# Estimation Rainfall-Runoff Erosivity Factor of RUSLE equation in the Euphrates River Watershed by GIS Modeling

# تخمين عامل انسابية الامطار لمعادلة RUSLE في جابية نهر الفرات بواسطة موديل نظم المعلومات الجغرافية

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## Abstract

The average annual erosion losses of the Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE) models with tons/acre/year units were depended on the rainfall-runoff erosivity factor (R) with US units in the present study. The (R) factor is mainly depended on precipitation data, the rainfall data can be derived from the thirty one gauge stations that spreading inside and outside of the Euphrates watershed basin which located in Iraq. The Inverse Distance Weighting (IDW) is the interpolation method to estimate the cell values at unknown location of map based on the distance between the unknown cell and the known points. The (IDW) method was provided in ArcMap 10.2 software. The precipitation data of watershed basin is classified into six category that ranging from 85.392 mm to 159.314 mm. The maximum watershed area of precipitation data is about 37% of entire area, it is ranged from 112 mm to 124 mm. The R factor with US units of the Euphrates watershed basin can be ranged from 3.653 to 9.998 hundred ft.ton.in.acre$^{-1}$.h$^{-1}$.year$^{-1}$.

**Keywords:** Erosion, RUSLE, Rainfall-Runoff Erosivity, Precipitation, Euphrates Basin

## الخلاصة

المعدل السنوي لفقدان التاكل لموديل معادلة فقدان التربة العالمية (USLE) ومعادلة فقدان التربة العالمية المنقحة (RUSLE) بوحدات طن/ فدان/ سنة كانت تعتمد على وحدات معامل انسيابية الامطار (R) بوحدات قياس عرفية امريكية US لهذه الدراسة الحالية. المعامل R يعتمد بصورة رئيسية على بيانات هطول الامطار ، بيانات هطول الامطار ممكن اشتقاقها من واحد وثلاثون محطة قياس والتي منتشرة في داخل وخارج حوض جابية الفرات والواقة في العراق. مقياس الترجيح العكسي (IDW) هو طريقة استيفاء لتخمين قيم الخلية مجهولة الموقع للخارطة بالاعتماد على المسافة بين الخلية المجهولة والنقاط المعلومة. طريقة (IDW) متوفرة في برنامج ارك ماب 10.2. البيانات لهطول الامطار لحوض الجابية ممكن تقسيمها الى ستة اصناف والتي تتراوح من 85.392 ملم الى 159.314 ملم. اعظم مساحة جابية لبيانات هطول الامطار تبلغ حوالي 37% من المساحة الكلية ، لها تراوح من 112 ملم الى 124 ملم. المعامل R بوحدات قياس امريكية US لحوض جابية الفرات كانت متراوحة من 3.653 الى 9.998 مئة قدم.طن.انج.فدان$^{-1}$.هكتار$^{-1}$.سنة$^{-1}$.

## 1- Introduction

The major reasons of the natural erosion loss are tectonic uplift, weathering, chemical breakdown and the long time action of water, wind, gravity and snow [15]. Since the raindrop is arrived and impacted on the ground surface detaches the particles, so the splash erosion was occurred [13]. The next phenomena, the rills were received the detaching particles by a thin overland flow. Rill erosion is an erosion process that happens when water from the sheet erosion assembly to form minor small concentrated channels [8]. This erosion is the most common kind of the ground erosion. After the water concentration in the rill, the water is transported to large channel as results the gully erosion [8]. When the concentration water is formed from rills and gullies, and the sediment is detached from streambed and bank of stream, the stream channel erosion is occoured [8]. Since the quantity of separation soil overcomes capacity, the sediment particles according to the transport capacity will be carried out to the downslope and the deposition of sediment in the streambed. There are many models to compute the soil erosion loss by identify the project areas of the conservation methods [1]. The most important of empirical models for estimation the soil loss erosion is the Universal Soil Loss Equation (USLE) [7]. The Revised Universal Soil Loss Equation (RUSLE) was developed in 1997 [18]. This model is widely applied in the computer program software gives more detailed about farming practices and topography for prediction the soil erosion loss. The RUSLE model studies the effect of climate, soil, topography and land cover on rill and interill soil erosion by energy impact of raindrop and ground runoff [18]. The equation (1) below is used for both models USLE and RUSLE to estimate the average annual soil erosion loss:

A=R.K.LS.C.P ………………………………………………………… (1)

Where, A is the average soil erosion loss per unit area (tons/acre/year or tons/ha/year), R is the factor of the rainfall-runoff erosivity, K is the soil erodibilty factor which is known as a 72.6-ft (22.1-m) length of uniform 9% slope in continuous clean-tilled fallow, L is the slope length factor, S is slope steepness factor, C is the cover-management factor and P is the support practice factor.

The effects of the raindrop impact and reflects the quantity is called the rainfall-runoff erosivity factor R [18]. By restricting factor other than rainfall constant, the soil losses from cultivated field are proportional to the total storm energy (E) times the maximum 30-min intensity $I_{30}$ [5]. The R factor is defined the long-term average product of the overall storm energy (E) and the maximum 30 minutes rainfall intensity. The method to find the the rainfall-runoff erosivity factor was described by Wischmeier and Smith (1978) and by Renard et al. (1994), that needed the extended records over a period of 20 years at least, with cyclical rainfall patterns less than or equal 30 minutes. This type of information in many parts of world is difficult to compute and its processing is time-consuming and hardworking [3]. For R factor values for region without data like Iraq, the researchers over the world can be computed this factor using the monthly or the annual precipitation data.

The researcher have been used to compute the R factor depended on directly of the annual precipitation data for many parts of world Stocking and Elwell, 1976; Rose, 1977; Arnoldus, 1977; Bollinne et al., 1980; Smithen and Schulze, 1982; Lo et al., 1985, Bertoni and Lombardi Neto, 1990; Renard and Freimund, 1994; Yu and Rosewell, 1996; Mikhailova et al., 1997; Torri et al., 2006. For this study can be used the Renard and Freimund's method (1994) of estimation the R factor for climatic station that separation in continental USA without long-term rainfall intensity data, this model was computed the R factor for average annual precipitation ranges from 67 to 1640 mm of 132 gages station as the equations below. The Euphrates watershed has been had the annual precipitation within ranges of the Renard and Freimund's method (1994) model, so these equation was adopted for the present study. The data of rainfall has been recommended at least 20 years to capture the natural climatic variation [23].

$$R = 0.0483 \times P^{1.61} \qquad P < 850\ mm \quad \ldots\ldots\ldots \quad (2)$$
$$R = 587.7 - 1.219 \times P + 0.004105P^2 \qquad P \geq 850\ mm \quad \ldots\ldots\ldots \quad (3)$$

Where:
P: is the annual precipitation (mm),
R: is the annual rainfall erosivity ($Mj.mm.ha^{-1}.h^{-1}.year^{-1}$).

## 2- Study Area

The Euphrates river watershed of Iraq composed of eight provinces, the watershed of present study was contained of seven provinces area 131722 $km^2$ about 30% from whole area of Iraq. Anbar province is excluded from the present study because the area of watershed became large due to this province and software program no operation to compute the soil loss of watershed. The provinces of watershed is included of Najaf, Karbala, Al-Qadisiyyah, Babylon, Al Muthanna, Dhi Qar and Basrah as shown in Fig. (1). This river is the longest and one of the most historically main rivers of Western Asia. The originating in eastern Turkey, the flows through Syria and Iraq to join the Tigris in the Shatt al-Arab.

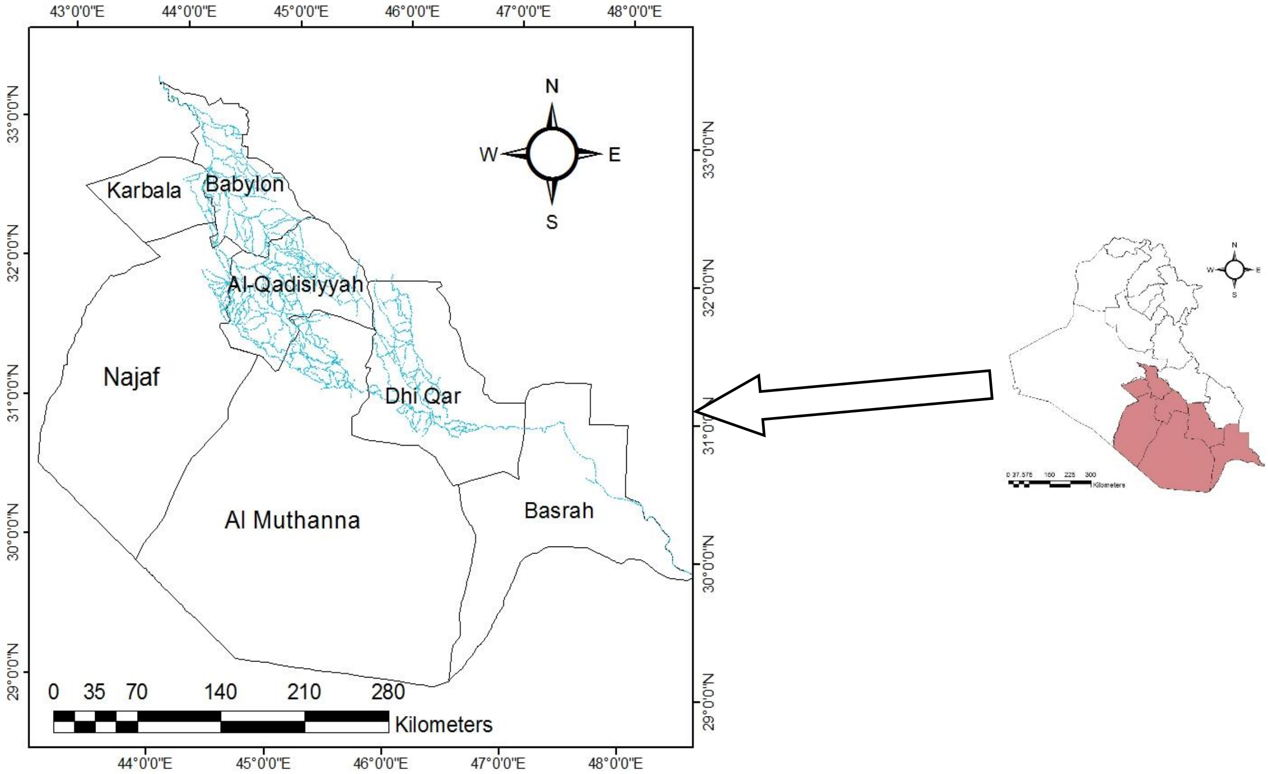


Fig. (1) Study area of watershed location map

The precipitation data of Euphrates watershed was contained from thirty one gauge stations spreading into and outside watershed to help with interpolation the precipitation data for the stations has located far from the boundary of watershed. The number of precipitation gauge inside of Iraq is twenty six stations, while four gauge in Saudi Arabia and one station in Kuwait as shown in Table (1) below. The calculation years of average precipitation were taken from the establishment year of station as written in the table to 2017. By using the ArcMap 10.2 software, the gauge stations of precipitation data can be projected of its location on the watershed map according to the longitude and latitude of each station as showed in the Fig. (2).

Table (1) Rainfall gauge stations in the Euphrates river basin (Iraqi Meteorological Organization and Seismology and General Authority for Statistics of Saudi Arabia & Kuwait)

| Station | Location | | Observation Station | | | Precipitation mm/year |
|---|---|---|---|---|---|---|
| | Longitude | Latitude | Begin Data | End Data | Country | |
| BAGHDAD | 44.24 | 33.2 | 1938 | 2017 | Iraq | 136.004 |
| NASIRIYA | 46.14 | 31.01 | 1940 | 2017 | Iraq | 118.326 |
| BASRA | 47.78 | 30.5 | 1937 | 2017 | Iraq | 138.934 |
| AL_HAI | 46.03 | 32.1 | 1941 | 2017 | Iraq | 136.680 |
| KIRKUK | 44.24 | 35.28 | 1924 | 2017 | Iraq | 367.666 |
| RUTBA | 40.17 | 33.02 | 1928 | 2016 | Iraq | 113.219 |
| DIWANIYA | 44.59 | 31.59 | 1929 | 2016 | Iraq | 113.416 |
| MOSUL | 43.09 | 36.19 | 1936 | 2016 | Iraq | 372.575 |
| FAO | 48.41 | 29.97 | 1941 | 2016 | Iraq | 143.125 |
| BASRA_AIRPORT | 47.67 | 30.55 | 1991 | 2017 | Iraq | 123.136 |

| | | | | | | |
|---|---|---|---|---|---|---|
| NAJAF | 44.32 | 32.03 | 1961 | 2017 | Iraq | 94.037 |
| NUKHAIB | 42.27 | 32.03 | 1939 | 2016 | Iraq | 70.358 |
| SAMAWA | 45.16 | 31.18 | 1941 | 2016 | Iraq | 101.802 |
| HILLA | 44.26 | 32.29 | 1935 | 2017 | Iraq | 108.346 |
| KUT | 45.45 | 32.3 | 1941 | 2016 | Iraq | 136.068 |
| AZIZYIA | 45.06 | 32.91 | 1992 | 2016 | Iraq | 116.082 |
| AIN_ALTAMUR | 43.48 | 32.48 | 1978 | 2016 | Iraq | 97.801 |
| KARBALA | 44.01 | 32.37 | 1935 | 2017 | Iraq | 99.956 |
| HADITHA | 42.22 | 34.04 | 1937 | 2014 | Iraq | 128.085 |
| AMARA | 47.1 | 31.51 | 1935 | 2017 | Iraq | 175.761 |
| ALI_ELGHARBI | 46.41 | 32.28 | 1940 | 2016 | Iraq | 197.137 |
| BADRA | 45.98 | 33.09 | 1994 | 2016 | Iraq | 198.749 |
| AL_KHALIS | 44.53 | 33.84 | 1966 | 2017 | Iraq | 155.057 |
| SAMARRA | 43.9 | 34.11 | 1941 | 2013 | Iraq | 148.165 |
| RAMADI | 43.2 | 33.45 | 1923 | 2017 | Iraq | 97.461 |
| HEET | 42.83 | 33.64 | 1951 | 2016 | Iraq | 104.862 |
| KUWAIT_AIRPORT | 47.97 | 29.24 | 1992 | 2015 | Kuwait | 123.274 |
| TURAIF | 38.73 | 31.69 | 1983 | 2015 | Saudi Arabia | 68.163 |
| ARAR | 41.14 | 30.9 | 1983 | 2015 | Saudi Arabia | 50.316 |
| RAFHA | 43.49 | 29.63 | 1983 | 2015 | Saudi Arabia | 69.797 |
| QAISUMAH | 46.12 | 28.33 | 1979 | 2015 | Saudi Arabia | 108.106 |

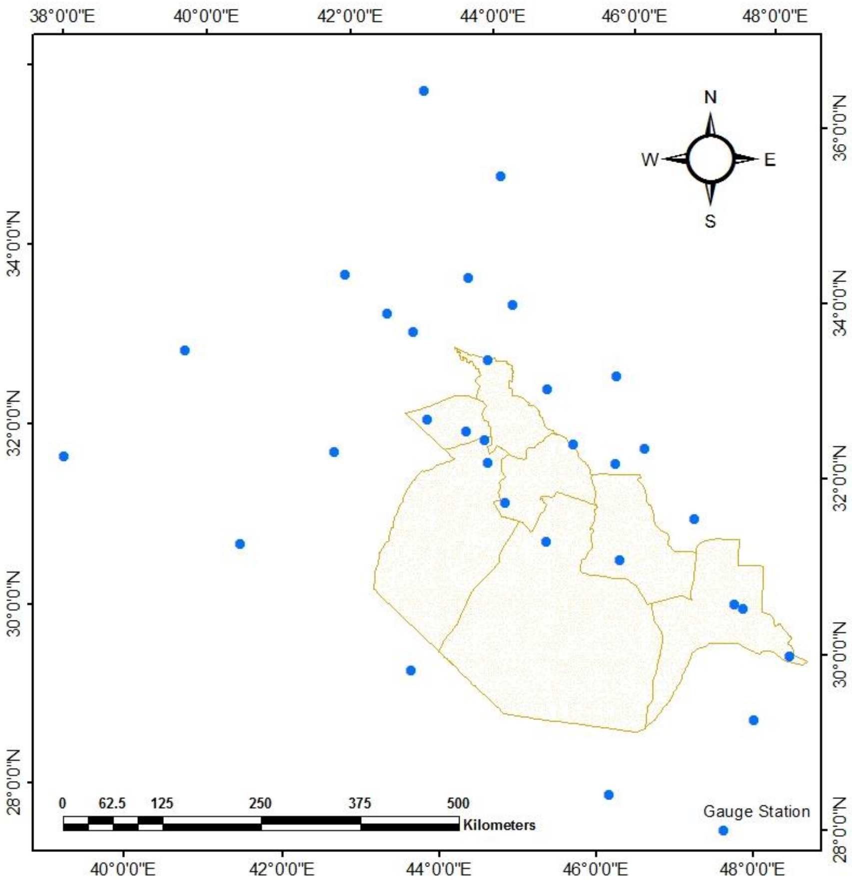


Fig. (2) Location of gauge stations for precipitation data

All precipitation data of gauge stations have been more than 20 year, the gauge stations in the Iraq country have been measured from date of establishing the gauge station [12], while the other data that references from General Authority for Statistics of Saudi Arabia and Kuwait to increase the points for more accurate of interpolation in southwest watershed.

## 3- The Results and Discussion

The precipitation map can be derived by using the Inverse Distance Weighting method (IDW) [11]. The IDW is the best mathematical (deterministic) method and it's a commonly used deterministic interpolation method. The procedure of this method is predicted the cell values at unknown location of map based on the distance between the unknown cell and the known points. The power option is found in this method to limit the influence of distance points. Furthermore, this method was adopted by many researchers to estimate the precipitation map, the method was provided in the ArcMap software. The precipitation map of watershed can be derived based on this method as showing in the Fig. (3).

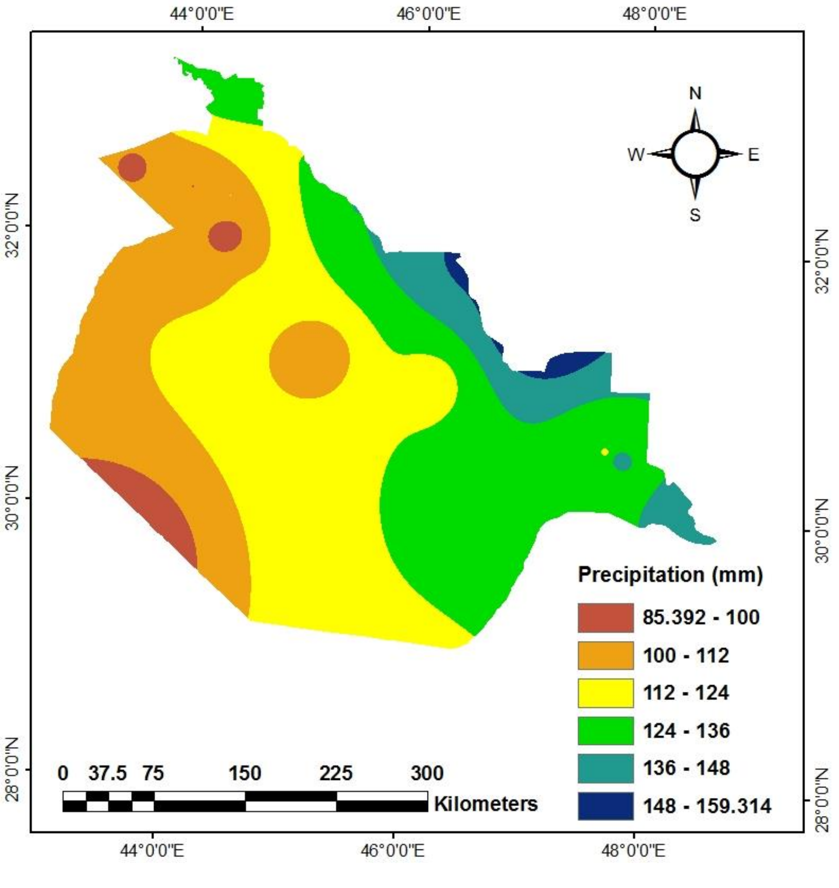


Fig. (3) Distribution map of Precipitation for Euphrates watershed

The distribution map of precipitation data can be classified into six categories, for using number of cells multiply by the cell size (30*30 m), the histogram of Fig. (4) is showed the relationship of the number of cells for each categories.

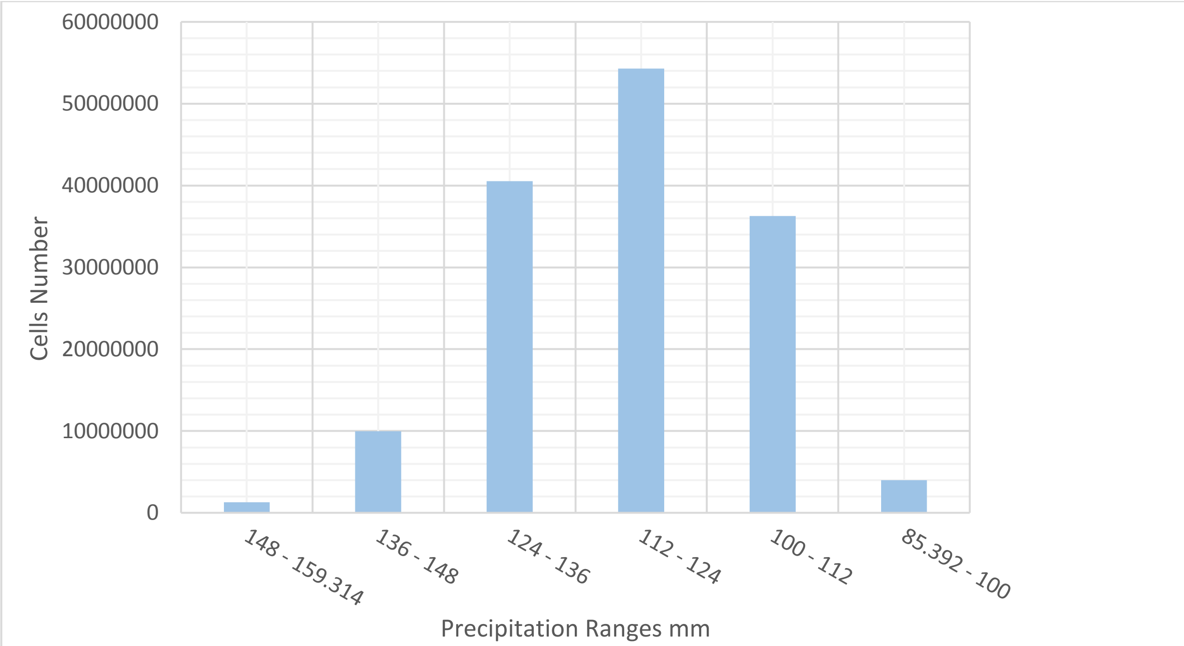


Fig. (4) Cells number of precipitation category

The areas and its percentages of each rainfall classification for Euphrates watershed can be found via multiply the cells number by the pixels area of each cell (30*30 m) as shown in table (2).

Table (2) Area percentage of each precipitation classification

| Precipitation category (mm) | Area ($km^2$) | Area % |
|---|---|---|
| 85.392 - 100 | 3607.4421 | 2.739 |
| 100 - 112 | 32632.4835 | 24.774 |
| 112 - 124 | 48871.7847 | 37.102 |
| 124 - 136 | 36463.4415 | 27.682 |
| 136 - 148 | 8969.0499 | 6.809 |
| 148 - 159.314 | 1177.8705 | 0.894 |
| Sum | | 100.000 |

All precipitation data of gauge stations for Euphrates watershed are less than 850 mm, so the equation (2) can be used to estimate the rainfall-runoff erosivity factor R. By using the Raster Calculator in the ArcGIS Spatial Analyst toolbox of the ArcMap 10.2 software, the raster of R factor map with SI ($Mj.mm.ha^{-1}.h^{-1}.year^{-1}$) units can be computed then this factor must be changed the unite to US (hundred $ft.ton.in.acre^{-1}.h^{-1}.year^{-1}$) by [6] equation below:

$$\frac{1\ MJ*mm}{ha*hr}*\left(\frac{368.78\ ft.ton}{MJ}\right)*\left(\frac{1\ hundred\ ft.ton}{100\ ft.tons}\right)*\left(\frac{1\ in}{25.4\ mm}\right)*\left(\frac{1\ ha}{2.471\ acre}\right)=$$

$$0.05876*\left(\frac{hundred\ ft.ton.in}{acre*hr}\right)$$

The main reason to change the R factor unit to compute the soil loss of watershed with unit (tons/acre/year). The Fig. (5) exposed the erosivity factor with US unit that ranged from 3.653 to 9.998 (hundred $ft.ton.in.acre^{-1}.h^{-1}.year^{-1}$). These R factor values were adopted of this watershed without comparison with field measurement because the equation (2) of Renard and Freimund's (1994) was applied with the same climate of the watershed which precipitation had ranged from 67 mm to 1640 mm for different area in the USA. Also, these equation was used from many researchers for different regions of world.

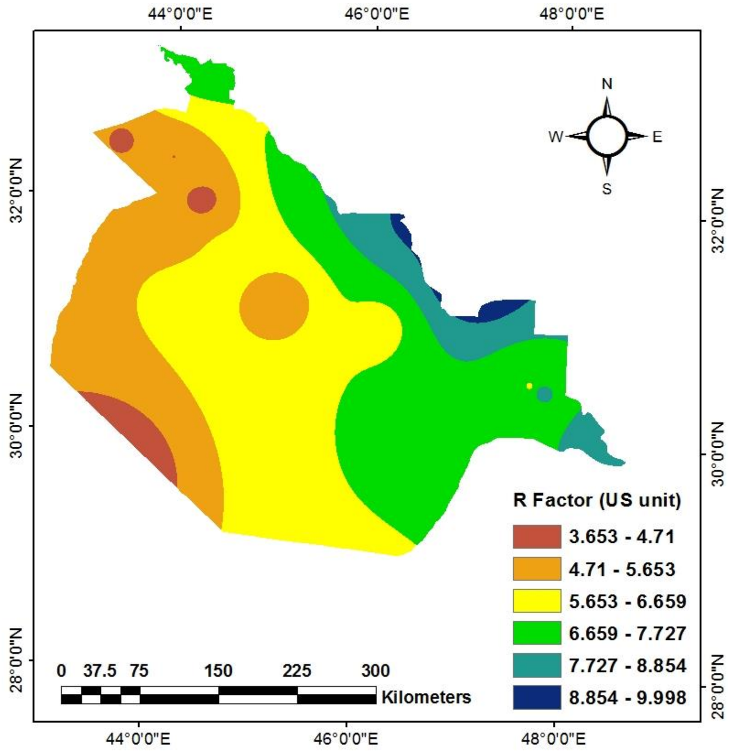


Fig. (5) The R factor of Euphrates watershed (hundred ft.ton.in.acre$^{-1}$.h$^{-1}$.year$^{-1}$)

## 4- Conclusion

The annul erosion losses of the RUSLE model with tons/acre/year units were depended on the rainfall-runoff erosivity factor R for US units. The R factor with US units of the Euphrates watershed basin can be ranged from 3.653 to 9.998 hundred ft.ton.in.acre$^{-1}$.h$^{-1}$.year$^{-1}$. The R factor was depended on the values of precipitation that measured on the different area inside and outside of the case study watershed. The precipitation data can be derived based on the Inverse Distance Weighting method (IDW) that depended on the thirty one gauge stations, this interpolation method is ranged the rainfall values from 85.392 mm to 159.314 mm of the Euphrates basin. The watershed area can be classified into six category of the precipitation data. The maximum watershed area of precipitation data is about 37% of entire area, it is ranged from 112 mm to 124 mm.

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