Estimation of Soil Erosion Risk of the Euphrates River Watershed Using RUSLE Model, Remote Sensing and GIS Techniques

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Abstract. The average annual soil erosion is the main problem of natural water resources and the agriculture, the most dominant factor that effect on the soil erosion is water. The aim of this study was estimated the average annual soil erosion by using RUSLE model and the ArcGIS software of the Euphrates river watershed, this model was based on five factors for calculation soil erosion map of the watershed. The rainfall-runoff erosivity (R) factor map was computed for precipitation data that content from thirty-one stations scattered within and outside the watershed area to assist in the interpolation estimation. The soil erodibilty (K) factor map of topsoil was derived based on data that provided from UN-FAO (Food and Agriculture Organization of the United Nations). The topographic factor map can be depended mainly on the raw images of the Digital Elevation Model (DEM) of the watershed which DEM of Euphrates watershed consisted of sixteen images with a spatial cell size 30m*30m. The cover/crop management (C) factor map can be calculated based on the NDVI (Normalized Difference Vegetation Index) map of the Euphrates basin, the NDVI map can be derived based on remote sensing of the data available in the United State Geological Survey (USGS) for multi-images of the study area. The support practice factor (P) can be assumed equal to 1 because the bare land area occupied about 92% of the total area for computational years 2013 and 2017. The average annual soil loss for the year 2017 was ranged from 0 to 2995.614 tons/ha/year, 99.69% of the watershed area had the slight soil erosion loss while 0.17% of the watershed was represented the soil erosion of the slight to moderate type. For the year 2013, the soil loss estimated from 0 to 2610.47 tons/ha/year, 99.7% of watershed had the slight soil erosion loss while 0.16% of the watershed was classified into the slight to moderate soil loss type. Furthermore, the other soil loss types such as moderate to extremely high were found in the riverbed of the Euphrates. The sediment delivery ratio can be computed for upstream of Al Shamia barrage based on the field value of sediment yield for the year 2013. The observation value equaled to 25.62% while it's equal to 26.12% based on the Renfro equation.
Keywords: Erosion, RUSLE, Remote Sensing, NDVI, Euphrates Basin

1- Introduction

The reasons to remove the soil surface particles are water and wind, the soil surface removal is called the soil erosion risk (Kirkby and Morgan 1980). The most dominant factor that effects on the soil erosion are water which includes separation, transportation, and deposition of soil particles by rain impact energy (Foster and Meyer 1977; Wischmeier and Smith 1978; Julien 2002). The major problems of soil erosion in the natural resources management and the agriculture, these problems are included to reduce the soil productivity, streams pollution and fills the reservoirs such as dams, regulators, barrage and so on (Fangmeier et al. 2006). There are many factors that effect to increase the soil erosion process such as human activity which included construction of roads, dams and control works on channel and rivers, mining, and urbanization (Julien 2010). When raindrop hit the ground surface and separation soil particles (sediment) by splash (Julien

2002). The sheet erosion or interrill erosion process begins when the separation particles are laterally transported to the rills by a thin overland flow (Foster and Meyer 1977). The rills have carried the flow with most downslope sediment transport. Furthermore, the water from sheet erosion combines to form concentrated small channel that process is called rill erosion (Fangmeier et al. 2006). The stream channel erosion results from two sediment sources, the first source is concentrated water forms from rills and gullies, and the second source is contained sediment removal from stream banks and streambed of a channel (Foster and Meyer 1977; Fangmeier et al. 2006).

The Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) are empirical models to estimate the soil erosion risk of identifying the watershed area (Fistikoglu and Harmancioglu, 2002). The upgraded version of USLE model is the RUSLE model (Renard et al. 1997). The RUSLE model has included the improvement in many of the factors estimations such as the new method to compute cover factor, algorithms to reflect rill to interrill erosion in the slope length and the steepness factors. The annual erosion losses of specify watershed can be estimated by RUSLE equation as shown below:

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

Where,

- A is the average annul of soil erosion loss per unit area (tons.acre^{-1}.year^{-1} or tons.ha^{-1}.year^{-1}).
- R is the factor of the rainfall-runoff erosivity, the rainfall-runoff erosivity factor is the quantity factor to reflect the effect of the raindrop impact (Renard et al. 1997). The R factor is directly depended on the annual precipitation data for various parts of the 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). The present study can be depended on the equation of the Renard and Freimund's method (1994) as shown below; which had the annual precipitation data between (67mm-1640mm) to compute the R factor. The study area has precipitation values within these ranges. The raw rainfall data are recommended at least 20 years to capture the natural climatic variation (Wischmeier and Smith, 1978).

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

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

It's important to change the R factor unit from SI units to US units to compute the soil erosion of the watershed with tons/acre/year units as below (Cooper K, 2011).

$$\frac{1\ MJ*mm}{ha*hr} * \left(\frac{368.78\ ft.ton}{MJ}\right) * \left(\frac{1\ hundred\ ft.ton}{100\ ft.tons}\right) * \left(\frac{1\ in}{25.4\ mm}\right) * \left(\frac{1\ ha}{2.471\ acre}\right) = 0.05876 * \left(\frac{hundred\ ft.ton.in}{acre*hr}\right)$$

- K is the soil erodibilty factor, the K factor is the soil resistance to the erosion of rainfall and runoff (Haan et al. 1994). To find the experimental of soil erodibility factor that measurement on a unit plot the rate of soil loss per rainfall erosion index unit for a specific soil, furthermore, the K factor is computed as being 72.6 ft (22.1 m) long, with a width of 6 ft (1.3 m), 9% slope, and continuously clean-tilled fallow state with tillage performed up and downslope (Wischmeier and Smith 1978). The present study is used the multi-equation that are depended on the topsoil content to estimate the soil erodibility factor (Sharpley & Williams; 1990, Williams; 1995 and Neitsch et al; 2000) as below:

$$K_{usle} = f_{csand} \times f_{cl-si} \times f_{orgc} \times f_{hisand} \quad \ldots\ldots \quad (4)$$

$$K_{Rusle} = K \text{ factor} = K_{usle} \times 0.1317 \quad \ldots\ldots \quad (5)$$

Where:

K_{usle} : USLE model soil erodibility factor

$$f_{csand} = \left[0.2 + 0.3 \times exp\left(-0.256 \times m_s \times \left(1 - \frac{m_{silt}}{100}\right)\right)\right] \quad \ldots\ldots \quad (6)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} \quad \ldots\ldots \quad (7)$$

$$f_{orgc} = \left(1 - \frac{0.25 \times orgC}{orgC + exp[3.75 - 2.95 \times orgC]}\right) \quad \ldots\ldots \quad (8)$$

$$f_{hisand} = \left(1 - \frac{0.7 \times \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + exp\left[-5.51 + 22.9 \times \left(1 - \frac{m_s}{100}\right)\right]}\right) \quad \ldots\ldots \quad (9)$$

m_s : the percentage of sand fration content (0.5-2 mm particale diameter) [%]
m_{silt} : the percentage of silt fration content (0.002-0.05 mm particale diameter) [%]
m_c : the percentage of clay fration content (<0.002 mm particale diameter) [%]
orgC : the percentage of orgaic carbon fration content) [%]

- LS is the topographic factor (L slope length factor & S slope steepness factor). The slope length factor L is the horizontal distance of the surface land flow from the original to point where either the slope gradient decreases enough that runoff becomes concentrated or deposition begins in a specific channel (Wischmeier and Smith 1978), also, the L factor is the ratio of soil loss of site slope length to soil loss from a 72.6 ft long plot under specific conditions. The slope steepness factor is the ratio of soil loss from the site slope gradient to soil loss from 9% slope under otherwise matching condition (Renard et al. 1997). The present study was adopted the equation below to estimate the topographic factor LS in ArcGIS based on the raw images of the Digital Elevation Model (DEM) (Moore and Burch 1985)

$$LS = \left(\frac{A_s}{22.13}\right)^m \times \left(\frac{\sin\theta}{0.0896}\right)^n \quad \ldots\ldots \quad (10)$$

Where:

A_s: is the identify catchment area, in ArcGIS, the A_s is computed the function of the hydrology – spatial Analyst Tool "flow accumulation" multiply by the cell size.

θ: is the slope angle in degree, in ArcGIS, θ is calculated the function of the Surface – Spatial Analyst Tool "slope"

m = 0.4 – 0.6 and n = 1.2 – 1.3

The equation (10) is applied by many researcher like Moore & Wilson; 1992, Moore et al; 1993, Jain & Kothyari; 2000, Van der Knijff et al; 2000 and other. The exponent value m can be taken that 0.4 while the value of n can be taken equal to 1.3 (Moore et al; 1993, Jain & Kothyari; 2000 and Van der Knijff et al; 2000).

- C is the cover/crop management factor, the C factor represents the effect of vegetation and other land covers. There are many methods to compute the C factor, Normalized Difference Vegetation Index (NDVI) is the best method to estimate the C factor for soil loss assessment with RUSLE model (De Jong 1994; De Jong et al., 1999; De Jong and Riezebos, 1997; Wang et al., 2002; Lin et al. 2002). The NDVI values are the indicator of the vegetation vigor is used with following formula to estimate the C factor map (Zhou et al., 2008; Kouli et al., 2009)

$$C = \exp\left(-\alpha \frac{NDVI}{\beta - NDVI}\right) \qquad \ldots\ldots\ldots \qquad (11)$$

Where α and β are a dimensionless parameter that depended on the shape of the curve relationship between the NDVI and the C factor. The scaling approach gave better results to assume a linear relationship, the value of α is equal to 2 while the value of β is equal to 1 (Van der Knijff et al. 2000). The equation (11) was succeeded application for estimation the C factor of the watershed area with similar terrain and climatic conditions (Prasannakumar et al., 2011a, b).P is the support practice factor, P factor is the ratio of soil loss with a specific support practice to upslope and downslope tillage of corresponding soil loss. The practices are affected of the erosion by regulating the flow pattern, steepness, or direction of land surface runoff and by reduction the amount and rate of runoff (Reynard and Foster 1983).

2- Study Area

Iraq is a country consisting of eighteen provinces and it is a West Asian country, Tigris and Euphrates are the main rivers in the country of Iraq. The Euphrates River is one of the longest historical rivers in Western Asia. The river flows from Turkey and runs through Syria and this country to meet the Tigris River in the Shatt al-Arab in southern Iraq. The Euphrates basin consists of eight governorates, the watershed of the study area was included the following seven governorates Najaf, Karbala, Al-Qadisiyyah, Babylon, Al Muthanna, Dhi Qar and Basrah as shown in Fig. (1). The total watershed area of the study is about 131722 km2 and 30% of the total area of Iraq.

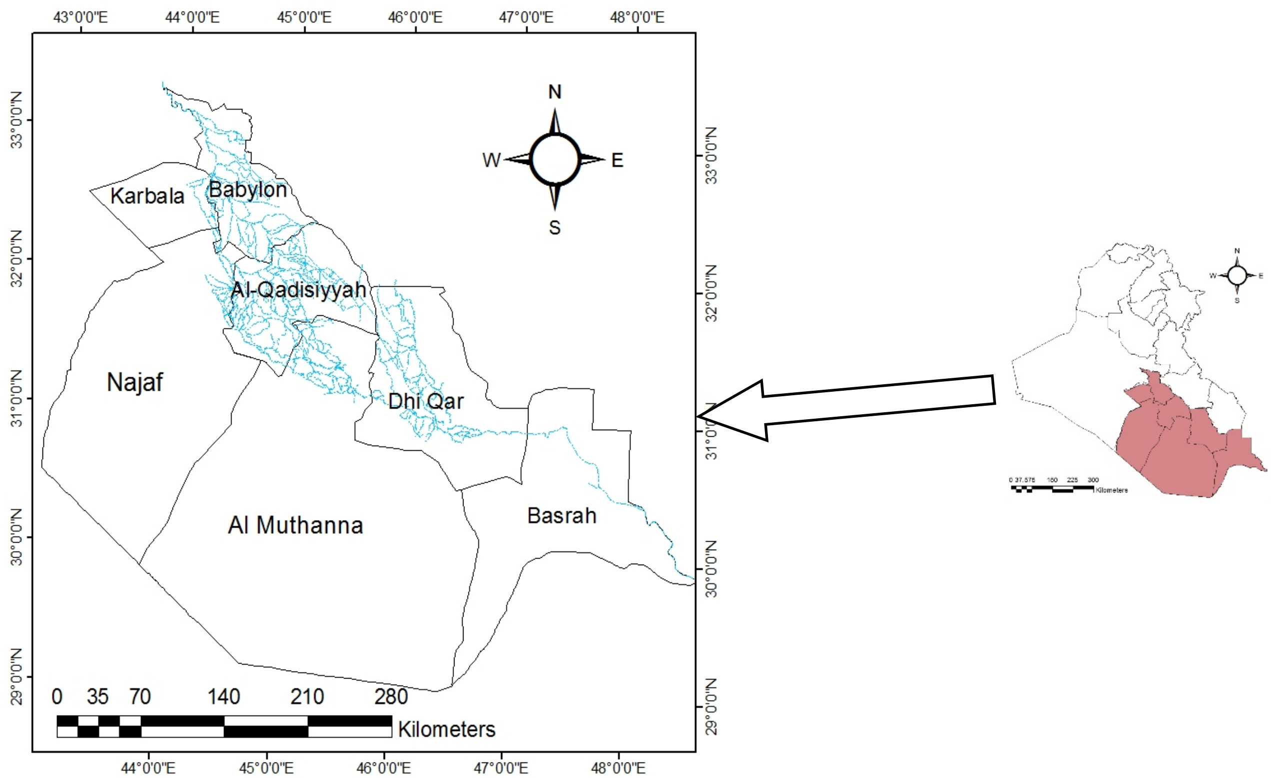

Figure 1. Study area of watershed location map

3- Calculation the factors by GIS software

All factors of Euphrates watershed map can be calculated using the ArcMap 10.2 software as below:

3-1 Calculation the rainfall-runoff erosivity factor R

Precipitation data is required to apply equations 2&3 to estimate the factor R of Euphrates watershed. Precipitation data were taken from thirty-one stations scattered within and outside the watershed area to give the interpolation estimation. The number of gauge stations for precipitation data in Iraq was twenty-six while in Saudi Arabia were four gauge station and in Kuwait country was one station as shown in the Table (1) and Fig. (2) below. All gauge stations have measured data greater than twenty years ago.

All precipitation data of gauges station were less than 850 mm, so the equation 2 will be applied to compute the R factor for years 2017 and 2013 in the figures (3) and (4) respectively. Two maps of R factor derived from data until to specify year, the resolution image was 30m*30m by using the Inverse Distance Weighting method (IDW). The IDW is the best mathematical (deterministic) method and it's a commonly used deterministic interpolation method.

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
KERBALA	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

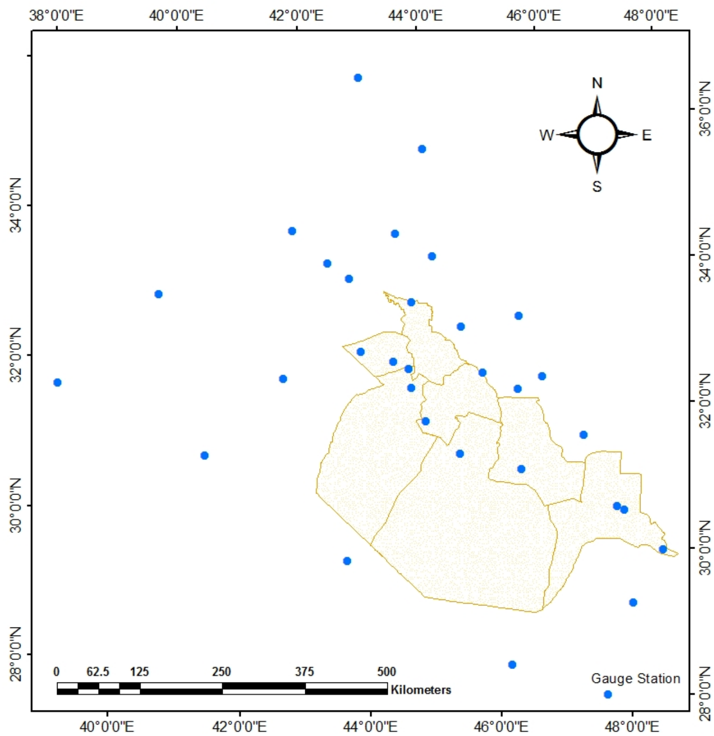

Figure 2. Location of gauge stations for precipitation data

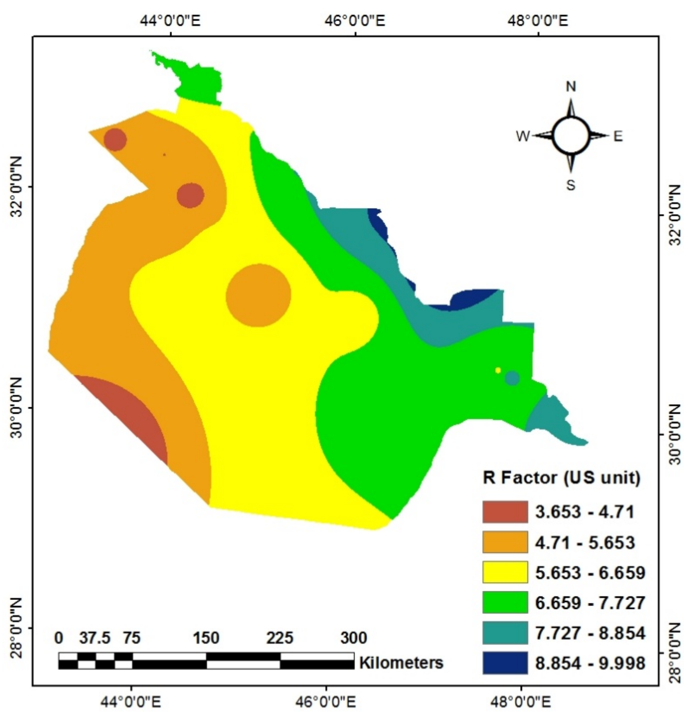

Figure 3. The R factor of Euphrates watershed, 2017 (hundred ft.ton.in.acre^{-1}.h^{-1}.year^{-1})

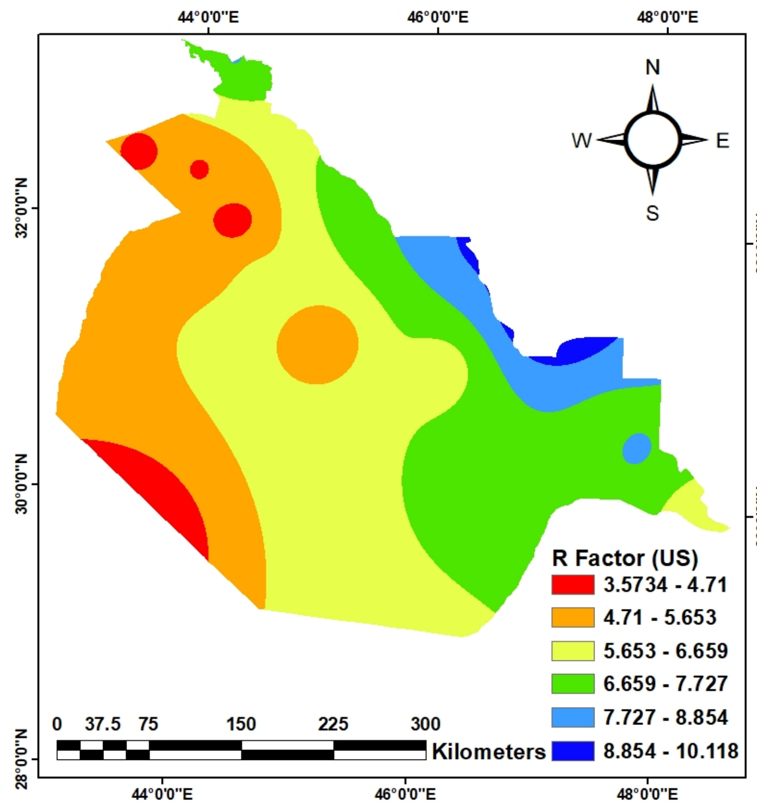

Figure 4. The R factor of Euphrates watershed, 2013 (hundred ft.ton.in.acre^{-1}.h^{-1}.year^{-1})

3-2 Calculation the soil erodibilty factor K

The K factor depends directly on the topsoil content of ground surface. Topsoil from ground surface can be derived based on UN-FAO (Food and Agriculture Organization of the United Nations 2007) as shown in Table (2). These data can be used to predict the K factor map for two years 2017 and 2013 because the data at these years were not available. The K factor map with cell size 30m*30m of Euphrates watershed can be estimated by application the equations 4, 5,6,7,8 and 9 as the Fig. (5).

Table 2. the percentage of the type of topsoil (UN-FAO)

Soil unit symbol	Sand % topsoil m_s	Silt % topsoil m_{silt}	Clay % topsoil m_c	Organic Carbon % topsoil *orgC*
Jc	39.35	39.54	20.46	0.65
Yk	63.38	17.78	18.58	0.26
Yy	48.96	10.68	40.23	0.13
Zo	43	24.43	32.17	0.4
Vc	22.2	24.3	52.81	0.69
Rc	63.25	18.9	17.09	0.76
Qa	92.34	3.27	3.52	0.87

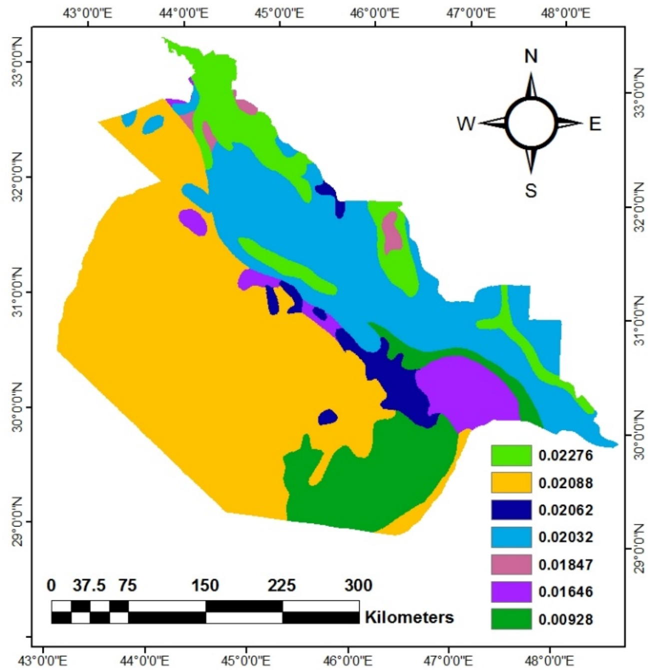

Figure 5. K factor values of the Euphrates basin

3-3 Calculation the topographic factor LS

The LS factor depends mainly on raw images of the Digital Elevation Model (DEM) of the watershed. The DEM of Euphrates watershed consisted of sixteen images with a spatial cell size 30m*30m. The raw DEM is available from Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global of USGS (United State Geological Survey) in September 2014, the DEM at the year 2014 can be used to estimate the LS factor at 2017 and 2013. After processing the raw DEM of Euphrates watershed by fills skins in surface raster to remove small imperfections in the raw sixteen images. The functions in ArcToolbox of ArcMap 10.2 software can be used to merge multi-images by the new raster of Euphrates watershed as shown in Fig. (6). The equation (10) can be applied after calculation the "flow accumulation" and "slope" by ArcToolbox of ArcGIS to estimate the topographic factor LS as shown in Fig. (7). The number of cells size of LS factor for every ten categories can be computed. Actually, 99.985% of the watershed area had the LS factor values from 0 to 100 and other areas about 0.015% was ranged the LS values from 100 to 8010.61.

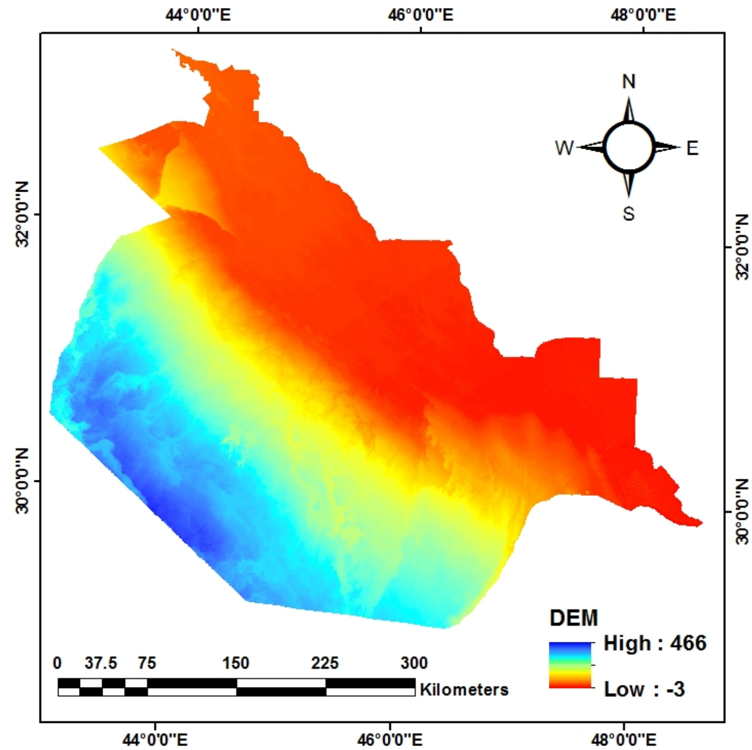

Figure 6. DEM map of Euphrates watershed

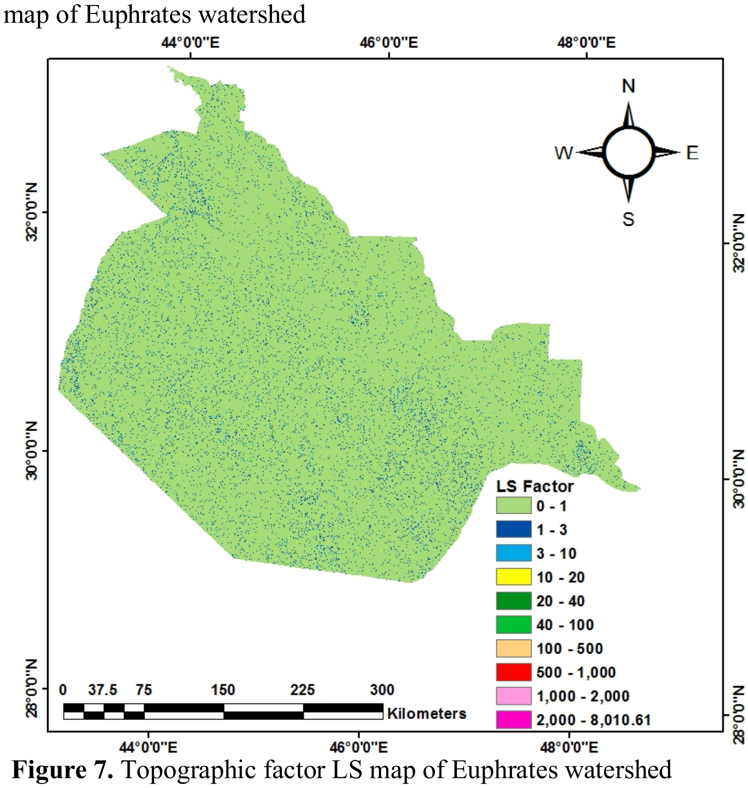

Figure 7. Topographic factor LS map of Euphrates watershed

3-4 Calculation the cover/crop management factor C

The equation (11) can be applied to estimate the C factor of watershed after computation the NDVI map of Euphrates basin. The NDVI map can be derived based on the data available in the United State Geological Survey (USGS) for multi-images of the study area, the date of images Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) February 2017 and April 2013. The images number are fifteen for each band to occupy the watershed study. By remote sensing (Image Analysis) of ArcMap 10.2 software to assemble and the process of multi-images, the values of NDVI map ranged from -0.338 to 0.654 in the Fig. (8) for 2017 while it ranged from -0.4005 to 0.5907 in the Fig. (9) for 2013. The C factor map of Euphrates watershed was ranged from (0.02267) to (1.658) for 2017 as exposed in the Fig. (10), this factor has values from (0.0558) to (1.7718) as shown in the Fig. (11). The bare land for values NDVI from 0 to 0.15 represented about 92% of the whole area of the watershed.

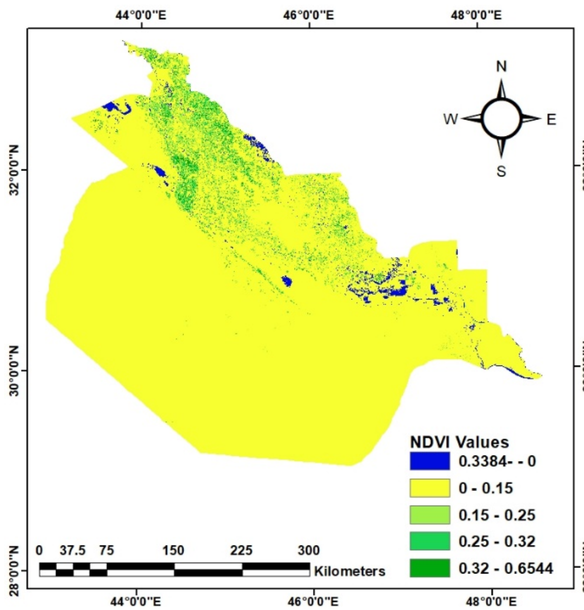

Figure 8. NDVI map of the study area, 2017

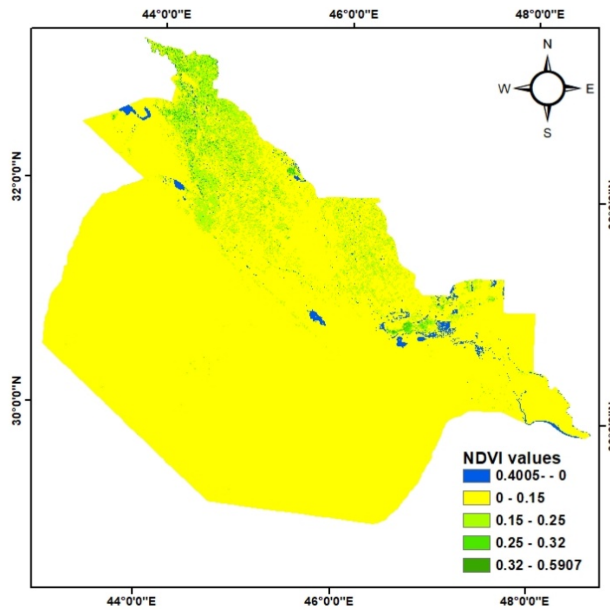

Figure 9. NDVI map of the study area, 2013

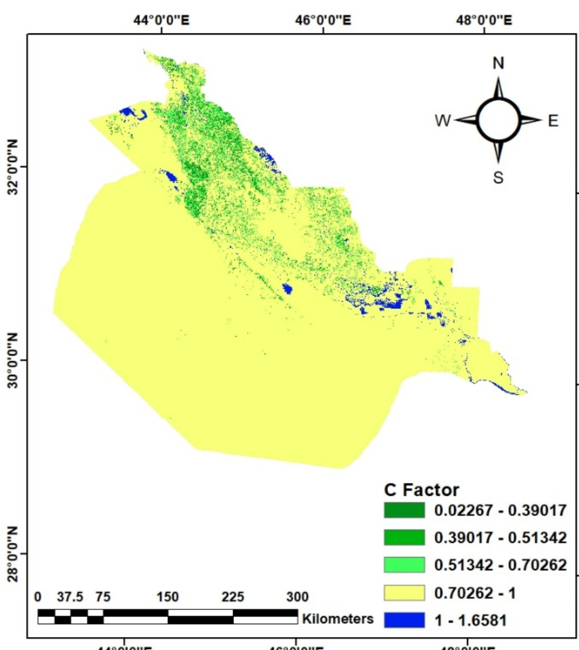

Figure 10. Values of C factor map, 2017

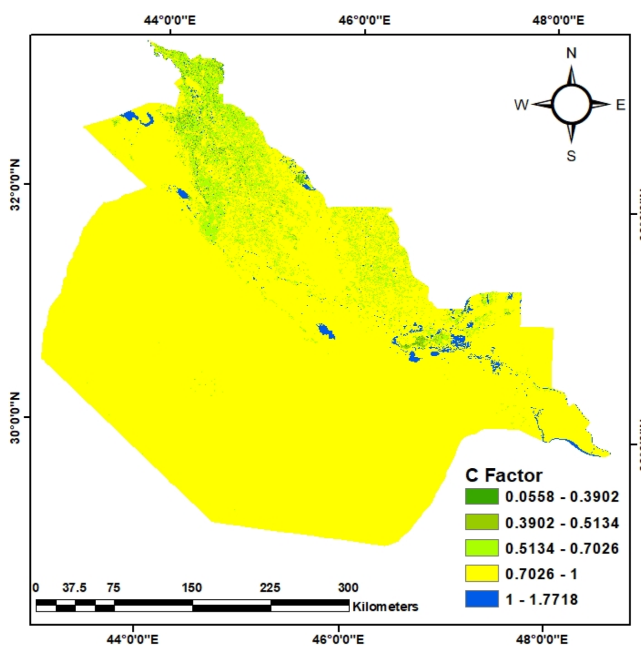

Figure 11. Values of C factor map, 2013

3-5 Calculation the support practice factor P

The P factor is ranged from 0 to 1. This factor is equal 1 when the land surface is plowed with upslope and downslope, and less than 1 when the soil erosion is reduced by adopting support practices of the above mentioned. The main common and effective of support practices on the site level are terracing and contouring. For the above mention of NDVI map of the watershed, the bare land (0 – 0.15) is represented the large of basin area about 92%. of the total watershed area. So the P factor of Euphrates river basin can be assumed no support practices implemented in the basin that equal to 1.

4- The Results and Discussion

The average annual soil erosion loss of the Euphrates watershed can be estimated for two different years 2017 and 2013 by using the RUSLE equation (1) as shown in the figure (12) and (13) below.

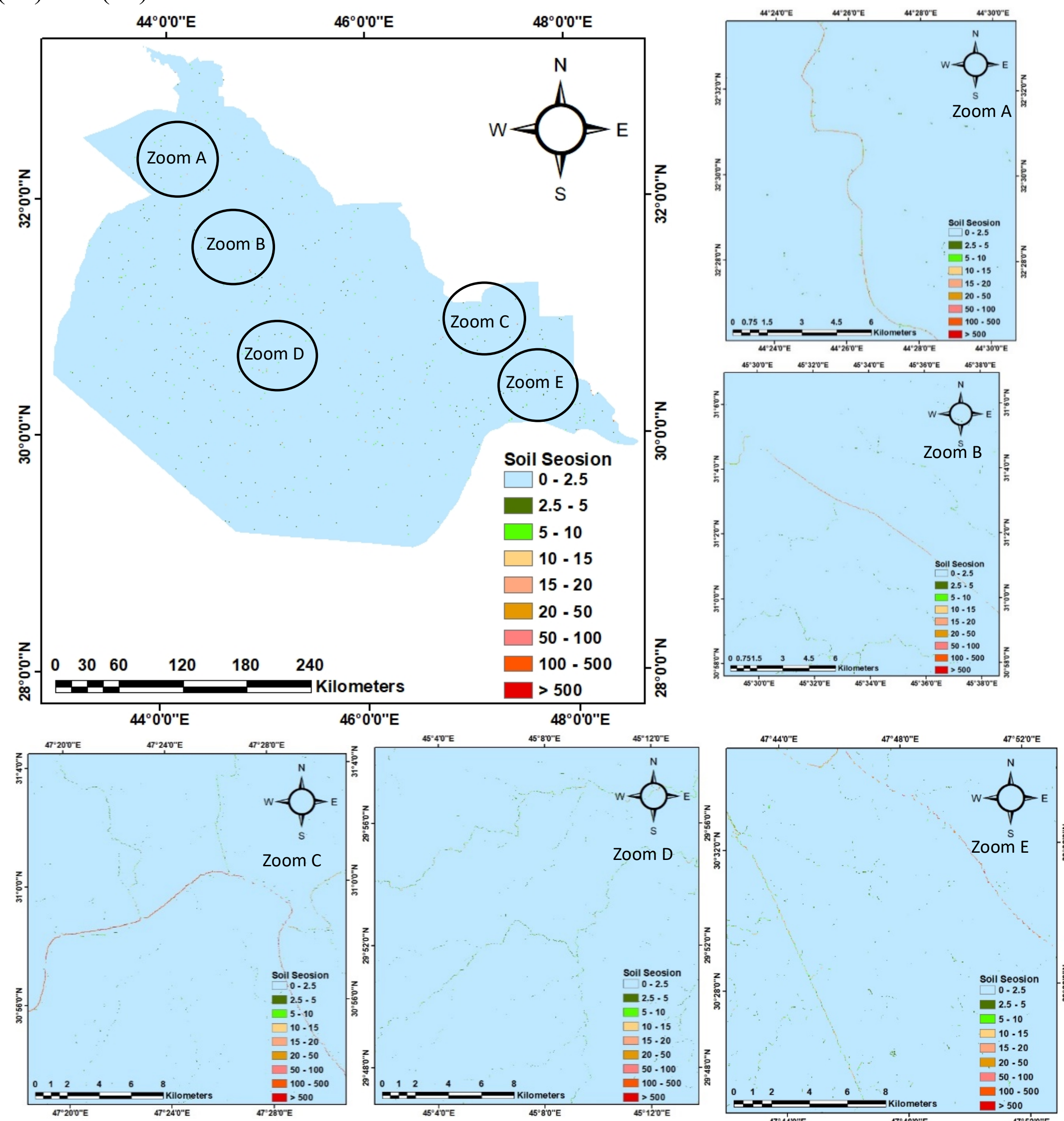

Figure 12. Average annual soil loss rate map of the Euphrates basin (ton/ha/year) 2017

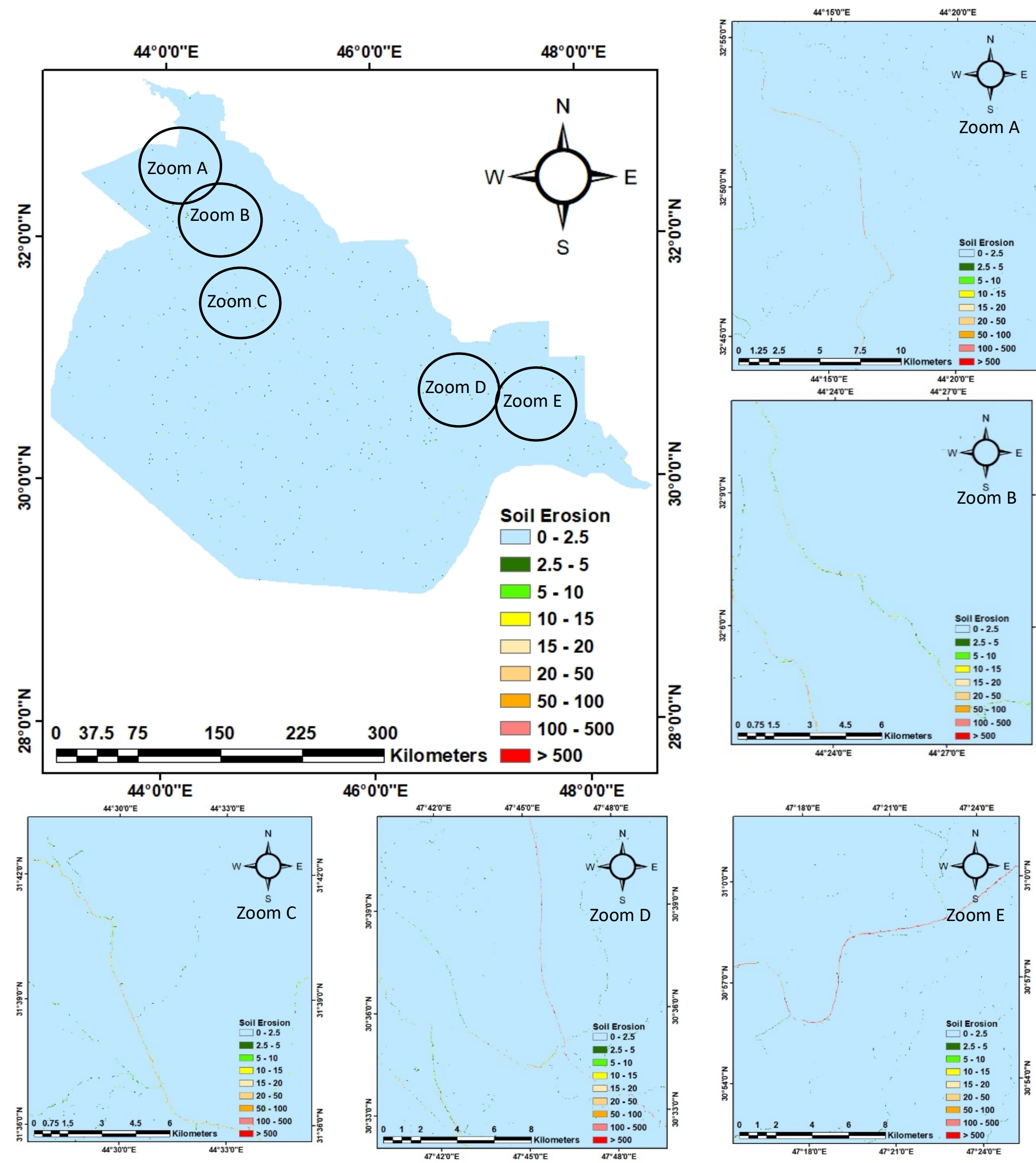

Figure 13. Average annual soil loss rate map of the Euphrates basin (ton/ha/year) 2013

The soil loss of two years can be classified two the categories in the tables (3) and (4) to explain the types of erosion. The average annual soil loss for the year 2017 was ranged from 0 to 2995.614 tons/ha/year, 99.69% of the watershed area had the slight soil erosion loss while 0.17% of the watershed was represented the soil erosion of the slight to moderate type. For the year 2013, the soil loss estimated from 0 to 2610.47 tons/ha/year, 99.7% of watershed had the slight soil erosion loss while 0.16% of the watershed was classified into the slight to moderate soil loss type. Furthermore, the other soil loss types such as moderate to extremely high were found in the riverbed of the Euphrates.

Table 3. Intervals of the soil losses and the areas of each classification (2017)

Soil loss intervals (ton/ha/year)	Soil loss types	Cells number	Area (Km^2)	Area %
0 - 2.5	Slight	145910123	131319.1	99.6941
2.5 – 5	Slight to Moderate	245622	221.0598	0.1678
5 – 10	Moderate	108507	97.6563	0.0741
10 – 15	Moderate to High	33916	30.5244	0.0232
15 – 20	High	16219	14.5971	0.0111
20 – 50	Very High	27989	25.1901	0.0191
50 – 100	Extremely	8460	7.614	0.0058
100 – 500	Extremely High	6267	5.6403	0.0043
> 500		742	0.6678	0.0005

Table 4. Intervals of the soil losses and the areas of each classification (2013)

Soil loss intervals (ton/ha/year)	Soil loss types	Cells number	Area (Km^2)	Area %
0 - 2.5	Slight	145923465	131331.119	99.7032
2.5 - 5	Slight to Moderate	237783	214.005	0.1625
5 - 10	Moderate	105844	95.260	0.0723
10 - 15	Moderate to High	33021	29.719	0.0226
15 - 20	High	15800	14.220	0.0108
20 - 50	Very High	27276	24.548	0.0186
50 - 100	Extremely	8284	7.456	0.0057
100 - 500	Extremely High	5712	5.141	0.0039
> 500		661	0.595	0.0005

The sediment delivery ratio can be computed based on the field data of sediment yield. The field sediment yield at the riverbed of Euphrates measured in 2013 at upstream of Al Shamia barrage as exposed the location in the Fig. (14). The field sediment yield equaled 96184.8 ton/year (Sadiq 2014). The watershed analysis can be used to compute the sub-basin of this point (barrage) by using HEC-GeoHMS (Hydrologic Engineering Center's Hydrologic Modeling System) which provided on the toolbox of ArcGIS as shown in the Fig. (15).

The soil loss value of this basin of RUSLE equation can be computed by the extract of the whole map of Euphrates watershed as exposed in the Fig. (16). The area of Al Ahamia basin found equal to 449.7 km2 and the soil loss at upstream of barrage equaled to 3.378 ton.acre-1.year-1. So the soil loss of this point is 375383.635 ton/year. The observation sediment delivery ratio of the sub-watershed is 25.62%. Renfro (1975) suggested the equation to calculate the sediment delivery ratio field area as following equation (12). The sediment delivery ratio by Renfro equal to 26.12%.

$$\log(S_{DR}) = 1.7935 - 0.14191 \log(A) \quad \ldots\ldots (12)$$

Where A is the drainage area in km^2 and S_{DR} is the sediment delivery ratio in percentage (%).

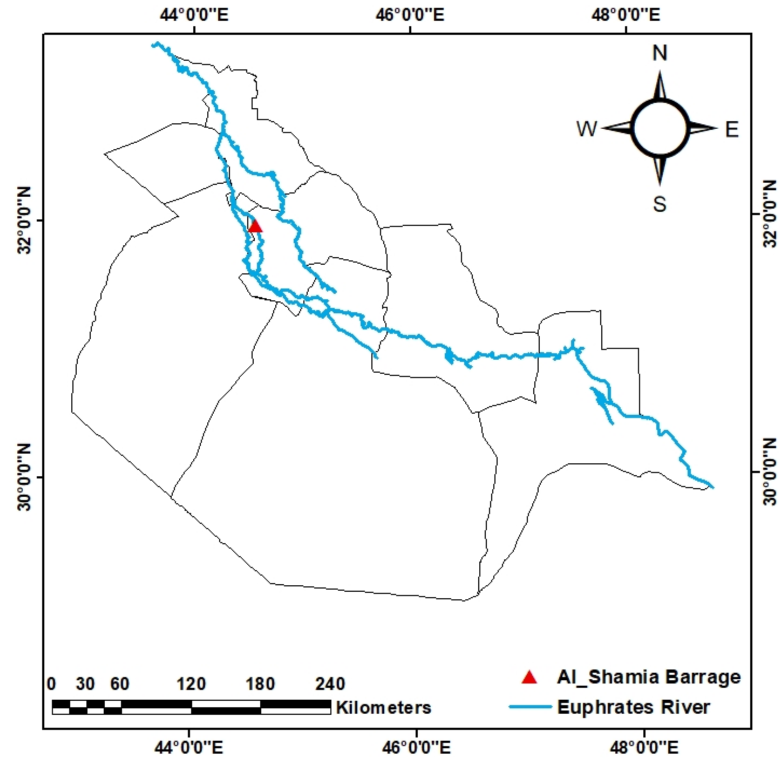

Figure 14. Al Shamia barrage location

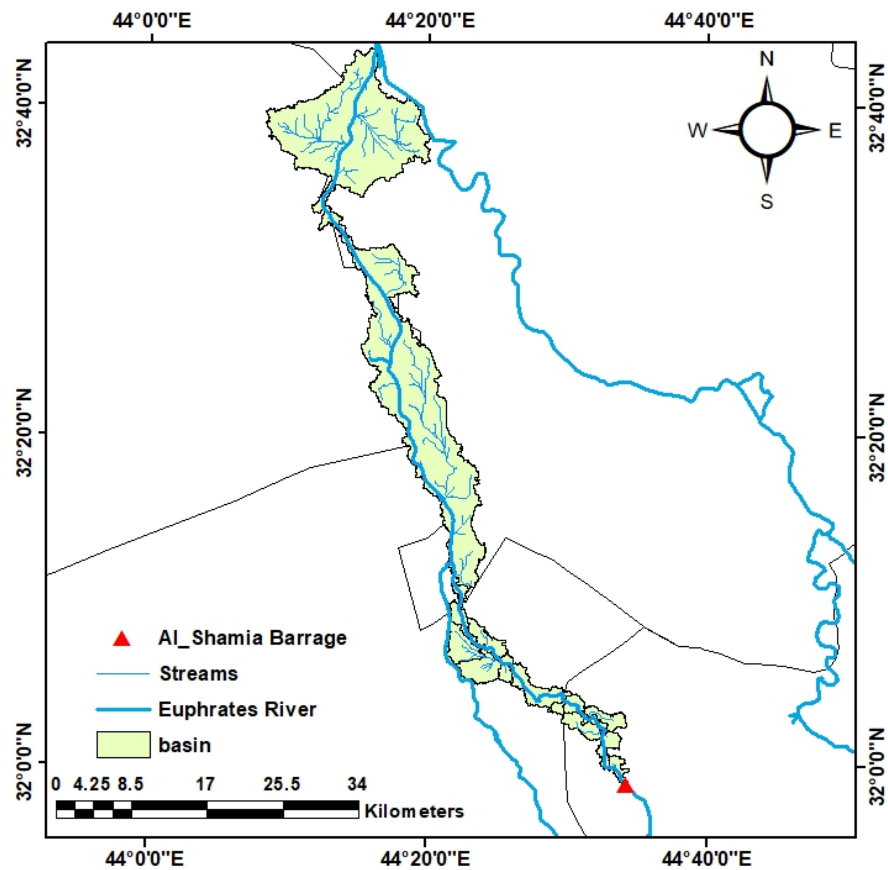

Figure 15. Al Shamia sub-watershed basin

5- Conclusion

The average annual soil loss of the Euphrates watershed of Iraq for the year 2017 was ranged from 0 to 2995.614 tons/ha/year, 99.69% of the basin area had the slight soil erosion loss while 0.17% of the watershed was represented the soil erosion of the slight to moderate type. For the year 2013, the soil loss estimated from 0 to 2610.47 tons/ha/year, 99.7% of watershed had the slight soil erosion loss while 0.16% of the watershed was classified into the slight to moderate soil loss type. Furthermore, the other soil loss types such as moderate to extremely high were found in the riverbed of the Euphrates. The sediment delivery ratio can be computed for upstream of Al Shamia barrage based on the field value of sediment yield for the year 2013. The observation value equaled to 25.62% while it's equal to 26.12% based on the Renfro equation.

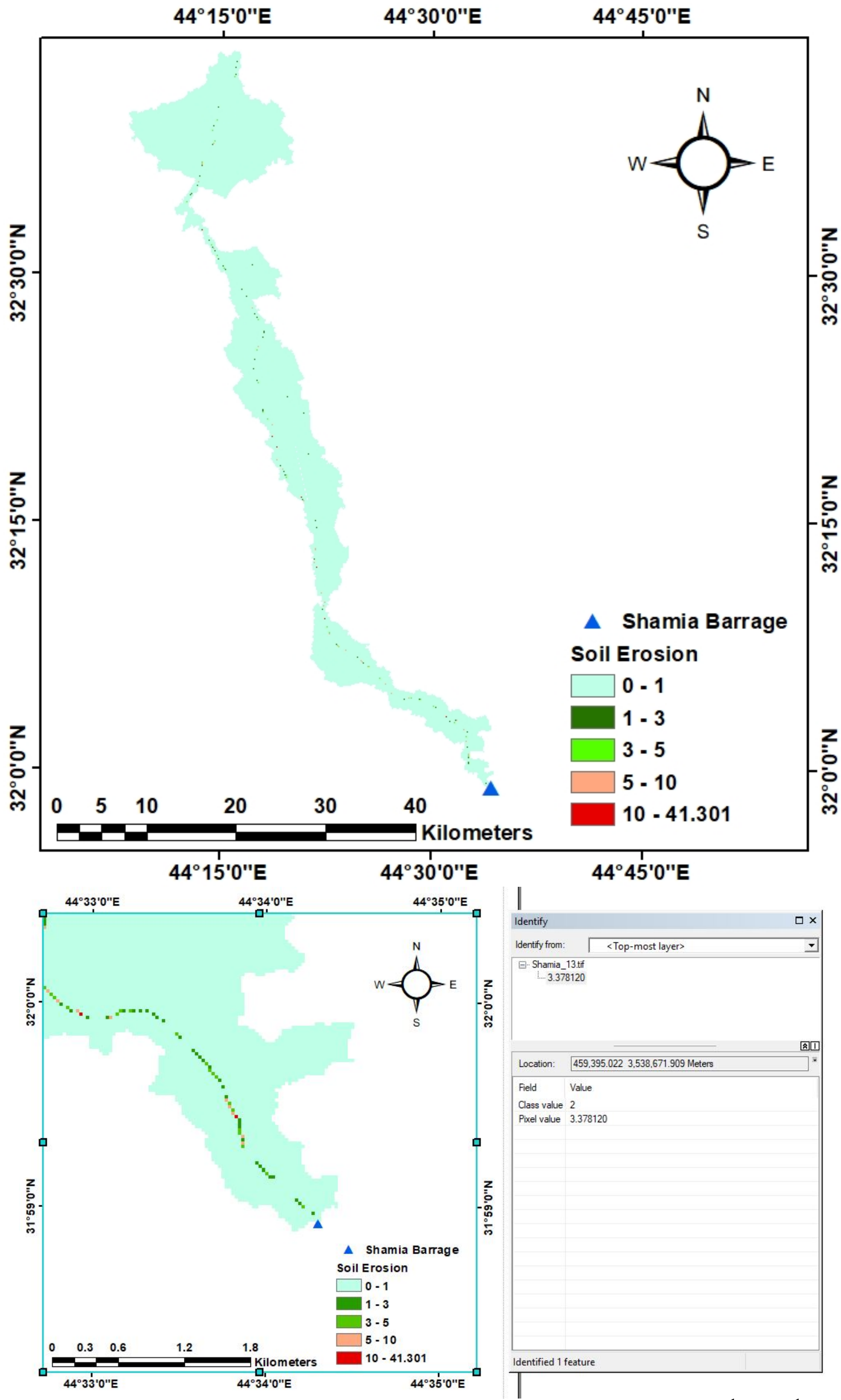

Figure 16. Average annual soil erosion of Al Shamia basin (ton.acre^{-1}.year^{-1})

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