Mapping evapotranspiration coefficients in the Paris metropolitan area

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ABSTRACT: Global changes involve adaptation and updated knowledge about the systems affected by these changes. Due to innovation and population growth also, the land cover pattern is exposed to modify its components, both natural and artificial, with implication for the several fields of Earth Sciences. Here, we present the spatial distribution of the land cover evapotranspiration coefficients (K_{clc}) in one of the most dynamic and important territories in Europe, in Paris metropolitan area. Specified crop coefficients were analysed for different crops and vegetative areas, but also the evapotranspiration coefficients related to the urban areas, bare soils and rocks, open water and rivers were presented in the present paper. The investigation has included the review and the adapted analysis of the land cover coefficients taken from the specific literature. Using the ArcGIS environment, the spatial distribution of the land cover coefficients related to four seasons (initial season, mid-season, end-season, and cold season) was carried out. The main results indicate maximum values up to 1.6 of the K_{clc} in the mid-season, for the areas occupied by the broadleaved forest. In the same season, the K_{clc} high values of 1.35 and 1.5 spread in the areas covered by complex cultivation patterns, nonirrigated arable land, respectively by mixed forest. The initial season presents values of Kclc that range from 0.1 to 1.3, while in the end season the land cover coefficients range from 0.2 to 1.5. The cold season indicates the lower values in major part of the Paris metropolitan area with few locations, in the South and East sides of the study area, where the coefficient reaches value 1. This work highlights the variation of the crop coefficients, but also of different land cover types in the metropolitan area of Paris with implications for agriculture management, hydrogeologists, and climatologists. Further investigations will include evapotranspiration calculations and climate effects assessment on the water resources in this area.

KEY WORDS: spatial distribution, crop coefficients, GIS, seasonal, Paris.

1. Introduction

Global regions are in changes and the climate regime is changing too (IPCC, 1996; IPCC, 2001; IPCC, 2007; Jiménez Cisneros et al., 2014). The understandings of the natural and artificial system's response at the major phenomenon which occur in a certain time are come to define good practice in spatial management of respective territory, in planning of urban and natural areas, but also in investigations of the existent resources. Nowadays, due to innovation and population growth (Nistor and Porumb-Ghiurco, 2015; Nistor et al., 2016), but also due to industrial and technological development in the large urban areas, the land use and land cover are subjects to modify its pattern. But these changes occur not only there, the natural regions and also the rural areas are facing with many changes such as desertification, agricultural area extension, house buildings and infrastructure constructions (Nistor, 2013; Nistor and Petcu 2014; Prăvălie, 2014). The main implications are easily seen in Regional Geography, Planning, Hydrogeology, Engineering Geology, and Environmental domains. Even if the improvements in social life are considerably, some of natural systems are sensitive to the landscape changes. Not in few cases, the human factor and its activity affected the natural resources. For instance, due to excessive salts irrigation and uses of improperly drainage systems, the groundwater quality in Harran Plain from southern side of Turkey was negatively affected (Yesilnacar and Yenigun, 2011). Also, in the South East part of Europe, the effects of different land use types on surface and groundwater have been exposed by Čenčur Curk et al. (2014). Regarding the forest ecosystems, the major sides of northern Romania were deforested and undesired hazards as landslides, flooding, and village damages occurred. On another hand, the land cover modifications together with the climate changes may conducts to high differences in water balance and infiltration. In this sense, it was demonstrated that highly temperatures implies increase of the evapotranspiration and combined with the land cover capacity to evaporate and/or evapotranspiration, contributes to the increase of land cover evapotranspiration. Recently, Nistor and Porumb-Ghiurco (2015), Nistor et al. (2016) analysed the seasonal crop evapotranspiration in the Emilia-Romagna region, respectively in the Carpathian Region, considering long period inventory of the climate data and the land cover layer. In theirs studies, the crop evapotranspiration at spatial scale were completed, considering the K_{clc} for each type of land use and land cover.

Present paper aims to expose the distribution of existent evapotranspiration coefficients in the metropolitan area of Paris using the land cover pattern. K_{clc} were collected from specialized literature, including reports and papers from the high ranking journals.

2. Study area

The metropolitan area of Paris is located in North of France, in the Île-de-France or so called Paris Region. It extends from 1°26’47” to 3°33’30” longitude East and from 481°7’12” to 41°14’31” latitude North (Figure 1). In the study area, there are included the city of Paris and more than 1700 communes, occupying about 12000 km^2. From orography point of view, the Paris metropolitan area is located in a lowland field with altitudes which fall below 300 m. The area is mainly crossed by Seine River, but there are also others water courses such Grand Morin, Essonne, Marne, Oise, and channels (e.g. Saint Denis Channel). The temperate climate is predominant in the Paris metropolitan area with oceanic influence. After Köppen-Geiger climate classification, the study area is found in the Cfa climate class, which is a warm temperate climate characterized by fully humid periods, warm summers and cool winters (Kottek et al., 2006).

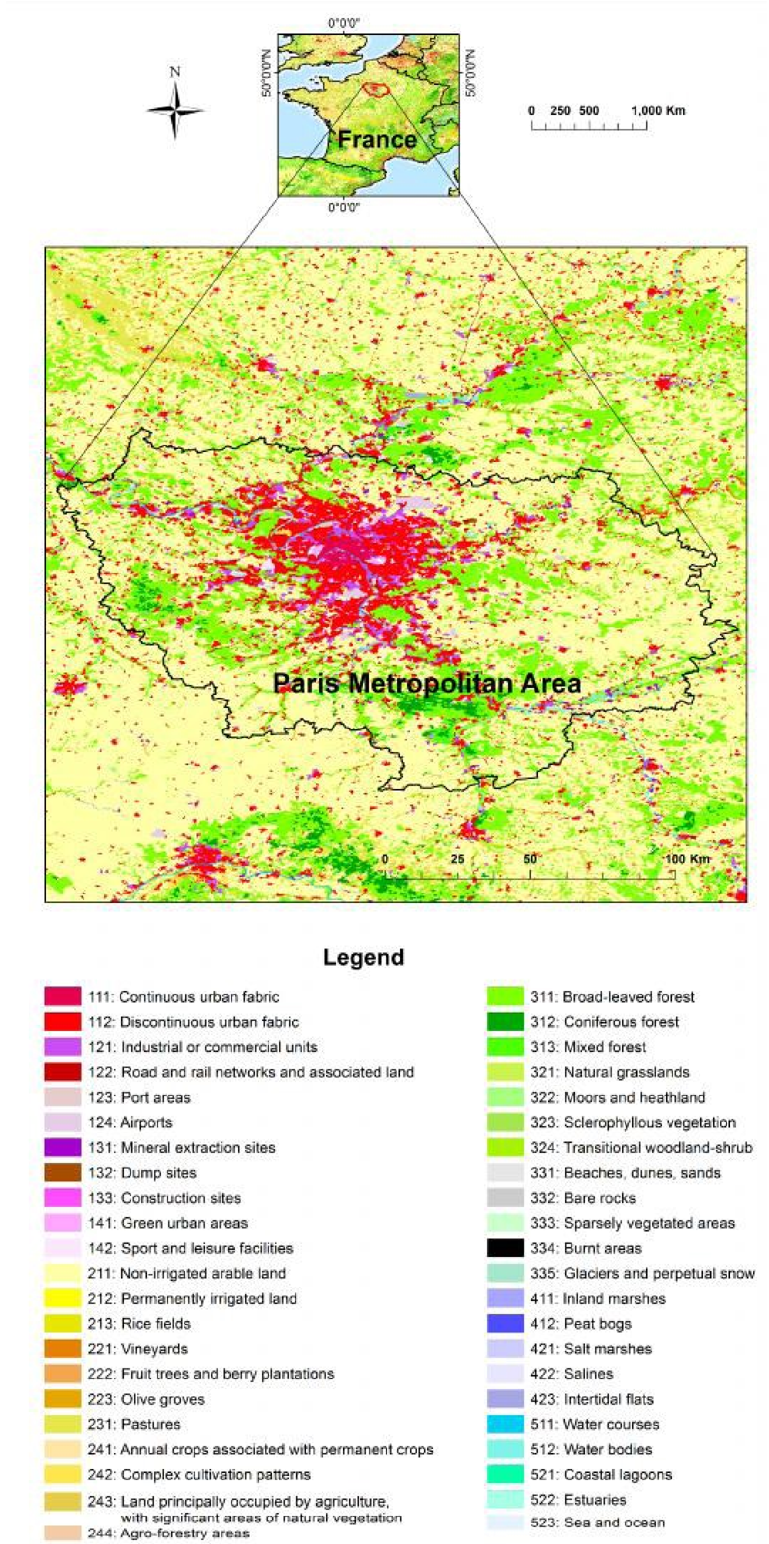

Figure 1 Location of the study area on France map (top) and land cover of the Paris metropolitan area (bottom). This figure is available in colour online at www.georeview.ro.

Figure 1 shows the existent land cover pattern in the Paris metropolitan area, but also for whole France's territory. The artificial areas occupied main core of the survey area but also the artificial areas widespread around. The eastern side is cover by agricultural areas which are found also in the marginal areas. In the southern and western sides could be found the forest areas which included broad-leaved forest, coniferous forest, and mixed forest. In the East and North spread also forest areas, but rarely and often there are presents stands of wood-land and shrub. In few places of the Paris metropolitan area, like in the North, west-central and east-central parts, the fruits tree and berry plantations are. The vineyards lands extends only in the northeastern sides of the study area. Water bodies and water courses are spread in whole land but in small areas, while the inland marshes appear in the southern part of the study area. Table 1 illustrates the present land cover classes from Paris metropolitan area which we have taken in consideration for this analysis.

Table 1 Corine Land Cover data used for the evapotranspiration coefficients in the Paris metropolitan area.

	Corine Land Cover
CLC code 2012	**CLC Description**
111	Continuous urban fabric
112	Discontinuous urban fabric
121	Industrial or commercial units
122	Road and rail networks and associated land
123	Port areas
124	Airports
131	Mineral extraction sites
132	Dump sites
133	Construction sites
141	Green urban areas
142	Sport and leisure facilities
211	Non-irrigated arable land
221	Vineyards
222	Fruit trees and berry plantations
231	Pastures
242	Complex cultivation patterns
243	Land principally occupied by agriculture, with significant areas of natural vegetation
311	Broad-leaved forest
312	Coniferous forest
313	Mixed forest
321	Natural grasslands
322	Moors and heathland
324	Transitional woodland-shrub
411	Inland marshes
511	Water courses
512	Water bodies

Source: Copernicus database (http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012/view).

3. Methodology

3.1. Land cover data

CORINE Land Cover database from Copernicus Programme (http://land.copernicus.eu/paneuropean/corine-land-cover/clc-2012/view) elaborated by European Environment Agency was used in the present paper to analyse and to represent the spatial distribution of K_{clc}. Due to a very good details of land classes, but also for the accuracy and georeferencing data, the CORINE Land Cover maps have been chosen for this survey. The raster data grid at very high resolution (250 m X 250 m) of land cover is an almost recent version of natural vegetation, water and bare lands, and land use pattern, dating from 2012. It is divided into five classes and fourth levels of details regarding the land typologies.

3.2. Land cover coefficients settings for evapotranspiration

The concept of crop evapotranspiration was coming up in a very explicit and scientific approach in the Food and Agriculture Organization (FAO) FAO Paper 56 carried out by Allen et al. (1998). Usually, for each type of crop could be assigned a crop coefficient value or, so called, evapotranspiration coefficient which can be slightly different from place to place, considering also the geographical location and local conditions. The advances studies bring forward values of evaporation/evapotranspiration also for the open water, glaciers, urban areas and bare soils. For instance, in the United States of America, Grimmond and Oke (1999) measured the coefficients of evapotranspiration for various urban areas and bare soils. Considering the appropriate latitude as factor of main influence, in the present paper we adopted the values of standard single crop coefficient (K_c), presented by Allen et al. (1998) and Grimmond and Oke (1999), to assign the K_{clc} for the land cover of the Paris metropolitan area. Thus, the entire database of land cover has attributed the K_{clc} which can be composed by K_c for plants, by evaporation coefficients for bare soils (K_s), by crop coefficient for urban areas (Ku), and by evaporation coefficient for open water (K_w).

In the temperate zone, the vegetation and also the main crops have different time steps during the growth which implies different values of the K_{clc} during one year (Allen et al., 1998). For the spatial analysis of crop evapotranspiration in the Emilia-Romagna Region from Italy, but also for the crop evapotranspiration in the transboundary region of Carpathians, Nistor and Porumb-Ghiurco (2015), respective Nistor et al. (2016) used in theirs studies four stages of growth. Based on this methodology, we elaborated our data following the division in four growth seasons as initial season ($K_{clc\ ini}$), mid-season ($K_{clc\ mid}$), end season ($K_{clc\ end}$), and cold season ($K_{clc\ cold}$). Allen et al. (1998) and Nistor (2016a) used the fifth stage related to the development plants period, which may have a large variety of days between initial season and mid-season, completed with growth calendar overlap for different crops. For this reason, at regional scale it was assumed that development stage may be included in the initial season, because the K_{clc} values are not properly highest to be associated at mid-season (Nistor and Porumb-Ghiurco, 2015; Nistor et al., 2016). Temporal scale of the K_{clc} values during one year includes the above mentioned stages as follow: the initial season extends from March to May, the mid-season extends from June to August, the late season extends from September to October, and the cold season extends from November to February.

3.3. Spatial mapping of the K_{clc}

Processing of CORINE Land Cover 2012 raster data was required to assign the K_{clc} values to each type of land cover from the Paris metropolitan area. The high spatial resolution was kept at 250 m^2 for a detailed perception, while the pixels values were changed accordingly to the K_{clc} values for land cover type classes. ArcGIS environment was chosen for this study due to its powerful in data management, mathematical calculations ande spatial analysis. Together with the remote sensing, ArcGIS became an important tool for the Earth's studies (Brown et al., 2005; Hadeel et al., 2010; Erdős et al., 2013; Sambah et al., 2014; Nistor, 2016b). Recently, the close methodology was completed by Nistor et al. (2017) for their investigation related to land cover evapotranspiration in the Pannonian basin, from central Europe. In aim to avoid presence of two or more K_{clc} values in the same class, "Unique Values" option was used for the symbology of spatial distribution of K_{clc} in Paris metropolitan area.

4. Results and Discussion

Paris metropolitan area is a heterogeneous space from land cover point of view, fact which implies the variety in the spatial distribution of K_{clc}. Analysing the variation of K_{clc} in the four seasons, the locations with high and low capacity for evapotranspiration are depicted. The $K_{clc\ ini}$ ranges from 0.1 to 1.3 during the initial season and the maximum values are located mainly in the South, West, North and in central sides of the area, but also are sparsely located in the East, northeastern and northwestern sides. The high values overlap with the pattern of broad-leaved and mixed forests. The lower values (below 0.25) of $K_{clc\ ini}$ are more compacted in the central part of the Paris metropolitan area, where the constructed and artificial units are located. Some parcels with lower values of $K_{clc\ ini}$ could be found also in the northwestern, southern, eastern and western sides. Figure 2 depicts the spatial distribution of $K_{clc\ ini}$ in the study area. The $K_{clc\ ini}$ values used in the present paper are reported in Table 2.

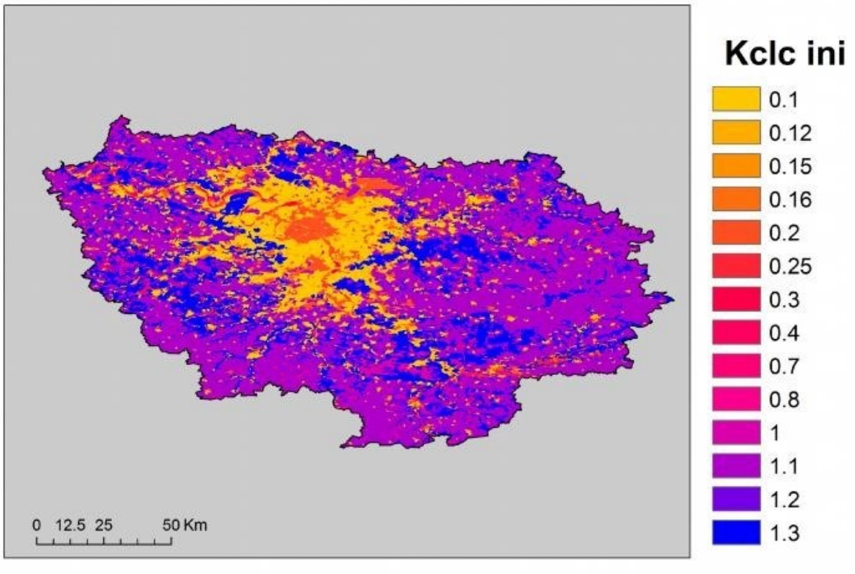

Figure 2 Spatial distribution of $K_{clc\ ini}$ in the Paris metropolitan area for the initial season stage. This figure is available in colour online at www.georeview.ro.

In the mid-season, the $K_{clc\ mid}$ ranges from 0.3 to 1.6, indicating the high values (over 1.3) in central, South, North, West sides of the land, but also in some sides of the eastern part. These values correspond to the broad-leaved forest, mixed forest, non-irrigated arable land and complex cultivation patterns. The minimum values of $K_{clc\ mid}$ are related to discontinuous urban fabric, but also to sport and leisure facilities with a value of 0.3 in both cases. The lower values of $K_{clc\ mid}$ occupy the large part of central areas and radial sides in South, southwest, North, and northwestern parts. Figure 3 illustrates the spatial distribution of $K_{clc\ ini}$ in the study area. The $K_{clc\ mid}$ values used in the present paper are detailed in Table 3.

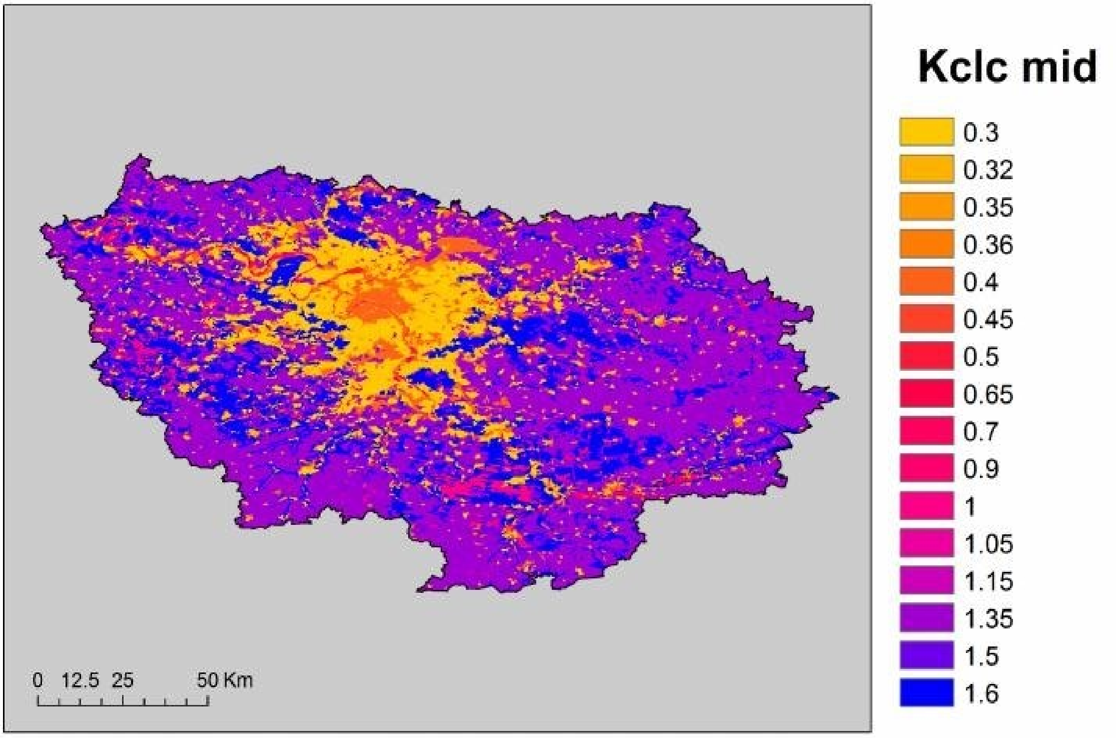

Figure 3 Spatial distribution of $K_{clc\ mid}$ in the Paris metropolitan area for the mid-season stage. This figure is available in colour online at www.georeview.ro.

The end season values of K_{clc} end varied between 0.2 and 1.5, where the maximum values are especially related to broad-leaved forest. Elevated values of K_{clc} spread in the North, South, West, and some sides of the East part and overlap with lands covered by broad-leaved and mixed forests. Lower values (below 0.3) are located in central and north-central parts of the Paris metropolitan areas, but also in few sides of the East, South and West parts. These areas corresponds mainly to artificial areas, with respect to fabrics, constructions, leisure and transportation infrastructure. The spatial distribution of K_{clc} in the end season is depicted in Figure 4. Table 4 reports the values of K_{clc} for the end season.

Table 2 Corine Land Cover coefficients used for the initial season in the Paris metropolitan area.

CLC code 2012	Corine Land Cover CLC Description	Kc ini season Kc	Ku	Kw	Kclc
111	Continuous urban fabric	–	0.2	–	0.2
112	Discontinuous urban fabric	–	0.1	–	0.1
121	Industrial or commercial units	–	0.2	–	0.2
122	Road and rail networks and associated land	–	0.15	–	0.15
123	Port areas	–	0.3	–	0.3
124	Airports	–	0.2	–	0.2
131	Mineral extraction sites	–	0.16	–	0.16
132	Dump sites	–	0.16	–	0.16
133	Construction sites	–	0.16	–	0.16
141	Green urban areas	–	0.12	–	0.12
142	Sport and leisure facilities	–	0.1	–	0.1
211	Non-irrigated arable land	1.1	–	–	1.1
221	Vineyards	0.3	–	–	0.3
222	Fruit trees and berry plantations	0.3	–	–	0.3
231	Pastures	0.4	–	–	0.4
242	Complex cultivation patterns	1.1	–	–	1.1
243	Land principally occupied by agriculture, with significant areas of natural vegetation	0.7	–	–	0.7
311	Broad-leaved forest	1.3	–	–	1.3
312	Coniferous forest	1	–	–	1
313	Mixed forest	1.2	–	–	1.2
321	Natural grasslands	0.3	–	–	0.3
322	Moors and heathland	0.8	–	–	0.8
324	Transitional woodland-shrub	0.8	–	–	0.8
411	Inland marshes	–	–	0.15	0.15
511	Water courses	–	–	0.25	0.25
512	Water bodies	–	–	0.25	0.25

Kc, coefficient used for the crops, plants, and trees; Ku, coefficient used for urban area; Kw, coefficient used for free water. Source: From Allen et al. (1998); Nistor and Porumb-Ghiurco (2015), Nistor et al. (2017).

Table 3 Corine Land Cover coefficients used for the mid-season in the Paris metropolitan area.

CLC code 2012	Corine Land Cover CLC Description	Kc mid-season Kc	 Ku	 Kw	 Kclc
111	Continuous urban fabric	–	0.4	–	0.4
112	Discontinuous urban fabric	–	0.3	–	0.3
121	Industrial or commercial units	–	0.4	–	0.4
122	Road and rail networks and associated land	–	0.35	–	0.35
123	Port areas	–	0.5	–	0.5
124	Airports	–	0.4	–	0.4
131	Mineral extraction sites	–	0.36	–	0.36
132	Dump sites	–	0.36	–	0.36
133	Construction sites	–	0.36	–	0.36
141	Green urban areas	–	0.32	–	0.32
142	Sport and leisure facilities	–	0.3	–	0.3
211	Non-irrigated arable land	1.35	–	–	1.35
221	Vineyards	0.7	–	–	0.7
222	Fruit trees and berry plantations	1.05	–	–	1.05
231	Pastures	0.9	–	–	0.9
242	Complex cultivation patterns	1.35	–	–	1.35
243	Land principally occupied by agriculture, with significant areas of natural vegetation	1.15	–	–	1.15
311	Broad-leaved forest	1.6	–	–	1.6
312	Coniferous forest	1	–	–	1
313	Mixed forest	1.5	–	–	1.5
321	Natural grasslands	1.15	–	–	1.15
322	Moors and heathland	1	–	–	1
324	Transitional woodland-shrub	1	–	–	1
411	Inland marshes	–	–	0.45	0.45
511	Water courses	–	–	0.65	0.65
512	Water bodies	–	–	0.65	0.65

Kc, coefficient used for the crops, plants, and trees; Ku, coefficient used for urban area; Kw, coefficient used for free water. Source: From Allen et al. (1998); Nistor and Porumb-Ghiurco (2015), Nistor et al. (2017).

The values of K_{clc} in the cold season vary from 0 to 1, with more classes which have values of 0 and 0.6. The maximum values of $K_{clc\ cold}$ occupy the South and southwestern sides of the Paris metropolitan areas, where the coniferous forest extends. The mixed forest has also a high value of 0.8 for this period, but this class spread in few sides and is very close to the coniferous forest. In this season, the broad-leaved forest type has a value of 0.6 and it spreads in the North, South, West, and in some location from the eastern sides. Figure 5 shows the spatial distribution of K_{clc} for the cold season in the study area. The K_{clc} values related to the cold season are exposed in Table 5.

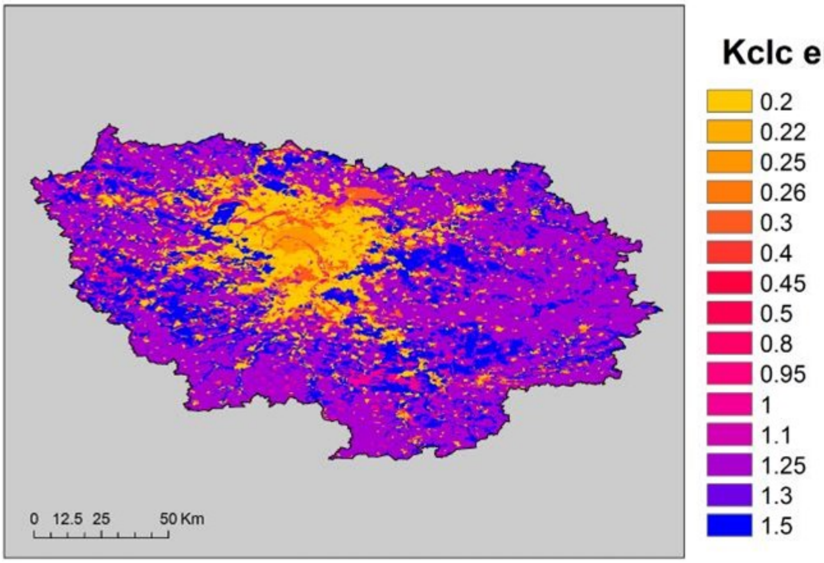

Figure 4 Spatial distribution of Kclc end in the Paris metropolitan area for the end season stage. This figure is available in colour online at www.georeview.ro.

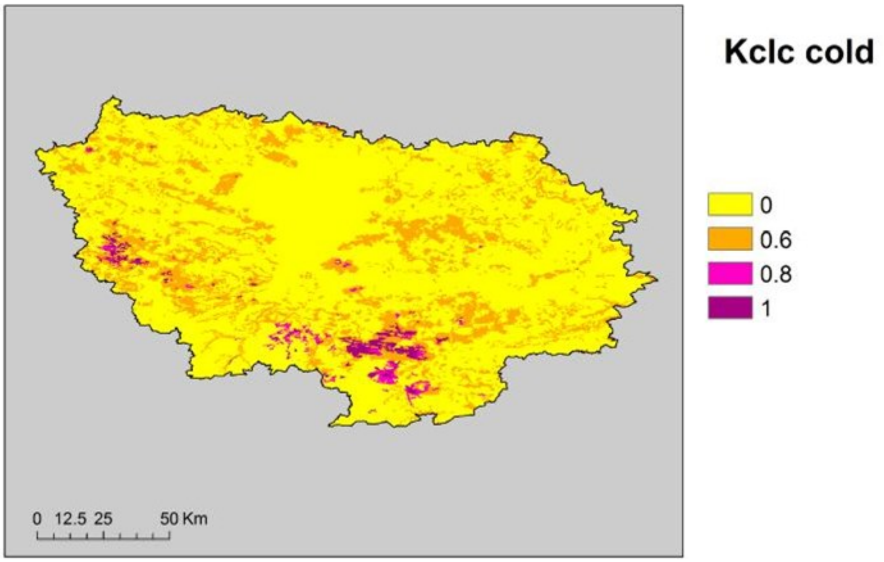

Figure 5 Spatial distribution of $K_{clc\ cold}$ in the Paris metropolitan area for the cold season stage. This figure is available in colour online at www.georeview.ro.

The main goal of the present work was to identify the typology of land cover and further to represent the spatial distribution of K_{clc} due by land cover pattern in the Paris metropolitan area. The most highly values of the K_{clc} were found in the mid-season stage (1.35, 1.5, and 1.6) in the territory occupied especially by complex cultivation patterns, non-irrigated arable land, mixed and broad-leaved forest. These classes spread almost in the whole part of the investigated area, less in the city of Paris. Comparing the initial season, mid-season, and end season, there are very appropriate pattern and the spatial changes of K_{clc} are few. The reason is correlated with the slightly changes of vegetation coefficients between these three stages. The cold season illustrates the major changes in the K_{clc} pattern with respect to others stages.

Table 4 Corine Land Cover coefficients used for the end season in the Paris metropolitan area.

Corine Land Cover		Kc end season			
CLC 2012	CLC Description	Kc	Ku	Kw	Kclc
111	Continuous urban fabric	–	0.25	–	0.25
112	Discontinuous urban fabric	–	0.2	–	0.2
121	Industrial or commercial units	–	0.3	–	0.3
122	Road and rail networks and associated land	–	0.25	–	0.25
123	Port areas	–	0.4	–	0.4
124	Airports	–	0.3	–	0.3
131	Mineral extraction sites	–	0.26	–	0.26
132	Dump sites	–	0.26	–	0.26
133	Construction sites	–	0.26	–	0.26
141	Green urban areas	–	0.22	–	0.22
142	Sport and leisure facilities	–	0.2	–	0.2
211	Non-irrigated arable land	1.25	–	–	1.25
221	Vineyards	0.45	–	–	0.45
222	Fruit trees and berry plantations	0.5	–	–	0.5
231	Pastures	0.8	–	–	0.8
242	Complex cultivation patterns	1.25	–	–	1.25
243	Land principally occupied by agriculture, with significant areas of natural vegetation	1	–	–	1
311	Broad-leaved forest	1.5	–	–	1.5
312	Coniferous forest	1	–	–	1
313	Mixed forest	1.3	–	–	1.3
321	Natural grasslands	1.1	–	–	1.1
322	Moors and heathland	0.95	–	–	0.95
324	Transitional woodland-shrub	0.95	–	–	0.95
411	Inland marshes	–	–	0.8	0.8
511	Water courses	–	–	1.25	1.25
512	Water bodies	–	–	1.25	1.25

Kc, coefficient used for the crops, plants, and tree; Ku, coefficient used for urban area; Kw, coefficient used for free water. Source: From Allen et al. (1998); Nistor and Porumb-Ghiurco (2015), Nistor et al. (2017).

We supposed to be more different due to the nil values which occur in this season at medium latitude. Interestingly image of the coniferous forest in the Paris metropolitan area, which has lower values during the initial season, mid-season, and end season than mixed forest and broad-leaved forest. In contrast, for the cold season the land occupied by coniferous forest has the highest value from all classes. This is explained by its capacity to have normal biological functions during the winter, even if the lower temperature are for many types of crops a factor which suspend the vital cycle. For this reason, the map with K_{clc} distribution in cold season looks much different than other maps.

Table 5 Corine Land Cover coefficients used for the cold season in the Paris metropolitan area.

CLC code 2012	Corine Land Cover CLC Description	Kc cold season Kc	Ku	Kw	Kclc
111	Continuous urban fabric	–	0	–	0
112	Discontinuous urban fabric	–	0	–	0
121	Industrial or commercial units	–	0	–	0
122	Road and rail networks and associated land	–	0	–	0
123	Port areas	–	0	–	0
124	Airports	–	0	–	0
131	Mineral extraction sites	–	0	–	0
132	Dump sites	–	0	–	0
133	Construction sites	–	0	–	0
141	Green urban areas	–	0	–	0
142	Sport and leisure facilities	–	0	–	0
211	Non-irrigated arable land	0	–	–	0
221	Vineyards	0	–	–	0
222	Fruit trees and berry plantations	0	–	–	0
231	Pastures	0	–	–	0
242	Complex cultivation patterns	0	–	–	0
243	Land principally occupied by agriculture, with significant areas of natural vegetation	0	–	–	0
311	Broad-leaved forest	0.6	–	–	0.6
312	Coniferous forest	1	–	–	1
313	Mixed forest	0.8	–	–	0.8
321	Natural grasslands	0	–	–	0
322	Moors and heathland	0	–	–	0
324	Transitional woodland-shrub	0	–	–	0
411	Inland marshes	–	–	0	0
511	Water courses	–	–	0	0
512	Water bodies	–	–	0	0

Kc, coefficient used for the crops, plants, and trees; Ku, coefficient used for urban area; Kw, coefficient used for free water. Source: From Allen et al. (1998); Nistor and Porumb-Ghiurco (2015), Nistor et al. (2017).

A significant observation is coming from the comparison of K_u values between the initial season and end season. The higher K_u values in the end season than in the initial season for continuous and discontinuous urban fabric, road and rail networks and associated land, mineral extraction sites, dump sites, construction sites, green urban areas, sport and leisure facilities indicates that standards coefficients takes into consideration the continuing of summer effects and the graduated dynamic changes between warm and cool periods.

As we expected, there are no areas with bare soils at this spatial level for Paris metropolitan area. There exists the possibility to appear some portions with bare soils or sands, but in the plains areas is difficult to found the outcrops and uncovered rocks. One of the reason is the presence of herbaceous plants in the low lands, which can be easily growth up in the areas with no cover, because of the fully humid climate. Other reason is based on the atrophic factor, which models the landscape, transforming the areas with no vegetation in extraction sites or other functionality lands.

5. Conclusions

The work presented in this paper is a simply key which illustrates how to set the K_{clc} for various types of crops, land use, and surface water areas. Spatial distribution of K_{clc} in Paris metropolitan area for the cold season is very different in comparison with others three seasons due to the lower values of temperature which can occur in temperate zone in the cold season and, as consequence, the plants reduce its biological functions.

The limitation of the study refers at some types of crops which can adhere, more or less, another crop calendar. For instance, the complex cultivation patterns can be different from one year to another, but also could be fit better into five season growth division. Using the previous researches and standard values of K_c from literature, this method could be completed with the field measurements in aim to obtain specific K_c for the respective area and to have better results. The mentioned gaps does not affect the investigation knowing that the method was applied on a regional scale that is much different than the local scale. For this reason the standard values for K_{clc} have been set. Considering the dynamic changes of the Paris surroundings, our findings are a useful input for the agricultural, climatic, and hydrogeological studies which are necessary to be taken into consideration for one of the bigger capital from Europe. Based on this type of survey, the crop evapotranspiration at regional scale could be drawn, but also the water balance and effective precipitation calculations can be carried out in the future works.

The results of the survey are coming to be important tools also for the environment space planning, water resources management and urban planning with completing for civil engineering.

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