EFFECTS OF GEOGRAPHICAL AND TOPOGRAPHICAL CO-VARIABLES ON RAINFALL INTERPOLATION IN LANG SUAN WATERSHED, THAILAND

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ABSTRACT: Latitude, distance from the sea and elevation are climatic controls affect rainfall. Latitude and elevation were used to combine with longitude into rainfall interpolation, application in ecological modeling. This study aims to investigate an appropriate spatial interpolation method of rainfall for application in disaster analysis processes in Lang Suan watershed by evaluating different integration and exclusion of latitude, distance from the sea, elevation and longitude data into spatial interpolation of rainfall. We used spatial interpolation techniques in GIS were inverse distance weighting (IDW), ordinary kriging (OK), simple kriging (SK), ordinary cokriging (OCK), and simple cokriging (SCK), interpolated 30-year mean annual rainfall data (1981-2010) from 14 meteorological stations in Southern Thailand East Coast and West Coast. Distance from the sea, including distance to the Andaman Sea and distance to the Gulf of Thailand data. Integration them were divided 25 types, by adding 1, 2, or 3 geographical and topographical data into interpolation (e.g. 2 data: elevation and latitude data). Cross-validation is used for evaluation. The results showed that: 1) integration latitude, distance from the sea and elevation, climatic controls, were unusually better than exclusion them, 2) effect of longitude on rainfall interpolation was similar latitude, distance from the sea and elevation, 3) appropriate method and co-variable should be considered together, and 4) OCK integrated with elevation, distance to the Andaman Sea and distance to the Gulf of Thailand, 3 climatic controls, was the most accurate model in term of minimum root mean square error (RMSE) and mean absolute error (MAE) values and the coefficient of determination (R^2) value was closer 1 than the other models. It can be concluded that OCK integrated with elevation, distance to the Andaman Sea and distance to the Gulf of Thailand data should be used for application in disaster analysis processes in Lang Suan watershed.

1. INTRODUCTION

Latitude, distance from the sea and elevation are geographical and topographical variables that are called climatic controls like ocean currents, wind and others (McKnight, 1992; Wali et al., 2009; U.S. National Weather Service, n.d). They affect rainfall. For example, distance from the Andaman Sea and the Gulf of Thailand affect monsoon rainfall in Lang Suan watershed, Southern Thailand. Lang Suan watershed is located in tropical area, regions of Chumphon Province, Surat Thani Province, Southern Thailand East Coast, and Ranong Province, Southern Thailand West Coast, between 9°31′0″ N and 10°4′4″ N to 98°37′0″ E and 99°10′0″ E as in Figure 1. It consists of mostly plateaus and mountainous regions in the west of the area that the distance to the Andaman Sea, Indian Ocean about 8 kilometers, and mostly plain and coastal plain regions in the east of the area that the distance to Gulf of Thailand, South China Sea about 30 meters. Monsoon season (mid-May to mid-February), the southwest monsoon (mid-May to mid-October) bring moisture from Indian Ocean to the area, whereas, the northeast monsoon (mid-October to mid-February) bring moisture from the Gulf of Thailand to the area, causing rain over area (Thailand Meteorological Department, n.d.), and also heavy rain triggers landslide and flood, especially heavy rain in the east of the area between September and December. Effects of them on monsoon season can be explained by using statistics, which shown relationship between monsoon rainfall and them, rainfall increased with latitude and elevation, and decreased with distance from the sea (Hayward and Clarke, 1996; Singh and Chattopadhyay, 1998).

Latitude and elevation were used to combine with longitude into spatial interpolation of rainfall for application in ecological modeling in Thailand (Jantakat, 2011). For applications in disaster analysis processes, such as landslide susceptibility zonation (Intarawichian, 2008) and hydrological modeling for impact assessment of land use and climate changes on flood (Phandee, 2011), they have never been integrate into spatial interpolation. However, many studies discovered that integration elevation into spatial interpolation of rainfall more accurate than exclusion it (Goovaerts, 2000; Diodato, 2005).

This study aims to investigate an appropriate spatial interpolation method of rainfall for application in disaster analysis processes in Lang Suan watershed by evaluating different integration and exclusion of latitude, distance from the sea, elevation and longitude data into spatial interpolation of rainfall.

2. MATERIALS AND METHODS

2.1 Data collection, selection and preprocessing

Daily rainfall data from 1981 to 2010 of 14 operating meteorological stations (Figure1, Table 1) was collected from Thailand Meteorological Department and Royal Irrigation Department. It was calculated into mean annual rainfall that was summarized in statistical term as Table 2, and transformed into points in GIS.

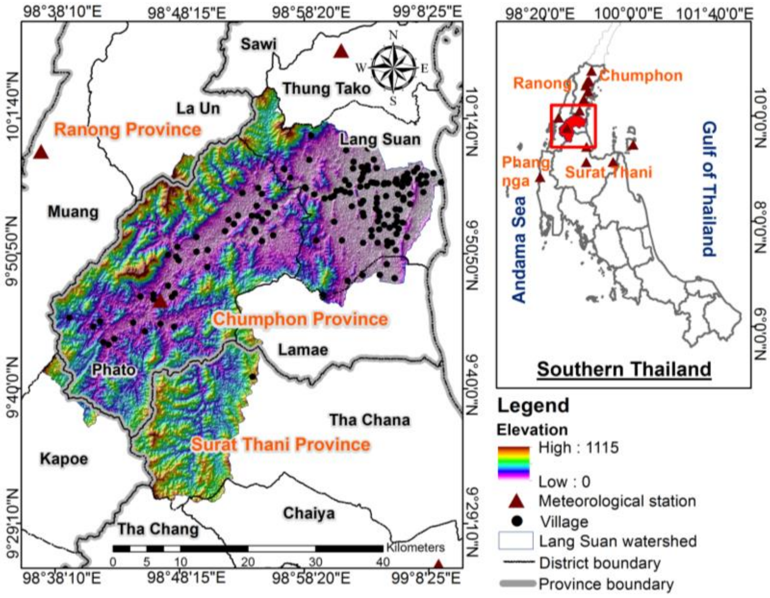

Figure 1. Locations of Lang Suan watershed study area and meteorological stations.

Table 1. Latitude, longitude, distance from the sea, elevation and meteorological stations.

Station	Weather zone	Coordinates		LAT (dd)	LONG (dd)	DISTA (km)	DISTG (km)	ELEV (m)
		X	Y					
Chumphon	East coast	520062.2	1158858	10.48	99.18	39.92	4.80	7
Sawi	East coast	510948.2	1142269	10.33	99.10	35.20	5.14	16
Ban Salui	East coast	527383.4	1201954	10.87	99.25	20.33	20.00	49
Thammachareon	East coast	502434.6	1118496	10.12	99.02	36.75	13.70	34
Ban Yaithai	East coast	522266.3	1181618	10.69	99.20	28.07	12.04	34
Ban Tha Sae	East coast	518744.1	1178790	10.66	99.17	27.60	13.73	23
Ban Wang khok	East coast	515466.6	1171110	10.59	99.14	31.40	12.45	10
Phato	East coast	475659.9	1081557	9.78	98.78	24.00	39.60	58
Ranong	West coast	457985.9	1103594	9.98	98.62	1.68	58.36	89
Surat Thani	East coast	516694.6	1009842	9.14	99.15	82.20	14.50	7
Koh Samui	East coast	615264.2	1046620	9.47	100.05	165.00	0.00	0
Ban Nai Thon	East coast	516833.2	1010274	9.43	99.15	68.44	11.50	23
Surat Thani Agromat	East coast	572852.7	1010274	9.14	99.66	145.00	15.60	25
Takua Pa	West coast	419361.3	978348.1	8.85	98.27	0.20	114.40	9

Table 2. Statistics for 30 year mean annual rainfall (1981-2010), geographical and topographical data.

Statistics	30-yr mean annual Rainfall	LAT	LONG	DISTA	DISTG	ELEV
Minimum	994.00	8.85	98.27	0.20	0.00	0.00
Maximum	4016.40	10.87	100.05	165.00	114.40	89.00
Median	1865.00	10.05	99.15	33.30	13.72	23.00
Mean	2090.17	9.97	99.13	50.41	23.99	27.43
Standard deviation	832.94	0.67	0.42	49.47	30.02	24.31
Skewness	1.43	-0.28	0.17	1.53	2.48	1.38
Kurtosis	1.53	-1.37	1.78	1.63	6.55	1.98
Coefficient of determination (r^2)	-	0.21	0.41	0.09	0.66	0.23

Geographical and topographical data (Table 1, Table 2), distance from the sea in this study including distances to the Andaman Sea (DISTA) and the Gulf of Thailand (DISTG) based on minimum distance from meteorological stations to the coastlines. Latitude (LAT) and longitude (LONG) were decimal degree format of location of stations. Elevation (ELEV) was extracted from the 30-m resolution ASTER GDEM v2 which obtained from Land Processes Distributed Active Archive Center, available at http://gdex.cr.usgs.gov/gdex/. r^2 in Table 2, represents rainfall versus them.

2.2 Interpolation and criteria for models

After data preprocessing, 30-year mean annual rainfall data was interpolated by estimators in GIS (Table 4), including cokriging integrated with geographical and topographical data from data preprocessing step, types of integration them as shown in Table 6, and method that exclusion them were kriging and inverse distance weighting (IDW) that used to interpolate rainfall in disaster analysis processes (Intarawichian, 2008; Phandee, 2011). In this study, IDW used power 2 (Goovaerts, 2000; Ly et al, 2011), kriging and cokriging including ordinary and simple kriging/cokriging, by using spherical semivariogram/covariance models (Goovaerts, 2000; Diodato, 2005) (Table 5). Finally, they were evaluated by using cross-validation (Table 3).

Table 3. Cross-validation evaluated models.

Cross-validation	Formula	Definitions
Coefficient of determination (R^2)	Least square regression, slope intercept	$\hat{Z}(s_o)$: estimated value, $Z(s_o)$: observed value, n : number of observation
Root mean square error (RMSE)	$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\hat{Z}(s_o) - Z(s_o)\right]^2}$	
Mean absolute error (MAE)	$MAE = \frac{1}{n}\sum_{i=1}^{n}\left\lvert\hat{Z}(s_o) - Z(s_o)\right\rvert$	

Table 4. Estimators/spatial interpolation methods and equations interpolated rainfall.

Estimator	Formula, definitions*		Sources
	Systems	Weight	
Inverse distance weighting (IDW)	$\hat{Z}(s_o) = \sum_{i=1}^{N}\lambda_i Z(s_i)$	$\lambda_i = \frac{d_{io}^{-p}}{\sum_{i=1}^{N} d_{io}^{-p}}$, $\sum_{i=1}^{N}\lambda_i = 1$	Isaaks and Srivastava (1989)
Kriging			
Ordinary kriging (OK)	$\hat{Z}(s_o) = \sum_{i=1}^{N}\lambda_i Z(s_i)$	$\begin{cases}\sum_{j=1}^{N}\lambda_j\gamma_{ij} + \mu = \gamma_{io} & for\, i = 1,\ldots,N \\ \sum_{j=1}^{N}\lambda_j = 1\end{cases}$	Webster and Oliver (2007)
Simple kriging (SK)	$\hat{Z}(s_o) = \sum_{i=1}^{N}\lambda_i\left[Z(s_i) - \mu\right] + \mu$	$\sum_{j=1}^{N}\lambda_j\gamma_{ij} = \gamma_{io} \quad for\, i = 1,\ldots,N$	
Cokriging			
Ordinary cokriging (OCK) (1co-variable)	$\hat{Z}(s_o) = \sum_{i=1}^{N}\lambda_i Z(s_i) + \sum_{i=1}^{N}\alpha_i Y(s_i)$	$\begin{cases}\sum_{j=1}^{N}\lambda_j\gamma(Z_i, Z_j) + \sum_{j=1}^{N}\alpha_j\,\gamma(Z_i, Y_j) + \mu_1 = \gamma(Z_o, Z_i)\, for\, i=1,\ldots,N \\ \sum_{j=1}^{N}\lambda_j\gamma(Z_j, Y_i) + \sum_{j=1}^{N}\alpha_i\gamma\,(Y_i, Y_j) + \mu_2 = \gamma(Z_o, Y_i)\, for\, i=1,\ldots,N \\ \sum_{i=1}^{N}\lambda_i = 1 \\ \sum_{i=1}^{N}\alpha_i = 0\end{cases}$	Goovaerts (1998)
Simple cokriging (SCK) (1co-variable)	$\hat{Z}(s_o) = \sum_{i=1}^{N}\lambda_i\left[Z(s_i) - \mu_1\right] + \sum_{i=1}^{N}\alpha_i\left[Y(s_i) - \mu_2\right] + \mu_1$	$\begin{cases}\sum_{j=1}^{N}\lambda_j\gamma(Z_i, Z_j) + \sum_{j=1}^{N}\alpha_j\,\gamma(Z_i, Y_j) = \gamma(Z_o, Z_i) \quad for\, i = 1,\ldots,N \\ \sum_{j=1}^{N}\lambda_j\gamma(Z_j, Y_i) + \sum_{j=1}^{N}\alpha_i\gamma\,(Y_i, Y_j) = \gamma(Z_o, Y_i) \quad for\, i = 1,\ldots,N\end{cases}$	

* $\hat{Z}(s_o)$: rainfall estimated value at o th location (x_o, y_o), $Z(s_i)$: rainfall measured value at i th location (x_i, y_i), $Y(s_i)$: co-variable value at i th location,

N : number of measured point, λ_i, λ_j : the weight at i th, j th location, α_i : the weight of 1 co-variable, $d_{i_o} = \sqrt{(x_i - x_o)^2 + (y_i - y_o)^2}$: distance between the estimated location (x_i, y_i) and each of the measured locations (x_o, y_o), p : a power parameter control weight, μ, μ_1 : in SK,SCK is known constant which were assumed, in OK and OCK is unknown constant which were estimated on weight calculation, μ_2 : known (SK, SCK) and unknown (OK,OCK) constants of 1 co-variable, γ_{ij} :values of semivariogram/covariance based on the distance between the two rainfall measured points at i th and j th locations, γ_{i0} : values of semivariogram/covariance based on the distance between measured point at the i th location and the rainfall estimated point at the o th location, $\gamma(Z_i, Z_j), \gamma(Y_i, Y_j), \gamma(Z_i, Y_j)$: values of semivariogram/ covariance of measured rainfall and 1 co-variable.

Table 5. Semivariogram/covariance models and equations used for kriging and cokriging.

Type	Formula, definitions**	Sources
Experimental (kriging)	Semivariogram: $\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(s_i) - Z(s_i + h)]^2$	Goovaerts (2000)
	Covariance: $C(h) = \frac{1}{N(h)} \sum_{i=1}^{N(h)} [Z(s_i) \cdot Z(s_i + h)] - \left[\frac{1}{N(h)} \sum_{i=1}^{N(h)} Z(s_i)\right]\left[\frac{1}{N(h)} \sum_{i=1}^{N(h)} Z(s_i + h)\right]$	Sun et al. (2003)
Experimental (cokriging)	Semivariogram: $\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(s_i) - Z(s_i + h)][Y(s_i) - Y(s_i + h)]$	Goovaerts (2000)
Spherical model (Sph) (combined with nugget effects)	Semivariogram: $\gamma(h) = \begin{cases} 0 \ for\ h = 0 \\ c_0 + c_1 \left(\frac{3}{2}\left(\frac{h}{a}\right) - \frac{1}{2}\left(\frac{h}{a}\right)^3\right) \ for\ 0 \le h \le a \\ c_0 + c_1 \ for\ a < h \end{cases}$	Ly et al. (2011)
	Covariance: $C(h) = \begin{cases} 0 \ for\ h = 0 \\ c_0 + c_1 \left(1 - \frac{3}{2}\left(\frac{h}{a}\right) + \frac{1}{2}\left(\frac{h}{a}\right)^3\right) \ for\ 0 \le h \le a \\ c_0 + c_1 \ for\ a < h \end{cases}$	Sun et al. (2003)

** $\gamma(h)$: semivariogram at distance h, $C(h)$: covariance at distance h, $N(h)$: number of measured pairs within h, s_i, $s_i + h$:measured locations separated by h, $Z(s_i)$, $Z(s_i + h)$: measured value of rainfall , $Y(s_i)$, $Y(s_i + h)$: co-variable values, $c_0 \ge 0$: nugget effect, $c_1 \ge 0$: partial sill parameter, $a \ge 0$: range parameter, h : distance between two locations, e.g. $h_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$ is distance between two measured points at i th and j th location, $h_{io} = \sqrt{(x_i - x_o)^2 + (y_i - y_o)^2}$ is distance between measured point at i th location and estimated point at o th location.

Table 6. Types of integration geographical and topographical data into estimators interpolated rainfall.

Type	Meaning
ELEV	1 data: Elevation data
DISTA	1 data: Distance to the Andaman Sea data
DISTG	1 data: Distance to the Gulf of Thailand data
LAT	1 data: Latitude data
LONG	1 data: Longitude data
ELEV_DISTA	2 data: Elevation and distance to the Andaman Sea data
ELEV_DISTG	2 data: Elevation and distance to the Gulf of Thailand data
ELEV_LAT	2 data: Elevation and latitude data
ELEV_LONG	2 data: Integration elevation and longitude data
DISTA_DISTG	2 data: Distance to the Andaman Sea and diatance to the Gulf of Thailand data
DISTA_LAT	2 data: Distance to the Andaman Sea and latitude data
DISTA_LONG	2 data: Distance to the Andaman Sea and longitude data
DISTG_LAT	2 data: Distance to the Gulf of Thailand and latitude data
DISTG_LONG	2 data: Distance to the Gulf of Thailand and longitude data
LAT_LONG	2 data: Latitude and longitude data
ELEV_DISTA_DISTG	3 data: Elevation, distance to the Andaman Sea and distance to the Gulf of Thailand data
ELEV_DISTA_LAT	3 data: Elevation, distance to the Andaman Sea and latitude data
ELEV_DISTA_LONG	3 data: Elevation, distance to the Andaman Sea and longitude data
ELEV_DISTG_LAT	3 data: Elevation, distance to the Gulf of Thailand and latitude data
ELEV_DISTG_LONG	3 data: Elevation, distance to the Gulf of Thailand and longitude data
ELEV_LAT_LONG	3 data: Elevation, latitude and longitude data
DISTA_DISTG_LAT	3 data: Distance to the Andaman Sea, distance to the Gulf of Thailand and latitude data
DISTA_DISTG_LONG	3 data: Distance to the Andaman Sea, distance to the Gulf of Thailand and longitude data
DISTA_LAT_LONG	3 data: Distance to the Andaman Sea, latitude and longitude data
DISTG_LAT_LONG	3 data: Distance to the Gulf of Thailand, latitude and longitude data

3. RESULTS AND DISCUSSION

The results of interpolation of 30-year mean annual rainfall by using different estimators/spatial interpolation methods and integration/exclusion geographical and topographical data as shown in Figure 2 and Table 7.

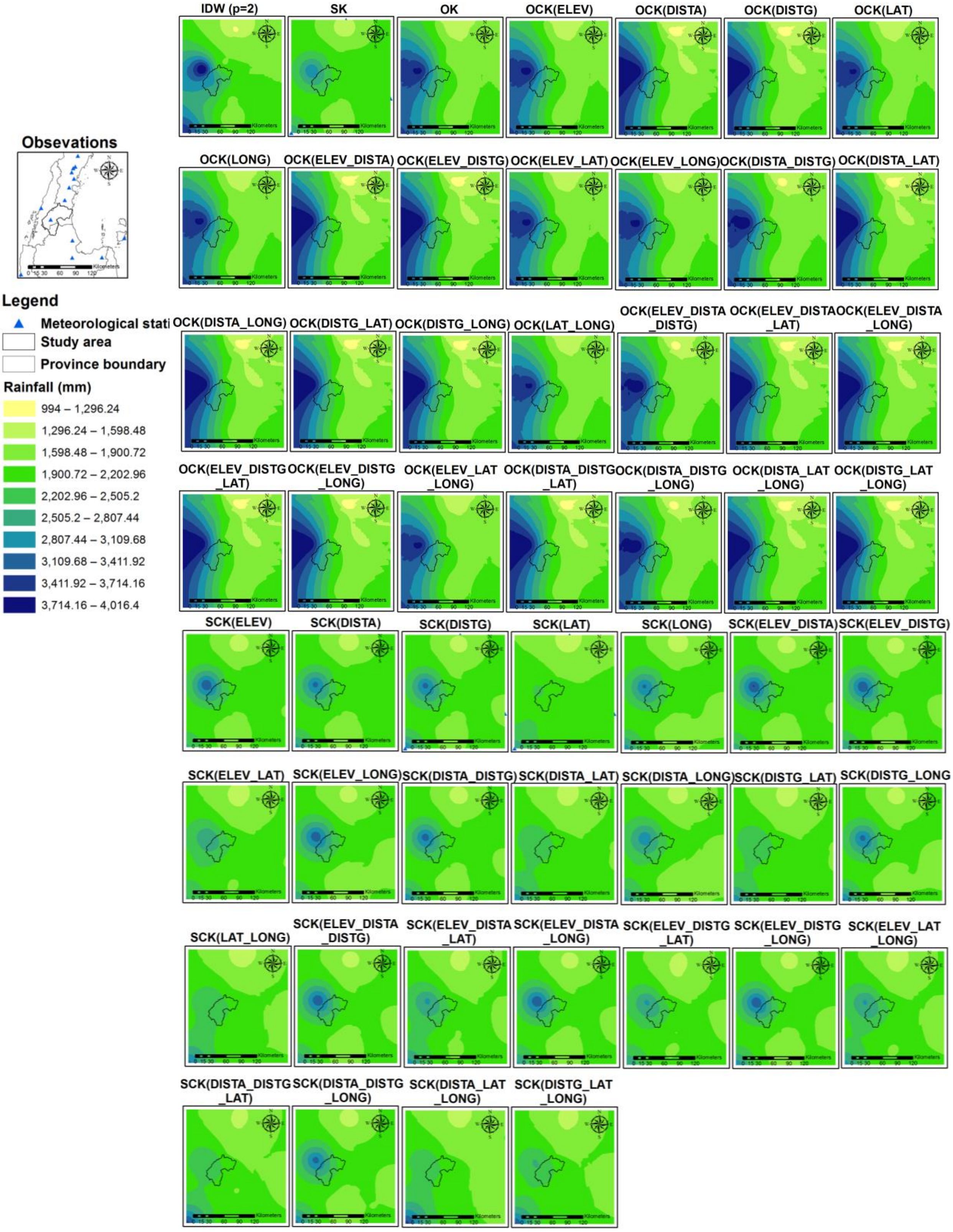

Figure 2. 30-year mean annual rainfall map obtained by interpolation of 14 meteorological stations by using different estimators/spatial interpolation methods and integration/exclusion of geographical and topographical data: IDW, SK, OK, OCK with different integration types, and SCK with different integration types.

Table 7. Cross-validation results from the interpolation of different estimators/spatial interpolation methods and integration/exclusion geographical and topographical data.

Model	Semivariogram/covariance model			Cross-validation		
	Nugget, c_0 (mm^2)	Partial sill, c_1 (mm^2)	Range, a (m)	R^2	RMSE (mm)	MAE (mm)
Inverse distance weighting	-	-	-	0.42	645.94	406.32
Ordinary kriging	51959	761460	123650	0.48	591.01	422.88
Simple kriging	0.30073	0.58999	74976	0.33	695.74	429.26
Ordinary cokriging						
ELEV	51656	752680	121690	0.56	551.60	395.21
DISTA	0	1503300	297280	0.53	561.03	432.68
DISTG	0	1512900	297280	0.61	514.23	402.00
LAT	51716	761380	123280	0.49	580.00	406.93
LONG	51959	761460	123650	0.56	545.97	418.45
ELEV_DISTA	0	1503300	297280	0.54	557.23	430.79
ELEV_DISTG	0	1512900	297280	0.62	510.10	400.37
ELEV_LAT	51656	752680	121690	0.59	529.64	383.66
ELEV_LONG	51656	752680	121690	0.62	514.57	395.18
DISTA_DISTG	0	972430	126590	0.72	428.58	342.69
DISTA_LAT	0	1503300	297280	0.55	550.27	427.27
DISTA_LONG	0	1503300	297280	0.56	545.86	429.82
DISTG_LAT	0	1512900	297280	0.60	515.11	401.17
DISTG_LONG	0	1512900	297280	0.62	504.78	401.26
LAT_LONG	51716	761380	123280	0.56	538.99	402.59
ELEV_DISTA_DISTG	0	972430	126590	0.77	389.15	314.77
ELEV_DISTA_LAT	0	1503300	297280	0.56	545.34	425.06
ELEV_DISTA_LONG	0	1503300	297280	0.56	542.49	428.19
ELEV_DISTG_LAT	0	1512900	297280	0.61	509.82	399.20
ELEV_DISTG_LONG	0	1512900	297280	0.63	501.18	399.85
ELEV_LAT_LONG	52125	753570	122390	0.64	497.60	377.10
DISTA_DISTG_LAT	0	1512900	297280	0.61	512.72	401.08
DISTA_DISTG_LONG	0	994270	131080	0.61	520.49	424.47
DISTA_LAT_LONG	0	1503300	297280	0.57	537.16	424.59
DISTG_LAT_LONG	0	1512900	297280	0.62	506.20	400.42
Simple cokriging						
ELEV	0.30073	0.58999	74976	0.44	630.70	385.62
DISTA	0.30073	0.58999	74976	0.64	590.29	388.12
DISTG	0.30073	0.58999	74976	0.72	504.96	351.57
LAT	0.4708	0.41992	107670	0.30	681.29	464.73
LONG	0.3219	0.56484	79335	0.65	541.48	381.49
ELEV_DISTA	0.30614	0.58488	75777	0.57	575.68	373.11
ELEV_DISTG	0.30075	0.5939	74976	0.67	519.57	359.74
ELEV_LAT	0.42588	0.50117	97900	0.58	575.28	384.48
ELEV_LONG	0.34275	0.5515	81634	0.62	538.41	371.10
DISTA_DISTG	0.30078	0.59764	74976	0.75	488.51	349.14
DISTA_LAT	0.49787	0.42291	112940	0.57	556.25	340.40
DISTA_LONG	0.40334	0.49642	93240	0.68	541.89	381.23
DISTG_LAT	0.42777	0.48919	98507	0.53	582.08	377.22
DISTG_LONG	0.3249	0.56585	78635	0.72	472.07	340.94
LAT_LONG	0.44989	0.47706	103140	0.58	547.47	348.50
ELEV_DISTA_DISTG	0.32497	0.57337	78635	0.71	501.14	355.78
ELEV_DISTA_LAT	0.43529	0.49955	99909	0.78	461.16	315.80
ELEV_DISTA_LONG	0.37493	0.52459	87411	0.64	531.30	366.92
ELEV_DISTG_LAT	0.38327	0.52006	89156	0.67	511.80	377.04
ELEV_DISTG_LONG	0.30074	0.59145	74976	0.74	468.79	346.44
ELEV_LAT_LONG	0.41887	0.51529	96460	0.74	476.87	323.41
DISTA_DISTG_LAT	0.4214	0.47321	97205	0.60	516.29	315.26
DISTA_DISTG_LONG	0.32502	0.5792	78635	0.74	473.16	343.70
DISTA_LAT_LONG	0.46861	0.44286	107060	0.60	516.83	318.61
DISTG_LAT_LONG	0.40422	0.49477	93469	0.62	514.94	316.62

From Figure 2 and Table 7, ordinary kriging (OK) excluded geographical and topographical data and ordinary cokriging (OCK) integrated with elevation data (ELEV) or elevation and latitude data (ELEV_LAT), were similar rainfall map, but OCK integrated with ELEV_LAT with produced R^2, RMSE and MAE value more accurate than ELEV and OK. Meanwhile, OCK integrated with latitude data (LAT), longitude data (LONG) or ELEV data were similar rainfall map, but OCK integrated with LAT or LONG did not produce R^2, RMSE and MAE value as well as ELEV, moreover, their MAE value were more than inverse distance weighting (IDW) that excluded geographical and topographical data. However, their R^2 and RMSE value were accurate than OK and simple kriging (SK) that excluded geographical and topographical data. OCK integrated with distance to the Andaman Sea data (DISTA) and distance to the Gulf of Thailand data (DISTG) were similar rainfall map, but OCK integrated with DISTA did not produce R^2, RMSE and MAE value as well as DISTG, moreover, their MAE value were more than IDW. OCK integrated with distance to the Andaman Sea and latitude data (DISTA_LAT), or distance to the Gulf of Thailand and latitude data (DISTG_LAT) were similar rainfall map but OCK integrated with DISTA_LAT did not produce R^2, RMSE and MAE value as well as DISTG_LAT, moreover, their MAE value were more than IDW. OCK integrated with distance to the Andaman, latitude and longitude data (DISTA_LAT_LONG), elevation, distance to the Andaman Sea and latitude data (ELEV_DISTA_LAT), or distance to the Gulf of Thailand, latitude and longitude (DISTG_LAT_LONG) were similar rainfall map, however OCK integrated with DISTA_LAT_LONG or ELEV_DISTA_LAT did not produce R^2, RMSE and MAE value as well as DISTG_LAT_LONG, moreover, their MAE value were more than IDW.

It is shown that different estimators, both integration and exclusion geographical and topographical data, produced different both rainfall map and cross-validation. Meanwhile, different integration geographical and topographical data into spatial interpolation of rainfall of same estimator produced similar rainfall map, but they produced different cross-validation. Furthermore, integrated 1, 2, or 3 data of latitude, distance from the sea (distance to the Gulf of Thailand and distance to the Andaman Sea), elevation and longitude were unusually more accurate than methods that excluded them (OK, IDW, SK). However, integration elevation data into OCK was more accurate than OK that corresponding with the previous studies (Goovaerts, 2000; Diodato, 2005). In addition, increasing number of different data unusually proved accuracy values of models. Moreover, increasing number of different data unusually proved accuracy values of models such as ELEV and ELEV_DISTA_LAT. While, R^2, RMSE and MAE value of ELEV was more accurate than OK, IDW and SK, MAE value of ELEV_DISTA_LAT was more inaccurate than IDW.

From Table 7, OCK integrated with ELEV or LAT produced R^2, RMSE and MAE values more accurate than SCK integrated with them. Whereas, SCK integrated with DISTA, DISTG or LONG produced R^2, RMSE and MAE values more accurate than OCK integrated with them, OK, IDW and SK. SCK integrated with distance to the Andaman Sea and distance to the Gulf of Thailand data (DISTA_DISTG), or distance to the Gulf of Thailand and longitude data (DISTG_LONG) produced R^2, RMSE and MAE values more accurate than OCK integrated with them, OK, IDW and SK. Moreover, R^2 values of both DISTA_DISTG and DISTG_LONG were very high ($R^2 = 0.75$ and $R^2 = 0.72$), while, RMSE and MAE values of both DISTA_DISTG and DISTG_LONG were very low (DISTA_DISTG: RMSE = 488.51 mm, MAE = 349.14 mm; DISTG_LONG: RMSE = 472.07 mm, MAE = 340.94 mm). SCK integrated with elevation, distance to the Andaman Sea and latitude data (ELEV_DISTA_LAT), or elevation, latitude and longitude data (ELEV_LAT_LONG) produced R^2, RMSE and MAE values more accurate than OCK integrated with them, OK, IDW and SK. Moreover, they produced very high R^2 and very low RMSE and MAE values (ELEV_DISTA_LAT: $R^2 = 0.78$, RMSE = 461.16 mm, MAE = 315.80 mm; ELEV_LAT_LONG: $R^2 = 0.74$, RMSE = 476.87 mm, MAE = 323.41 mm). OCK integrated with elevation, distance to the Andaman Sea and distance to the Gulf of Thailand data (ELEV_DISTA_DISTG) produced R^2, RMSE and MAE values more accurate than SCK integrated with them, OK, IDW and SK. Furthermore, it produced very high R^2 and lowest RMSE and MAE values ($R^2 = 0.77$, RMSE = 389.15 mm, MAE = 314.77 mm).

It is shown that, integration types which included 2 or 3 geographical and topographical data that were climatic controls affect rainfall (e.g. DISTA_DISTG) were unusually more accurate than integration types which included 1 or 2 geographical and topographical data that were climatic controls and 1 geographical data that was not climatic control (e.g. DISTG_LONG). In addition, combination of elevation, latitude and longitude data that were used integration into rainfall interpolation for application in ecological modeling (Jantakat, 2011) was good co-variable for SCK estimator, but for OCK was not. Good co-variable for OCK was unusually good co-variable for SCK. They were uncertainly appropriate co-variables. Appropriate method and co-variable should be considered together. In this study, OCK integrated with elevation, distance to the Andaman Sea and distance to the Gulf of Thailand, 3 geographical and topographical data that were climatic controls affect rainfall was most accurate models.

4. CONCLUSIONS & RECOMMENDATIONS

From the results and discussion, it is shown that: 1) integration latitude, distance from the sea and elevation, climatic controls, were unusually better than exclusion them, 2) effect of longitude on rainfall interpolation was similar latitude, distance from the sea and elevation, 3) appropriate method and co-variable should be considered together, and 4) ordinary cokriging (OCK) integrated with elevation, distance to the Andaman Sea and distance to the Gulf of Thailand, 3 climatic controls, was the best method. It was better than kriging and inverse distance weighting methods that used to interpolated rainfall for application in disaster analysis processes in Thailand were kriging (Intarawichian, 2008; Phandee, 2011). Therefore, it was used for application in disaster analysis processes in Lang Suan watershed next study. We expected it is possibly used for further applications which related with rainfall interpolation such as hydrological/forest ecological modeling and weather/disaster forecasting in Lang Suan watershed or similar areas. For other areas that were difference, it is recommended that it should be evaluated types of integration geographical and topographical data and estimators together with considering,

1) Types of semivariogram/covariance models of geostatistical estimators (e.g. kriging, cokriging).
2) Models of non-integrated co-variables methods such as changing of power parameter in IDW models.

Evaluation these, would improve confirmation the results of rainfall interpolation.

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REFERENCES

Diodato, N., 2005. The influence of topographic co-variables on the spatial variability of precipitation over small regions of complex terrain. International Journal of Climatology, 25, pp. 351-363.

Goovaerts, P., 1998. Ordinary cokriging revisited. Mathematical Geology, 30 (1), pp. 21-42.

Goovaerts, P., 2000. Geostatistical approaches for incorporating elevation into the spatial interpolation of rainfall. Journal of Hydrology, 228, pp. 113-129.

Hayward, D., and Clarke, R. T., 1996. Relationship between rainfall, altitude and distance from the sea in the Freetowm Peninsula, Sierra Leone. Hydrological Sciences Journal, 41 (3), pp. 377-384.

Intarawichian, N., 2008. A comparative study of analytical hierarchy process and probability analysis for landslide susceptibility zonation in lower Mae Chaem watershed, Northern Thailand. Doctoral dissertation, Suranaree University of Technology, Nakhon Rat Chasima, Thailand.

Isaaks, E. H., and Srivastava, R. M., 1989. Inverse distance methods. In: Applied geostatistics. Oxford University Press, Inc., New York, pp. 257-259.

Jantakat, Y., 2011. Prediction of forest type distribution using ecological modeling in Ping basin, Thailand. Doctoral dissertation, Suranaree University of Technology, Nakhon Rat Chasima, Thailand.

Ly, S., Charles, C., and Degre, A., 2011. Geostatistical interpolation of daily rainfall at catchment scale: the use of several variogram models in the Ourthe and Ambleve catchments, Belgium. Hydrology and Earth System Science, 15, pp. 2259-2274.

McKnight, T. L., 1992. The study of climate: Climatic controls. In: Physical geography. Prentice Hall, Inc., New Jersey, pp. 61-63.

Phandee, W., 2011. Development of Grid-Based hydrological model for impact assessment of land use and climate changes on flood in Chiang Mai municipality area. Doctoral dissertation, Suranaree University of Technology, Nakhon Rat Chasima, Thailand.

Singh, G. P., and Chattopadhyay, J., 1998. Relationship between mid-latitude circulation indices and Indian Northeast Monsoon Rainfall. Pure and Applied Geophysics, 152, pp. 811-818.

Sun, X., Manton, M.J., and Ebert, E.E., 2003. Regional rainfall estimation using double-kriging of raingauge and satellite observations, BMRC Research Report No. 94, the Bureau of Meteorology, Melbourne, Australia.

Thailand Meteorological Department, n.d. Climate of Thailand. Retrieved August 5, 2015,
from http://www.tmd.go.th/en/downloads.php.

U.S. National Weather Service, n.d. Factors that influence climate. Retrieved August 5, 2015,
from http://www.climateandweather.net/global-warming/factors-that-influence-climate.html.

Webster, R., and Oliver M. A., 2007. Local estimation on prediction: kriging. In: Geostatistics for environmental scientists. John Wiley & Son, Ltd., Chichester, pp. 153-184.

Wali, M. K., Evrendilek, F., and Fennessy M. S., 2009. Atmosphere, climate, and organism. In: The environment: science, issues, and solutions. CRC Press Taylor and Francis Group, Florida, pp. 33-50.