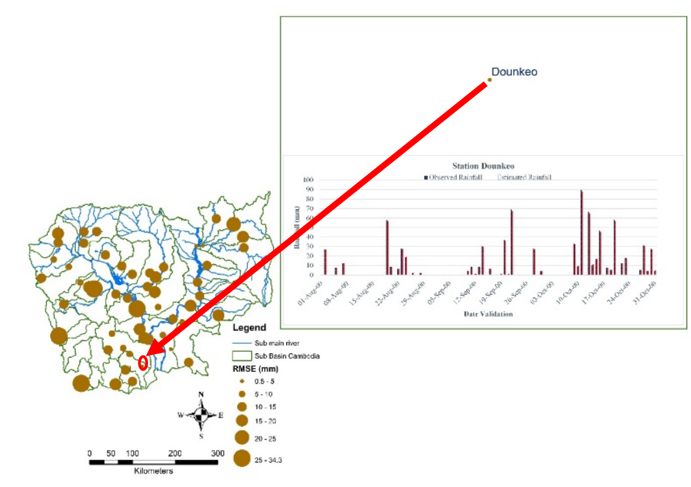

Fig.10. Specific area of the station **Dounkeo** which has the smallest RMSE

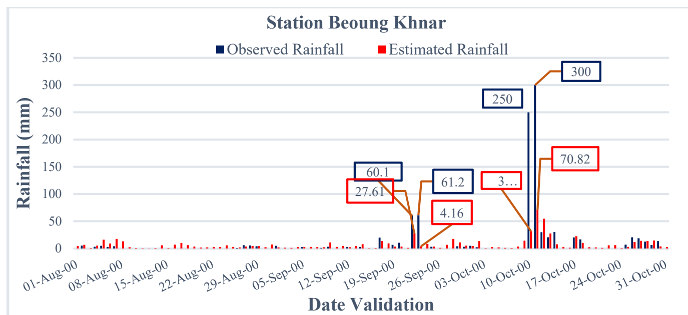

Fig.11. Station **Beoung khnar** which is the most error among 56 stations. A most different value is noted in two day on 23 Sept 2000 and 11 Oct 2000.

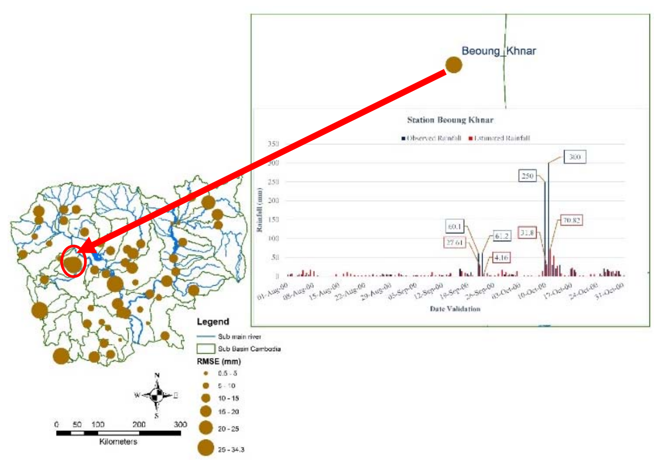

Fig.12. Specific Area of the station **Beoung Khnar** which has the largest RMSE

As mention above the distant D is a very important parameter of the IDW method to interpolate using the observed point. From Tobler, (1970) and Mitas & Mitasova, (1999), Miller, (2004), would influence to the output result of the validation RMSE.
In the case of the Station **Beoung Khnar** (RMSE=34.3 mm) is considered into three cases by giving condition of observed points to the estimated point, and the result of RMSE change when observed point is limited to 4, 8 and 16 stations **Fig.13** respectively; however, the result is not much different from the cross validation that the estimated point.

Table 2. The 3 conditions of validation for the high error of station **Beoung Khnar** within the three months period August to October.

No. Stations	**RMSE (mm)**
4 stations	33.7
8 Stations	33.6
16 stations	33.9
167 stations	34.3

Therefore, in this case IDW is not perform well in this spatial interpolation compared to the observed data, yet to show the result just a bit lower than the using other 167 stations even though in a far distance. This result can be assumed by the sparse distribution of the nearby stations (the observed point is not dense). Anyway, a search radius, about 30 km but not more 60 km may recommended when the result RMSE change to lower then before with the interpolation is done using 8 observed stations **Table 2** and **Fig.13**

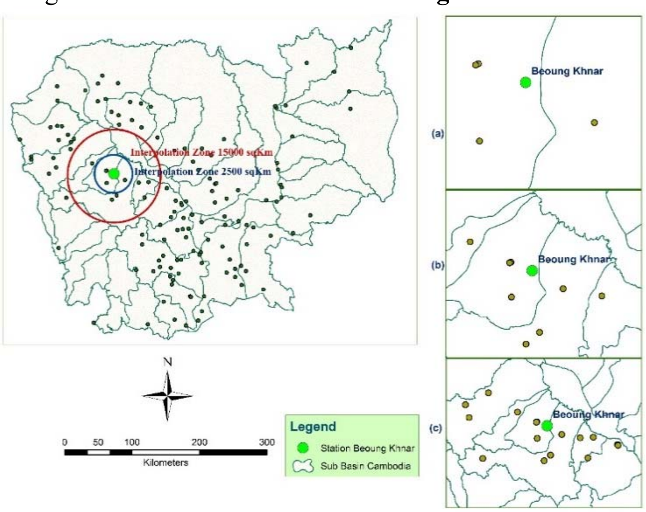

Fig.13. The three conditions study of the higher RMSE stations. (a). Interpolation using the nearby 4 stations. (b). Interpolation using the nearby 8 stations. (c) Interpolation using the nearby 16 station. The background is the Sub Basin Cambodia.

Furthermore, the three other cases are done, Station **Dounkeo** (RMSE = 0.5 mm), Station **Phnom Penh**, and Station **Veun Sai**. In the result, Station **Dounkeo**, its RMSE change from 0.5mm to 0.2 mm when using the observed station in a radius R = 44 km. In **Table 3**, Station Phnom Penh change differently from other; however, to some extent that the smaller number 5 observed stations (RMSE = 20.9 mm) does not give a better result than using radius 44 km (14 observed station, RMSE = 20.5 mm).

Table 3. The change of RMSE (mm) when using Radius = 44 km

No Station	***167 stations***	***Radius 44 km***
Phnom Penh	19.9	20.5
Veoun Sai	21.6	20.0
Svay Dounkeo	0.5	0.2

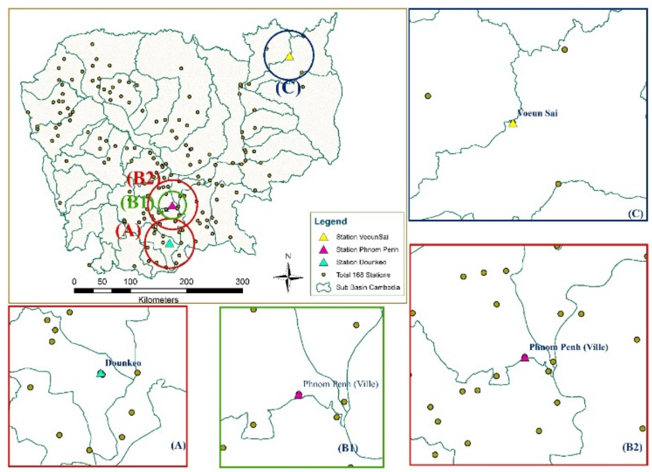

Fig.14. The different interpolation zone using IDW. (A). Stations **Dounkeo** by using radius 6000 km^2. (B1) Station **Phnom Penh** in zone 1800 km^2. (B2) Station **Phnom Penh** in zone 6000 km^2. (C) Station **Veoun Sai** in zone 6000 km^2.

The rainfall change is significantly high compared to the publish report from National Water Status Report. However, it occurs the same highest rainfall (mm) at the coastal area. Anyway, using Inverse distance weighting to interpolate and mapping the rainfall distribution in Cambodia give a high error. The result from all cases show that the very basic input point for interpolation of IDW acquire high density of the observed point. The rain gages distribution is not dense in Cambodia. Even though the distance between observed and estimated point is far from each other, the estimate point will be influenced only the nearer points as many as possible. The total area 181035 km^2 using only 168 observed stations will not sufficient enough to provide a better outcome of the applied method. In different condition of the area interpolation and the numbering point of observed stations can be infered that the observed point must be needed as many as possible to ensure the accuracy of the model performance. The performance of IDW is better than before when using the local stations of the smaller zone for instance, station **Dounkeo**.

4. CONCLUSIONS

The rainfall distribution varies significantly throughout the year and the coastal experienced the highest rainfall almost every year with average rainfall 1447 mm, maximum rainfall 3815 mm and the minimum rainfall 1058 mm. Yet, the root mean square error provides a high error and illustrate somewhat in more critical result references to the observed value and the recorded period for validation. RMSE varies from a minimum 0.5 mm to 34.3 mm of the maximum error for some station of the 56 stations from the partial validation. A search radius and number of observed point is slightly important to control error of the result from interpolation. A sparse observed data must be the result to that high error.

Using only IDW is not lean to decide the most accuracy method and provide an acceptable result. Indeed, toward the further study:

- Using IDW in this large scale, a search radius of around 45 km for interpolated zone extended nearly 6000 km^2 of the nearby point is recommended, when there is the limitation of data distribution.
- IDW would be perform well in a smaller scale than this study area with the dense of observed rain gages (some catchment of the lower Mekong and the Tonle Sap).
- Other methods is recommended to be comparable to the present method; for instance, Ordinary Kriging (Geostatistical Method) for its precious result shown in the previous study area in Belgium (Ly et al., 2011).

The rainfall recorded is needed while the recent use are not enough for the interpolation.

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