THE USE OF GIS IN ESTIMATING RAIN FALL EROSIVITY FACTOR OF ONKAPARINGA WATERSHED- SOUTH AUSTRALIA

Trias Rahardianto

Civil Engineering Department of the State Polytechnic of Malang
E-mail: trias.polinema@gmail.com

Abstract

The study is aimed at the examination of spatial distribution of rainfall to produce rainfall erosivity map in Onkaparinga watershed, utilising Geographic Information System (GIS). Rainfall data was obtained from rainfall stations in and around the watershed as monthly precipitation data. Ordinary least square (OLS) method implemented to observe the relationship between rainfall erosivity as dependent variable, and both of rainfall and elevation as the explanatory variable. To create the continous surface of the site specific monthly and annual average precipitation data, the universal kriging interpolattion was implemented. The regression model shows that 96% of the predicted R factor value matches the observed R factor value. The result of this study is characterised the rainfall on the watershed as high temporal variability.

Keywords : GIS, DEM, Universal kriging, OLS, Rainfall erosivity

1. INTRODUCTION

Soil erosion caused by rainfall and its impact on land productivity is recognized as a major environmental problem in Australian land management. It also reduces the quality of water in streams and water storages. On the other hand, conducting soil erosion assessment is time consuming, and the availability of soil erosion rate distribution data across the nation is limited *(Lu et al.,2001)*. The identification of area which prone to soil erosion is required to minimise the degradation of soil productivity and water quality as well as optimisation of the resource's used for soil conservation. Therefore, the study on soil erosion distribution could contribute to the information adequacy for land management practices.

The main cultivated area of South Australia region and some of other states across the coastal region are indicated to experience large soil erosion rate *(Bui et al., 2010)*. Therefore, the monitoring and controlling the soil resources over the long term is demanded, and it was expressed in a recent report undertaken by the Australian government through the Department of Agriculture, Fisheries and Forestry, as noticed by Leys et al (2009) cited in *(Bui et al., 2010)*.In this case, national soil resources monitoring and controlling are aimed to provide information on soil conditions for prioritising government investments, and discovering the impact of improved land management practices on soil erosion.

The national scale soil erosion observation of Australia performed by Lu et al. (2001) aimed to provide the estimation of nationwide soil erosion. The authors claimed that the information could be used as identification of vulnerable catchment and some other purposes related to soil erosion.However, it also suggested for not using that information to estimate soil erosion rate in a finer scale, therefore further investigation is required to achieve the better estimation *(Lu et al., 2001)*.

Soil erosion assessment could be conducted using empirical models which are developed based on observations. The effectiveness of empirical models when implemented on the area outside the range of experimental condition where they were developed should be considered. However, implementations of these methods across the world is appropriate with the adjustment on the value of relevant factors*(Renard and Freimund, 1994)*. In addition, the adjustment that is made should refer to the condition of the location where the models will be implemented.

The magnitude and complexity of parameters interaction causing soil erosion are somehow raising the problem in soil erosion modelling. Several assessment methods and models have some limitations to provide adequate information about soil erosion spatially and temporally. To meet these limitations of information adequacy are by means costly, time-consuming and biased*(Dabral et al., 2008)*. However, current developments in the implementation of remote sensing (RS) and geographic information system

(GIS) on soil erosion study offer considerable potential solution to meet these requirements. The GIS is an efficient tools in managing spatial data which could be derived from RS technique, therefore these tools and techniques have been implemented in many studies on soil erosion *(Lee, 2004)*.

Vulnerability to soil erosion varies from watershed to watershed depending on the configuration of some parameters. They are topography, soil characteristics, local climatic conditions and the land use and management practices. *(Renard et al., 1997)*. Among all parameters, rainfall as an eroding agent is the most important factor which results in the soil erosion. It represents a natural environmental constraint that restrains and controls the land uses and management practices *(Angulo Martinez et al., 2009)*. The R factor usually refers to the impact of rainfall on soil surface. Therefore, R factor is commonly known as the best indicator of the erosive potential of raindrops impact.

The R factor is defined as total storm energy (E) times the maximum 30 minutes rainfall intensity (I_{30}). The total storm kinetic energy is notated by (E) in foot-tons per acre, while (I) is rainfall intensity in inches per hour *(Wischmeier and Smith, 1978)*. To estimate R factor in one region requires the sufficiency of rainfall data which are derived from pluviographic records. However, in many parts of the world the availability of this information is not easy and even hard to get.Similarly, the processing of this kind of information by some means is time-consuming and hard-working *(Silva, 2004)*. Consequently, formulating equation to estimate the spatial distribution of rainfall as well as R factor are necessary.

Marquinez et al.(2003) indicated that the accuracy of precipitation data only exist in the location of climatic station where the data derived *(Marquínez et al., 2003)*. Since the availability of climatic station in one area is limited, the interpolation method is then required to fill the gap of data between stations as well as to generate isoerodent map of rainfall erosivity factor. Many studies implement interpolation method to observe the spatial distribution of climate variable *(Silva, 2004, Angulo Martinez et al., 2009)*, and achieve the satisfactory isoerodent map even though implement on area that has limited data *(Pandey et al., 2009)* and complex terrain *(Hofierka et al., 2002)*. However, interpolation technique only reflect spatial relationship of precipitation data without considering topological properties *(Marquínez et al., 2003)*.

Spreen (1947) and Smith (1979) stated that there are relationship between precipitation and elevation. Some other studies have also developed relationship between precipitation and another topographic variables such as altitude, distance from the sea, etc. *(Ninyerola et al., 2007, Marquínez et al., 2003)*. One method to find examine relationship between variables is through statistical tool named regression analysis *(Post et al., 2006)*.

Since there is an indication of large soil erosion rates in main cultivated area of South Australia region, the purpose of the study istherefore to examine the spatial distribution of rainfall to produce rainfall erosivity map in Onkaparinga watershed. This study will utilize GIS tools to models the interaction between climates and topography to obtain rainfall erosivity map as the main trigger of soil erosion by water.

3. STUDY AREA

The study is addressed on Onkaparinga watershed of South Australia. Onkaparinga watershed with approximately 562 km^2 in area and 95 km length flows from its source near Mount Torrens in the Mount Lofty Ranges, and flows in south west direction to an estuary at Port Noarlunga. The Onkaparinga River is the second major river of the Adelaide region, after the River Torrens. Much of its flow diverted through a tunnel from the Clarendon Weir to the Happy Valley Reservoir, that in turn contributes some 40 % of Adelaide's water supply.*(Cryer, 2011)*.
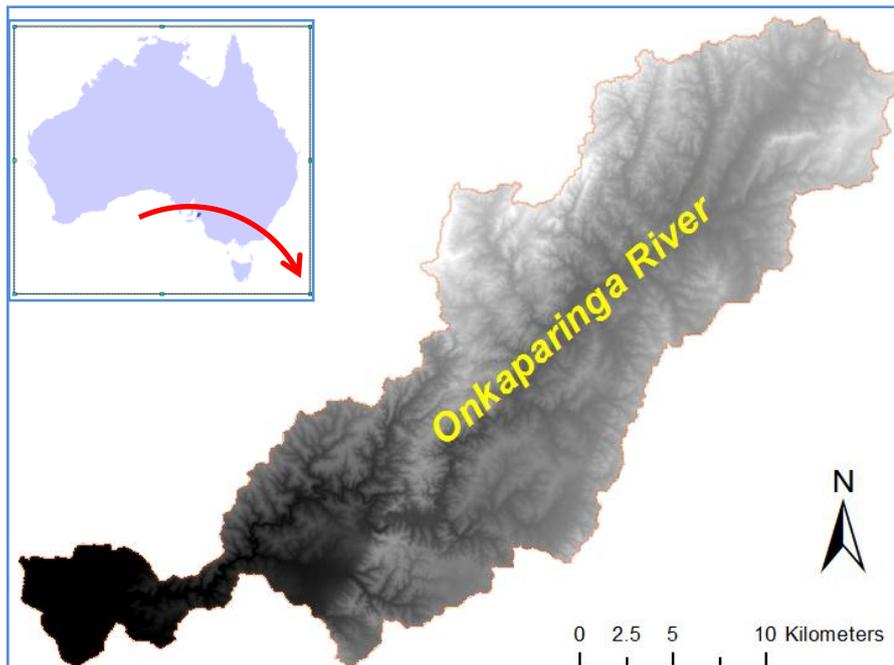
Fig. 1. The Onkaparinga watershed used as study area

The eastern part of the study area is gently sloping hills with major topography dominated by high summit pane plain. The elevation ranges from the lowest point of +0.5 m at the western side to 711 m above the mean sea level. The soil type is dominantly yellow mottled coarse sandy material which is moderately permeable in nature. The rising Mount Lofty range provides a good height to block the warm moist air blowing from the southwest, bringing rainfall mostly in spring and winter seasons and making it one of the highest rainfall receiving regions in South Australia. Grazing is the predominant type of land use in the area. The catchment also upholds a varieties of agriculture and horticulture activities*(Cryer, 2011)*.

3. MATERIALS AND METHODS

3.1 Data preparation

All maps produced are projected in GDA 1994, South Australia Lambert Conformal Conic Projection coordinate system.

3.2 Meteorological data

The rainfall maps are developed from rainfall data which downloaded from climatic stations located in and around the study area which available online through the Australian Bureau of Meteorology website. The type of derived rainfall data is monthly rainfall data of at least ten years, but most of them had a continuous recording for more than 20 years. The derived data conveyed no information related to rainfall intensity records as they were not freely available.

3.3 Elevation data

The elevation map of study area is represented by digital elevation model (DEM). The raw data of DEM were spot heights and contour feature map of South Australia. Using topo to raster tools in ArcGIS 10 environment then DEM was generated in 10m x 10m resolution.

Method

Since the absent of rainfall intensity and total storm energy, the monthly rainfall data then were used for computing R factor. The method applied by Renard and Freimund (1994) and later by Dabral et al. (2008) and Pandey et al. (2009) is applied here *(Renard and Freimund, 1994, Dabral et al., 2008,Pandey et al., 2009)*. The equation (1) is:

$$R = \sum_{i=1}^{12} 1.735 \times 10^{(1.5\frac{\log 10 (p_i 2)}{p})-0.08188)} \tag{1}$$

Where:

R = rainfall erosivity factor (MJ.mm.ha^{-1}h^{-1}year^{-1}),

Pi = monthly rainfall (mm.yr^{-1}), and

P = annual rainfall (mm.yr^{-1}).

The site specific data of monthly and annual average precipitation were established from equation (1). Subsequently, to create the continous surface which represent the distribution of monthly R value, interpolation techniques was then beutilized. The 10 meter resolution of monthly R value distribution map were derived using universal Kriging interpolation for this technique showed the consistentperformance and provided reliable estimation *(Naoum and Tsanis, 2004, Lu et al., 2001)*.

In GIS environment, regression analysis is defined as a set of statistical techniques for examining, modelling, and exploring data relationships and spatial data relationships *(Scott and ESRI, 2009)*. Linear regression analysis is aimed to explore relationship between two or more variables, and also to predict the independent variable, Ott and Longnecker (2001) cited in*(Post et al., 2006)*. The linear regression equation could be express as follow *(Scott and ESRI, 2009)*:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_n X_n + \mathcal{E} \tag{2}$$

Where:

Y = dependent variable which will be modelled,

X = explanatory variable which impacting independent variable,

β = values which reflect how strong or weak and logical relationship between explanatory variable and dependent variable,

$\mathcal{E}$ = residual which reflect the portion of dependent variable that is not explained by the model.

Post et al., (2006) propose the use of linear regression analysis to estimate R factor as a function of average annual precipitation and elevation *(Post et al., 2006)*, therefore the equation model of R factor estimation is modified as follow:

$$R = \beta_1 P + \beta_2 E + \mathcal{E} \tag{3}$$

Where:

R = dependent variable which reflectsRainfall erosivity factor,

P = explanatory variable which reflects precipitation data processing from daily or monthly data,

E = explanatory variable which reflects elevation of any observation point,

β = values which reflect how strong or weak and logical relationship between explanatory variable and dependent variable,

$\mathcal{E}$ = residual which reflect the portion of dependent variable that is not explained by the model.
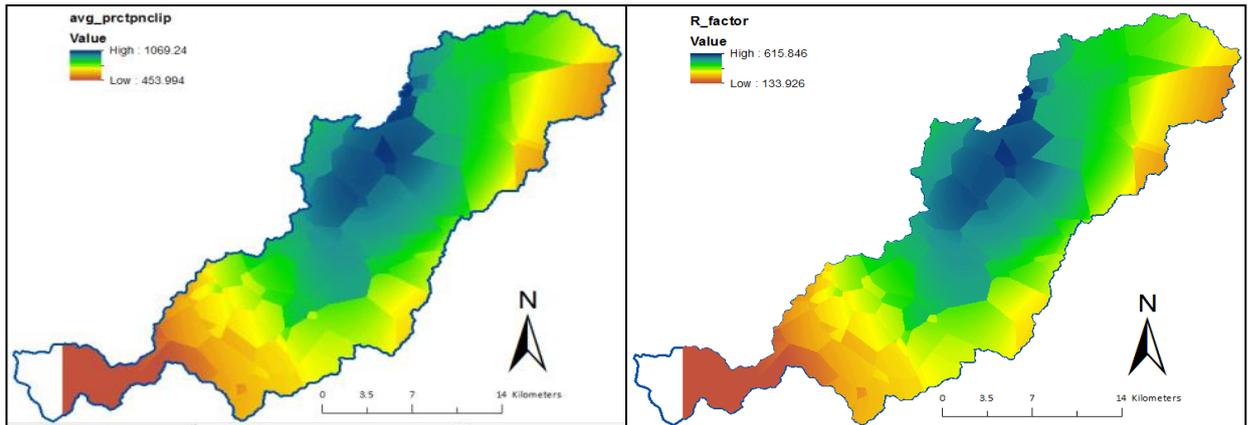
Fig. 2. Comparison of (a) Annual Average Rainfall (in mm/yr) and (b) annual erosivity maps (in $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$)

Once reliable R factor equation is established, then the R factor can be determined. The estimation of R factor is performed by substituting explanatory variables with raster grid maps which obtained from interpolation technique, using raster calculator tools in GIS. Explanatory P is substituted by raster grid of precipitation data, while explanatory E with raster grid of elevation. The final output of this process is R factor estimation map.

4. RESULTS AND DISCUSSION

Figure 2 represents the distribution maps comparison of both annual average rainfall and the annual erosivity index. The annual average rainfall shows a range of 453.994-1069.24, with the lowest value falls in western region which have low elevation in average (fig. 3). On the other hand, the R factor shows the very similar pattern to annual rainfall map with the minimum value of 133.9, maximum value of 615.85 and 448.965 in average ($MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$).
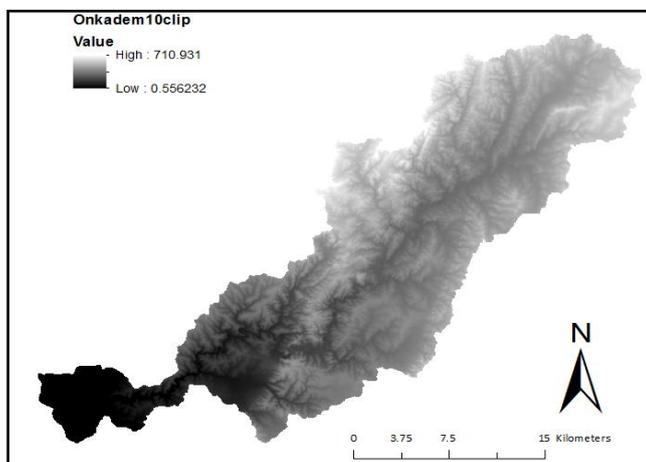

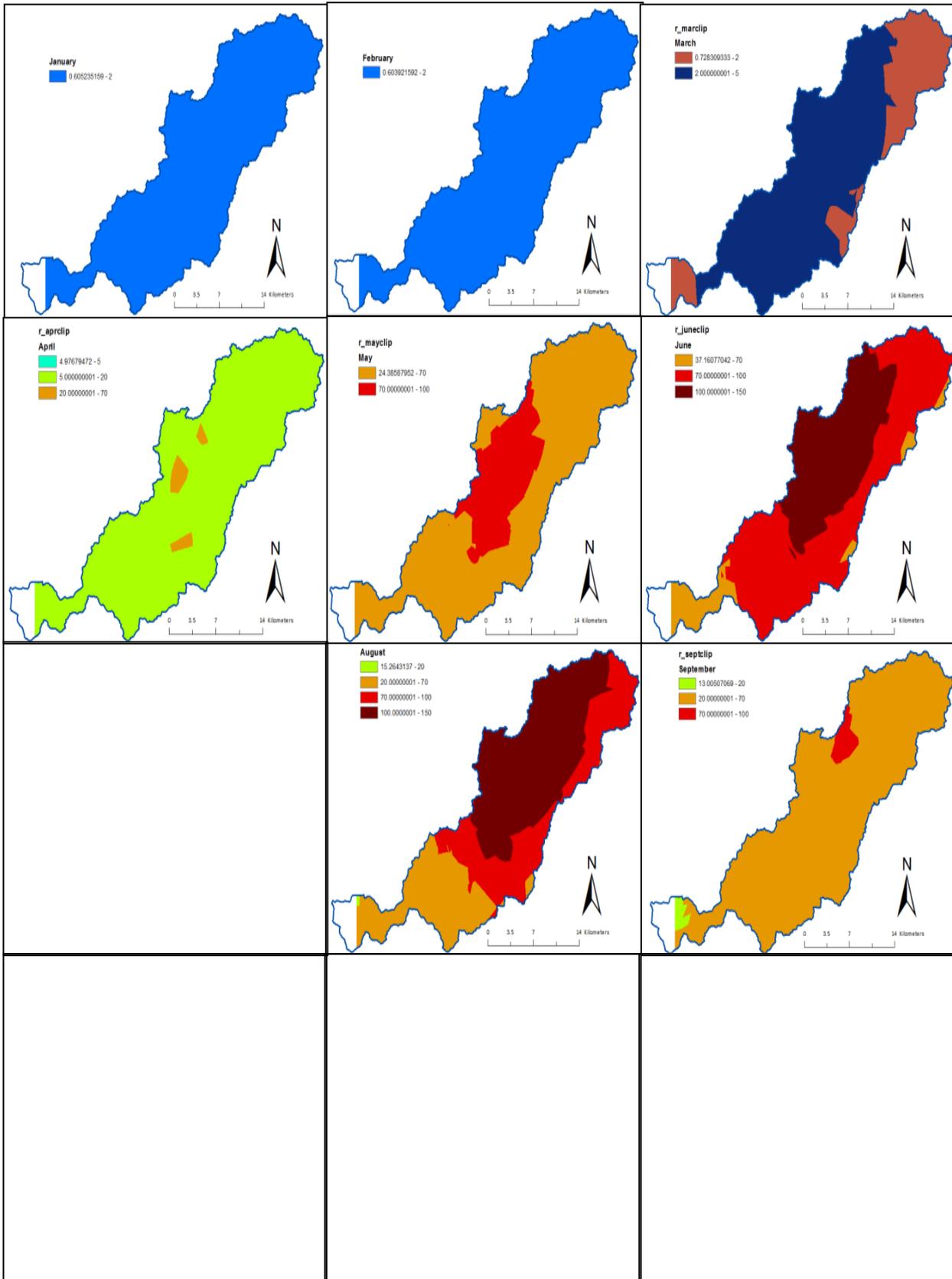Fig. 3. The digital elevation model of Onkaparinga watershed

Fig. 4. Distribution of monthly rainfall erosivity rate

The R factor map was derived using ordinary least square method involving rainfall parameter and topographic variation according to the following equation:

$$R_{factor} = 0.788P - 0.006E - 223.31 \tag{4}$$

Where, **P** represents the annual average rainfall, and**E** is elevation.

The relevance of the model was evaluated through the linear regression equation. The coefficient of precipitation shows the positive sign mean the rainfall erosivity will increase with the rainfall. While the elevation shows very weak correlation in negative sign, which seems illogical. This weak correlation is evident from figure 2 where both maps show the very similar pattern. In other words, it can be concluded that the rainfall is not impacted by elevation or the contribution is very weak.The statistical significant probabilities conforms that the elevation is not statistically significant to the model, therefore it is suggested not to be involved in analysis.

On the other hand, this model explains that 96% of the predicted R factor value matches the observed R factor value, indicated by the adjusted R-square value of 0.961.

The monthly erosivity maps are presented in figure 4, shows the monthly erosivity factor from January to March ranges from 0.6-3.4 (MJ.mm.ha^{-1}.h^{-1}.yr^{-1}). These are the lowest values compare with the value of other months. The rainfall erosivity factor on April seems to be increased from 4.98 to 78.27 (MJ.mm.ha^{-1}.h^{-1}.yr^{-1}), which is in line with the increase of the rainfall amount. This value is then raise significantly during May to August. The average rainfall erosivityfactor show the highest rate during June to August, and the peak falls on July with the rate of 180.52 (MJ.mm.ha^{-1}.h^{-1}.yr^{-1}).On September, the erosivity rate declines in the range of 13–76 (MJ.mm.ha^{-1}.h^{-1}.yr^{-1}). The erosivity rate is dropped from 25.65 (MJ.mm.ha^{-1}.h^{-1}.yr^{-1}) as the highest rate on October to the lower peakof 6.59 (MJ.mm.ha^{-1}.h^{-1}.yr^{-1}) on November. Thedecreases of this rainfall erosivity factor continued and reach the lowest value of0.96 (MJ.mm.ha^{-1}.h^{-1}.yr^{-1}) during December. This fluctuation of rainfall erosivity factor result seems to be characterised by high temporal variability, which relevant to the climatic condition of South Australia.

5. CONCLUSION AND RECOMMENDATION

The research demonstrates the implementation of GIS to model the relationship between rainfall erosivity, precipitation distribution and elevation. It also reveals the implementation of universal kriging interpolation to create the continous surface of the site specific precipitationdata as a map which is examined in monthly and annual average basis. The comparison between annual erosivity map and annual precipitation shows there seem that the range of elevation in study area give no impact to the result of annual rainfall erosivity. On the other hand, the monthly precipitation shows dynamic variability from month to month. It could be concluded that the rainfall erosivity index in Onkaparinga watershed could be characterised by high temporal variability.

The noticeable bias when performing regression analysis is shown by Jarque-Bera test which reflects the residuals value. Therefore, the selection of rainfall data and site observation are necessary to validate the result.

6. REFERENCE

ANGULO MARTINEZ, M., LOPEZ VINCENTE, M., VINCENTE SERRANO, S. M. & BEGURIA, S. 2009. Mapping Rainfall Erosivity at A Regional Scale: a comparison of interpolation methods in the Ebro Basin (NE Spain). *Hydology and Earth System Science,* 13**,** 1907-1920.

BUI, E. N., HANCOOCK, G. J., CHAPPELL, A. & GREGORY, L. J. 2010. Evaluation of tolerable Erosion Rates and Time to Critical Topsoil Loss in Australia. *In:* CSIRO (ed.) *National Research FLAGSHIPS Sustainable Agriculture.* Canberra: The Australian Government's Caring for our Country.

CRYER,A. B. 2011. *Onkaparinga River Explained* [Online]. Available : http://everything.explained.at/Onkaparinga_River/ [Accessed on October 2011].

DABRAL, P. P., BAITHURI, N. & PANDEY, A. 2008. Soil Erosion Assessment in a Hilly Catchment of North Eastern India Using USLE, GIS and Remote Sensing. *Water Resources Management,* 22**,** 1783-1798.

HOFIERKA, J., PARAJKA, J., MITASOVA, H. & MITAS, M. 2002. Multivariate Interpolation of Precipitation Using Regularized Spline with Tension. *Transactions in GIS,* 6**,** 135-150.

LEE, S. 2004. Soil erosion assessment and its verification using the Universal Soil Loss Equation and Geographic Information System: a case study at Boun, Korea. *Environmental Geologi,* 45**,** 457-465.

LU, H., GALLANT, J., PROSSER, I. P., MORAN, C. & PRIESTLEY, G. 2001. Prediction of Sheet and Riil Erosion Over the Australian Continent, Incorporating Monthly Soil Loss Distribution. *In:* WATER, C. L. A. (ed.) National *Land & WAter Resource Audit.* Natural Heritage Trust.

MARQUı́NEZ, J., LASTRA, J. & GARCı́A, P. 2003. Estimation models for precipitation in mountainous regions: the use of GIS and multivariate analysis. *Journal of Hydrology,* 270**,** 1-11.

NAOUM, S. & TSANIS, I. K. 2004. Ranking Spatial Interpolation Techniques Using a GIS-based DSS. *Global Nest: the International journal,* 6**,** 1-20.

NINYEROLA, M., PONS, X. & ROURE, J. M. 2007. Monthly precipitation mapping of Iberian Peninsula using spatial interpolation tools implemented in a Geographic Information System. *Theoritical and Applied Climatology,* 89**,** 195-209.

PANDEY, A., MATHUR, A., MISHRA, S. K. & MAL, B. C. 2009. Soil Erosion Modelling of a Himalayan Watershed Using RS and GIS. *Envronment Earth Science,* 59**,** 399-410.

POST, C. J., GODDARD, M. A., MIKHAILOVA, E. A. & HALL, S. T. 2006. Advanced GIS Exercise: Predicting Rainfall Erosivity Index Using Regression Analysis. *Journal of Natural Resource and Life Science Education,* 35**,** 113-117.

RENARD, K. G., FOSTER, G. R., WEESIES, G. A., MCCOOL, D. K. & YODER, D. C. 1997. A guide to Conservation Planning With The Revised Universal Soil Loss Equation (RUSLE). *Agriculture Handbook.* Washington DC: U.S. Department of Agriculture.

RENARD, K. G. & FREIMUND, J. R. 1994. Using monthly precipitation data to estimate the R-factor in the revised USLE. Journal *of Hydrology,* 157**,** 287-306.

SCOTT, L. & ESRI 2009. Regression analysis Basics in ArcGIS 9.3. New York: ESRI.

SILVA, A. M. D. 2004. Rainfall Erosivity Map for Brazil. *Catena,* 57**,** 251-259.

WISCHMEIER, W. H. & SMITH, D. D. 1978. Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. *Agriculture Handbook.* Washington DC: US Department of Agriculture.