Research Article

Identifying Surface Runoff Distribution and Amount in Stream Basins: Ergene River Basin

Akarsu Havzalarında Yüzeysel Akış Dağılış ve Miktarının Belirlenmesi: Ergene Nehri Havzası

Atilla Karataş
Marmara University, Faculty of Science and Literature Geography Department, 34722 İstanbul, Turkey
atilla.karatas@marmara.edu.tr
Received Date: 12.08.2017, Accepted Date: 09.03.2018

Abstract

The undisputable significance of water resources necessitates solving problems related to the amount and distribution of water. However, existing methods and the outcomes obtained via these methods are continuously criticized and do not meet the expectations in terms of reliability. On the other hand, increasing need to plan water resources and lack of alternative methods to determine the water potential in areas where flow measurement does not exist make it impossible to evade dependency on these methods. With this purpose generated flexible, comprehensive and reliable runoff distribution map was formed on the basis of weighted overlay in parallel to impact degrees of effective parameters. The calibration of the obtained map was done on the basis of pixels based on both theoretical and empirical data. As a result of the analyses, it was seen that an accurate runoff distribution model that fully reflects the characteristics of the field can only be developed by calibrating it based on the real flow data obtained from remote sub-basins that are free from external interventions. It would be impossible to free the theoretical approaches from errors since these approaches are related to amount of water which has an active nature and interacts with factors that are beyond measure. As a result of implementing the method on Ergene River Basin, the sample basin, a surface runoff volume of an average183,45mm/year/m², i.e. a total of 2100000000m³/year ±2% was obtained for the basin and this result has at least 27% difference from the results obtained with existing methods.

***Keywords**: Surface runoff, runoff modeling, runoff distribution, water potential, Ergene River Basin*

Öz

Su kaynaklarının tartışmasız önemi bu maddenin miktar ve dağılışına dair problemlerin çözülmesini zorunlu kılmaktadır. Ancak mevcut yöntemler ve bu yöntemlerin verdikleri sonuçlar sürekli olarak tenkitlere maruz kalmakta, güvenilirlik açısından beklentiyi karşılayamamaktadır. Buna karşılık su kaynaklarının planlanması hususunda her geçen gün artan zaruret ve akım ölçümünün bulunmadığı alanların su potansiyelini belirlemenin başka bir yolunun olmayışı söz konusu yöntemlere bağımlılıktan kurtulmayı imkânsız hale getirmektedir. Dolayısıyla esnek, kuşatıcı ve güvenilir bir yüzeysel akış dağılış modeline olan ihtiyaç su kaynaklarının sevk ve idaresi konusundaki en temel meselelerden biridir. Bu amaçla öncelikle yüzeysel akışa etki eden parametreler üzerinden bir sayısal akış dağılış haritasının oluşturulması, ardından da bu haritanın en doğru sonuca ulaşacak şekilde kalibre edilmesi temelinde bir model geliştirilmeye çalışılmıştır. Akış dağılış haritası etken parametrelerin etki dereceleri parelelinde ağırlıklı çakıştırma eksenli olarak şekillendirilmiştir. Sonuçta elde edilen haritanın kalibrasyonu ise hem teorik hem de ampirik verilere göre piksel bazlı olarak yapılmıştır. Bütün analizlerin neticesi olarak doğru bir akış dağılış modelinin ancak sahanın özelliklerini tam olarak yansıtan bir akış dağılış haritasının dış müdahalelerden uzak alt havzalardan elde edilecek reel akış verilerine göre kalibre edilmesiyle şekillenebileceği anlaşılmıştır. Çünkü hareketli bir doğası olan ve sayılamayacak kadar çok faktörle etkileşim halinde bulunan suyun miktarına dair teorik yaklaşımların hatalardan arındırılması mümkün olmayacaktır. Metodun örnek havza olan Ergene Nehri Havzasında uygulanması sonucunda mevcut yöntemlerin verdikleri sonuçlar ile en az %27 oranında fark içerecek şekilde havza için ortalama 183,45mm/yıl/m² yani toplam 2100000000m³/yıl seviyesinde bir yüzeysel akış hacmine ulaşılmıştır.

Anahtar kelimeler: *Yüzeysel akış, akış modelleme, akış dağılışı, su potansiyeli, Ergene Nehir Havzası*

Introduction

It is crucial to plan and utilize water, which is one of the prerequisites for the existence of living creatures, in an extremely meticulous manner due to increased demands for its use, irregularities in its regional and seasonal distribution and its nature that is not unlimited. Supply and demand equilibrium is one of the prominent instruments that will guide this process. Therefore, existence and accuracy of the data for water distribution and amount which are the basic dynamics of water demand play a determinative role in taking well directed steps in water resources management. It is undisputable that errors and drawbacks in this regard will disrupt all the work in this area.

While it is possible to date the work in the field of hydrology way back to the history of humanity, the literature in the field started to shape with Halley's work (1694) in regards to measurement of evaporation from water surfaces and Dalton's (1802) work in measuring basin-based evaporation and permeability. During the first part of the 20th century, with Horton's works (1935; 1938; 1939), surface runoff calculations based on the relationship between infiltration capacity and surface runoff started to take place. Later, surface runoff modeling, that structurally matured with the works of Thornthwaite (1944; 1948), Penman (1948), Blaney and Criddle (1950; 1962), Thornthwaite and Mather (1955; 1957), presented an integrated outlook with the work and calculations on evapotranspiration for a long time (Makkink, 1957; Jensen and Haise, 1963; Baier and Robertson, 1965; Priestley and Taylor, 1972; Doorenbos and Pruitt, 1975; 1977; Hargreaves and Samani, 1982; 1985; Shuttleworth and Wallace, 1985; Jensen et al., 1990; Cohn et al., 1997; Alexandris et al., 2006). However, flow calculations and modeling were separated from one another as independent areas during the process. While studies by Jury and Tanner (1975), Allen and Pruitt (1986), Allen et al. (1998), Samani (2000), Irmak et al. (2003), Trajkovic

(2007), Jabulani (2008), Fooladmand and Ahmadi (2009), Jensen (2010), Lima et al. (2013), Rao et al. (2014) and Feng et al. (2017) aimed mainly to develop evapotranspiration calculation methods on one hand, flow data continued to be generated on the other. Evapotranspiration-surface runoff relationship, which indirectly continued to be taken into consideration in implementations, has been a medium through which science is generated in the framework of assessments in the form of continuous comparison of methods (Cruff and Thompson, 1967; Grace and Quick, 1988; Allen, 1993; McKenney and Rosenberg, 1993; Xu and Singh, 2000; 2002; Alexandris et al., 2008; Irmak et al., 2008; Weib and Menzel, 2008; Mohawesh, 2011; Sammis et al., 2011; Shahidian et. al., 2012; Tukimat et al., 2012; Lingling et al., 2013; Jensen, 2014; Callistus, 2015; Pereira et al., 2015; Çobaner et al., 2016). Studies towards narrowed targets increased in the name of protecting data integrity especially when Geographical Information Systems were started to be used and studies on evapotranspiration calculation started to become separate in the natural course of the process (Dockter, 1994; Zhou et al., 2006; Foolandmand, 2011; Diouf et al., 2016; Morales Salinas et al., 2017). Later, studies on determining water balance undertaken mainly to identify the need for agricultural water (Blaney and Criddle, 1950; 1962; ASCE, 1990; Baldwin et al., 2002; Neitsch, 2011) transformed into practices to calculate surface runoff distribution (Berry and Sailor, 1987; Drayton et al., 1992; Mattikalli et al., 1996; Gitika and Ranjan, 2014; Gajbhiye, 2015). While some of these practices gravitated towards analyses based on Lidar images (Pagh et al., 2005; Gonzalez Jorge et al., 2015), some presented new examples in the framework of methods such as existing Thornthwaite (1948) (Singh et al., 2004), Thornthwaite and Mather (1955; 1957) (Roy and Ophori, 2012) and USDA (1986) Curve Number (Sharma and Singh, 1992; Khatun, 2016; Vojtek and Vojtekova, 2016; Kaletova and Nemetova, 2017).

While today runoff calculations based on direct precipitation-runoff relationship are conducted (Nash and Sutcliffe, 1970; Lane, 1984; Ranzi et al., 2003; Reintjes, 2004; Liebe et al., 2009; Tedela, 2012; Poullain, 2012; Idowu et al., 2013; Kellagher, 2013) surface runoff and water balance modeling (Thornthwaite, 1948; Thornthwaite and Mather, 1955; 1957; SCS; 1986; Xu et al., 1996) are still in practice. These models and calculations are often used in various fields and for varying purposes such as effects of climate change (Gleick, 1986; 1987; Schaake and Liu, 1989; Arnall, 1992), underground water balance and flow (Sauer and Ries, 2002; Tstsumi et al., 2004; Stanton et al., 2013), amount of permeability (Zimmermann, 2006), erosion (Knisel, 1980), basic flow (Santhi et al., 2008), soil moisture (Pastor and Post, 1984), flood risk (Hewlett and Hibbert, 1966; Borga, 2002; Tayfur and Moramarco, 2008) and drought risk (Majumder and Sivaramakrishan, 2016). However, a great deal of work which criticizes, critiques and corrects the existing water balance identification methods is noteworthy (Lane, 1984; Calvo, 1986; Klemes, 1986; Steenhuis and Van der Molen, 1986; Wilcox et al., 1990; Xu and Vanderwiele, 1994; Ponce et al., 1996; Xu and Singh, 1998; Xu, 1999a; Beven, 2000; Xu and Singh, 2005; Black, 2007). This observation points to nonexistence of a single model that can perfectly explain runoff (Harssema, 2005) and at the same time clearly shows that existing methods and models are not satisfactory. The fact that even the SCS-CN model, the most commonly and often used method is far from solving problems (Rallison and Miller, 1982) since it does not have the ability to keep pace with the variables to solve hydrologic problems in wide and heterogeneous areas due to its simplicity shows that this issue is yet to be solved.

Problem Statement

Runooff models can roughly be categorized into two as lumped or distributed or deterministic or stochastic (Harssema, 2005). The opposite of lumped model that treats the whole basin as a single unit and presents it with a single average value is the distributed model that represents the basin with the value of grid based variables. Along the same lines, the opposite of the stochastic model that addresses the probable range of input-output balance is the deterministic model which is used in many runoff models and refers to the constant value that corresponds to a variable (Ward and Robinson, 1990; Beven, 2000; Rientjes, 2004; Harssema, 2005). Although it is systematically possible to make such an assessment, it should be remembered that this is problematic with many aspects from the parameters taken as basis to the period of calculation, from the dimensions of the study area to variability of calibration.

The first issue that should be emphasized in relation to the inadequacy of existing methods is the issue of what calculation methods or models actually aim. At this point, the models that aim to determine agricultural water necessity and the models to determine underground water irrigation or models that set out to present water balance with flood risk after precipitation will not reach the same conclusions by identifying the same route and methods and therefore they will not be able to solve the same problem and use it for the same purpose. Along the same lines, difference of period in models or calculations is another area which causes separation of techniques. The runoff that occurs after the precipitation that is sought in precipitation-runoff equations is a completely specific event and it is only relevant for the time and location for which the calculation is undertaken. Generalizing such data will cause serious errors. The same can be observed between models that depend on daily climactic data which make it impossible to study in wide areas and models that depend on monthly data. There can be very distinct anomalies between daily and monthly data and the core of planning is the monthly data, i.e. the regime of annular average.

Similar to differences in results in data due to differences in periods, there are differences in results in data resulting from the differences in area. The main reason for this is the lack of homogenous distribution of runoff in almost any of the basins. It is a dire error to interpret the data obtained at the level of points to include the whole area or whole basin by putting aside the fact that each point and each pixel in the model has unique conditions. Each point has its own conditions in terms of the parameters in the model and reflects a different level of relationship with surface runoff based on the impact level of the parameters. Hence, accurately identifying the runoff distribution design that demonstrates heterogeneous conditions almost everywhere will make it possible to present the specific runoff dynamics for the whole basin or area or its sections or sub units. At this point, it is crucial to determine effective parameters and compare their impact values.

The process of identifying the parameters in the model starts with eliminating the confusion in relation to goals and period. Although very different parameters such as infiltration capacity and permeability values (Horton, 1935; 1938; 1939; Brakensiek, 1955), precipitation (Snyder, 1963; Fiering, 1967; Tuffuor and Labadie, 1973; Kuczera, 1982; Gabos and Gasparri, 1983), precipitation and temperature (Thornthwaite and Mather, 1955; Palmer, 1965; Thomas, 1981; Alley, 1984), monthly precipitation and potential evapotranspiration (Pitman, 1973; 1978; Van der Beken and Byloos, 1977; Roberts, 1978; 1979; Krzystofowicz and Diskin, 1978; Hughes, 1982), daily precipitation and potential evapotranspiration (Haan, 1972; Kuczera, 1983), interception (Mulder, 1985), land use (Bultot et al., 1990; Bhaduri et al., 1997; 2000; Krause, 2002), land use and soil texture (Lane, 1984; Liang et al., 1994), lithology, land use and soil texture (Westenbroek et al., 2010) and geographical and geological characteristics, land use and climactic characteristics (Nielsen et al., 1973; Ries, 1990; Neitsch et al., 2011) are taken as basis for calculations and model development in various studies; comprehensive and satisfactory results have not been achieved. It was expressed that all runoff models, even the models that include nine (Langford et al., 1978) or eleven (Salas et al., 1986) parameters are full of errors (Cowen, 1957; Mockus, 1964; Kent, 1966; 1973; Rallison and Miller, 1982; Harssema, 2005; Tayfur and Singh, 2011).

It is possible to classify the parameters that affect precipitation primarily as meteorological factors such as type, amount, density, distribution and duration of precipitation, storm destination, soil moisture based on precipitation, temperature, wind, relative humidity and seasons and physical factors such as land use, flora, soil type, drainage area, basin geometry, elevation, slope, topography, aspect, drainage network and reservoirs (Arnold et. al., 1999; USGS, 2017). Data related to special conditions such as soil texture, underground water table and underground water depth (Batelaan and Smedt, 2007) and snowfall, cumulative snow, snow melt and actual evapotranspiration (Xu, 1999b) can be added to these conditions. All these climactic and surface data can be assessed in conjunction with each other with the help of Geographical Information Systems to identify the distribution characteristics of precipitation that presents a complex design at the surface (Batelaan and Smedt, 2007; Gajbhiye, 2015). Despite problems of all types, some reasons increase dependency for these models such as abundance of basins for which no flow measurements are taken and the fact that runoff models generate more accurate data compared to river flow measurements in regards to surface runoff, changes in soil moisture, evapotranspiration and underground water irrigation-discharge values (Gleick, 1987). As a result, in addition to increasing the number of observation stations; various alternatives such as creating computer software to develop existing models and calculations, produce new models and facilitate the use of existing models continue to be presented and attract attention (Stone, 1988; Birsoy and Ölgen, 1992; Westenbroek et. al., 2010; Doğdu, 2011).

Method

Generally, all modeling based on empirical and/or physical data is composed of hypotheses expressed as mathematical estimates of effective elements (Beven, 2000). However, the existence of factors -the numbers of which are difficult even to specify- that affects water potential shows the fact that assumptions or generalizations in such models are inevitable. Considering the essentiality that each assumption should be recognized or based on knowledge to ensure that the theory will be taken into consideration, it is crucial to prove that results are produced in a specific confidence interval. Therefore, forming a methodological framework depends on a delicate balance among many issues each of which is significant enough to affect results, from identifying data that will form the basis of theory or model to establishing an accurate relationship among them, from ensuring the ability to revise the mode based on conditions to producing field specific results that fit a definitive confidence interval. At this point, the first step in the study was the identification of the basic components that affected the distribution design regarded as the foundation.

Without doubt, basins that should be regarded as unique hydrological units in terms of runoff dynamics include many characteristics that shape the runoff distribution design in their own conditions. While some of them are more dominant and determinative of the basic pattern, some others have relatively lower impact capacity. For instance, it would be unnecessary to take the lithological data of the field into consideration while identifying the runoff design in a basin composed of homogeneous alluvial deposition areas in terms of lithology. Hence, parameters that direct the runoff design in terms of study area will demonstrate differences based on field conditions.

For this study; precipitation and potential evapotranspiration values in mms., hydro-geological structure, land use, soil types, slope and soil texture data were obtained from the sample field site Ergene River Basin (NW Turkey) (Table 1). ASTER GDEM V2 with 15m resolution digital elevation model (METI&NASA) was utilized in relief based analyses. Filed conditions played a direct and complete role in identifying which parameters to be taken into consideration. On the other hand, the rate of parameter impact on runoff and impact coefficients of units included on the database of parameters on runoff distribution design were determined based on reference work in literature related to the field and units (Horton, 1932; 1945; Langbein, 1947; 1949; 1980; Strahler, 1952; 1957; Ardel, 1957; 1965; Melton, 1957; Kurter, 1963; Yalçınlar, 1968; Eagleson, 1970; Fleming, 1975; Warnick and Nielsen, 1980; Verstappen, 1983; Atalay, 1986; Chow et al., 1988; Miller, 1990; Özer, 1990; Bayazıt et al., 1991; Dumlu et al., 2006; Hoşgören, 2012; Karataş and Korkmaz, 2012) in addition to expert views focused on determining the relative relationship among units (Table 1). The obtained multiplier values were transformed into a quantitative surface runoff distribution map with the help of weighted overlay method (Clerici et al., 2002; Saha et al., 2002; Esri, 2017) based on conditions related to identifying impact factor levels with theoretical classification of effective elements. At this point, it is evident that abundance of units as multipliers will reduce error amplitude and enhance reliability of results. However, since impact values assigned while generating the afore-mentioned digital map did not have real numerical equivalents, it should be remembered that the obtained map is a relative digital runoff distribution design map in need of calibration.

Data included in the table in relation to precipitation and potential evapotranspiration were compiled from the records at the meteorology stations in the study area (Turkish State Meteorological Service, 2016) and their equivalents reproduced by spreading the elevations of these records to specific benchmarks (Schreiber, 1904). Thornthwaite (Thornthwaite and Mather, 1957) method was utilized to obtain potential evapotranspiration data. Data from the enlarged climactic data points in the basin were taken as basis to determine potential evapotranspiration values for each point. Later, both precipitation and potential evapotranspiration data in point based form were interpolated to obtain weighted distribution maps for both climactic parameters. ArcMap Geostatistical Wizard-CoKrigging (Esri, 2013) device was used for interpolation process by taking both point based climactic data and areal climactic data zones divided according to elevation levels into consideration. As a result, quantities in the obtained maps were classified to generate five impact classes and each was assigned a value of coefficient “3” by observing that precipitation and potential evapotranspiration were the dominant parameters that affected runoff in the study area (Table 1).

Table 1

Classes and Impact Values Used in Weighted Overlay Method

Parameter	**Classification**	**Coefficient**	**Impact Value**	**Multiplier Effect**
Precipitation (mm)	861-932	3	5	15
	781-860		4	12
	701-780		3	9
	621-700		2	6
	540-620		1	3
Potential Evapotranspiration (mm)	450-550	3	5	15
	550-650		4	12
	650-750		3	9
	750-850		2	6
	850-950		1	3
Hydrogeology	Gneiss, Schist, Meta-granite	2	5	10
	Granite, Marble, Schist		4	8
	Undifferented Terrestrial Clastics		3	6
	Clastics and Basalts		2	4
	Alluvium		1	2
Land Use	Irrigated Areas	2	5	10
	Grassland and Pastures		4	8
	Forest, Shrubbery, Vineyard-Orchard		3	6
	Urban Areas		2	4
	Dry Farming Areas		1	2
Soil Type	Alfisols	2	5	10
	Vertisols		4	8
	Mollisols		3	6
	Urban Areas		2	4
	Entisols		1	2
Slope (%)	20 +	1	5	5
	15-20		4	4
	10-15		3	3
	5-10		2	2
	0-5		1	1
Soil Texture	Rocky	1	5	5
	Very shallow (0-20cm)		4	4
	Shallow (20-50cm)		3	3
	Medium depth (50-90cm)		2	2
	Deep (90+ cm)		1	1

Hydro-geological units in the field were classified into five relative classes among themselves based on their porosity and permeability characteristics and their support for surface runoff. Similarly, land use design and distribution of soil types in the basin were classified into five classes each based on their relative contribution to surface runoff and "2" was assigned as coefficient for each of these three parameters (Table 1). When basin conditions are taken into consideration, the impact of these three parameters on surface runoff in the basin is lower than that of precipitation and potential evapotranspiration but higher than that of slope characteristics and soil texture. Slope values and soil texture classified into five among themselves were assigned a coefficient of "1" and it was ensured that they were determinant corresponding to the level of their impact while generating the surface runoff distribution map (Table 1). Since characteristics related to precipitation, potential evapotranspiration, slope values and soil texture were divided into equal or equivalent numerical categories, the impact values of units in these parameters were assigned in accordance with their quantities. Units for hydro-geology, land use and soil types were assigned impact values based on their characteristics emphasized in literature related to the field (Ardel, 1957; 1965; Kurter, 1963; Yalçınlar, 1976; Ardos, 1995; Pelen et al., 2003; Horvat and Rubinic, 2006; General Directorate of Mineral Research and Exploration, 2006; Aksoy, 2007; Aksoy et al., 2007) and their relative impact rates on surface runoff based on the relationships among these characteristics.

During the last phase of the study, weighted overlay procedure (Esri, 2017) was undertaken in conformity with Table 1 with the help of "Raster Calculator" module of ArcMap 10.3 application included in ArcGIS package program and the runoff distribution model of the basin was presented. While a numerical value existed for each pixel in the obtained digital map, these numbers were only unitless expressions that were the results of multiplication conducted during the implementation of weighted overlay. In order to transform these expressions to numeral values represented by actual units, the map was calibrated according to indicators such as annual average precipitation depth, average flow value of the main river at the mouth and flow data in sub basins with wild flow with the methods of Langbein et al., (1949), Turc (1954), Thornthwaite (1957) and USDA (1986). Correlation of intermediate values with maximum and minimum values provided intermediate values in calibrations.

Results

The methodology proposed in this study was conducted in an applied manner in Ergene River Basin which was selected for implementation. The basin is situated in northwest Turkey and is composed of 11036 km² wide water catchment area that includes Ergene River and its branches, the sub basin of Meriç River Basin (Figure 1).

The main factors that played determinant roles in basin selection were the variable but not too complex structure of components that affect runoff -mentioned beforehand in relation to methodology-, existence of various surface and climactic areas and abundance of data that allow the control and validation of implementation output.

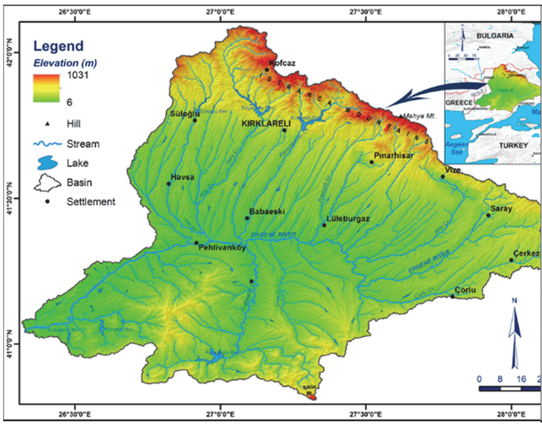

Figure 1. Location and topography map of Ergene River Basin.

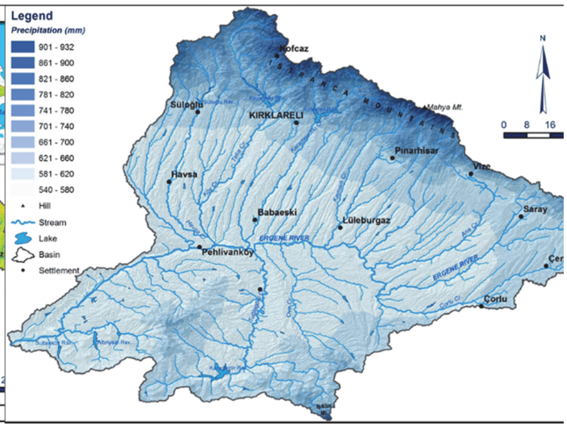

Figure 2. Distribution of average annual precipitation distribution in Ergene River Basin.

The first component to determine surface runoff distribution design of Ergene River Basin was the precipitation distribution map of the field (Figure 2). Instead of direct interpolation of the points with climactic data in the basin, CoKrigging (Esri, 2013) multi parameter interpolation -in which changes in precipitation according to elevation levels were included in the equation- was preferred and precipitation data were mapped in a manner to form a numerical surface. At this point, increase in the amount of precipitation from basin floor to higher areas which can be roughly defined as the increase from center to periphery was clearly observed. Precipitation depth that changes between annual averages of 540–932mm is congruent with meteorology station data and real climactic indicators observed in the basin in terms of amount and distribution. According to existing table, compared to central parts of the basin, meteoric water input that supported surface runoff was higher in Istranca (Yıldız) Mountains that covered the northern section of the basin and relatively in the southern section that was close to Işıklar Mountain. Especially the southern slopes of Istranca Mountains appeared as the most prominent potential meteoric water reservoir in the basin. Therefore, it was expected that these sections would provide higher values in the surface runoff distribution obtained at the end of the analysis process.

The second parameter in the basin related to surface runoff distribution design was the amount and distribution of potential evapotranspiration. Since no regular and common evaporation measurement existed in the basin, Thornthwaite (1957) water balance measurement method was utilized to present the amount and distribution of this parameter in the basin. Thornthwaite adjusted potential evapotranspiration values were taken into consideration in order to remove dry spell effects. While generating the map; the same path was followed as the precipitation distribution map and evapotranspiration change zones formed by taking into consideration the changes in temperature and precipitation based on climactic data points and elevation were operationalized via compound CoKrigging (Esri, 2013) method. Annual average potential evapotranspiration values of Ergene River Basin were found to change between 450-950mm according to numerical potential evapotranspiration map obtained in this process (Figure 3). Especially the middle sections closer to the valley floor in the central part of the basin and the west-southwest sections towards Ergene River downstream were found as the areas with increased potential evapotranspiration. Severity of evapotranspiration was determined to decrease towards Istranca Mountains, supporting the assumption that surface runoff would present higher flows in these mountainous areas where precipitation was higher.

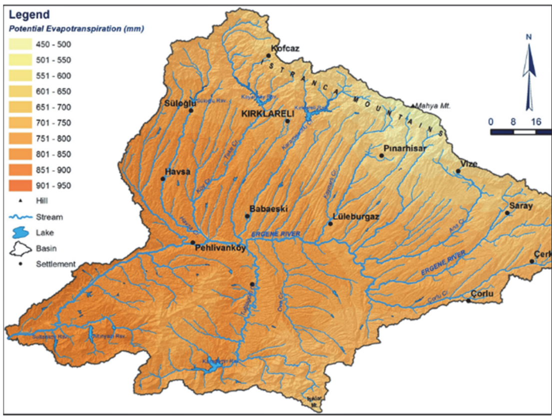

Figure 3. Distribution of average annual pot. evapotranspiration in Ergene River Basin.

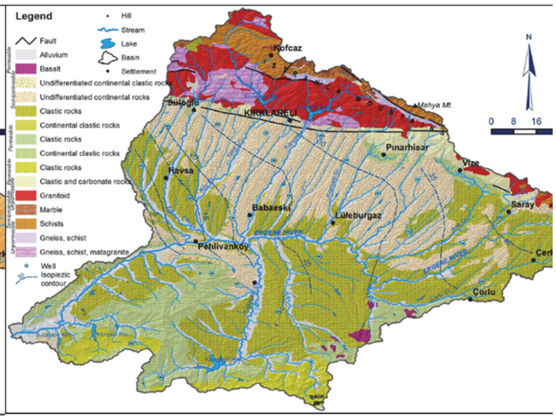

Figure 4. Hydrogeological structure of Ergene River Basin.

One of the compounds with significant effects on basin surface runoff distribution design -albeit not as much as precipitation and potential evapotranspiration- is the lithological characteristics of the ground. The main lithological structure of the basin includes metamorphites and clastics (Figure 4).

Metamorphites (gneiss, schist, marble), older than clastics, are generally known with their low permeability. It can be argued that fissured or jointed texture of sporadic marble, schist and granitoid units increase porosity albeit in low amounts and therefore form semi-permeable areas. Clastics in the basin are composed of permeable units generally called terrestrial clastics. However, the clayish-marly levels observed in younger and unsegmented elements among these units decrease permeability. Basalt crops found in the southeastern part of the basin in the form of holms and alluvium found in valley floors can be cited as units prominent with their high permeability. In this case, while non-permeable units and units with low permeability surfacing especially in Istranca mass support surface runoff, units with permeability that cover the center and south parts provide conditions for a weaker surface runoff. In addition, tectonic lines found in north and northeast are estimated to affect surface runoff. However, it was difficult to reach a definitive conclusion as to whether this effect had a negative direction in the form of increased permeability or positive direction via springs along fault.

Land use and flora are significant factors that affect surface runoff. Ergene River Basin has wide-spread dry farming areas that support permeability (Figure 5). Indeed, dry farming areas which are dominant in the basin make negative surface runoff conditions especially in middle and southern parts more apparent. In addition, forest areas, second largest after dry farming areas are relatively disadvantageous in terms of surface runoff. It should be remembered that interception plays an important part in this. On the other hand, porosity decreases and surface runoff is supported in irrigated agricultural fields mostly found in valley floors largely based on to the fact that they are water logged. Just like urban areas, meadows and orchards that are less observed on the basin scale provide less support for surface runoff compared to irrigated agricultural areas but give more support compared to dry farming areas. As a result, contribution to surface runoff in terms of land use is lower in slopes in the inner parts of the basin and in interflow zones; medium along Istranca mass and hilly areas in south-southwest sections and high in valley floors. This finding gives Istranca mountainous mass an advantageous position in terms of surface runoff.

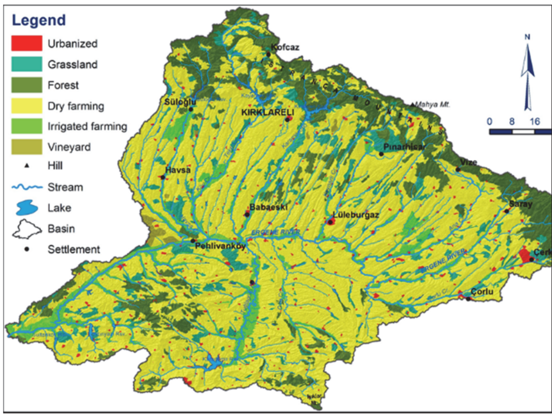

Figure 5. Current land use in Ergene River Basin.

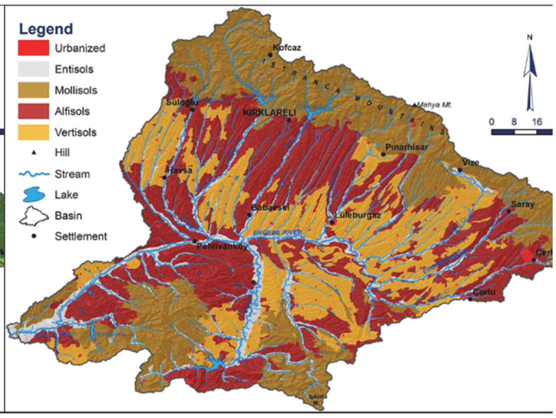

Figure 6. Distribution of soil types in Ergene River Basin.

As in land use design, distribution of soil types have a determinant role in regards to surface runoff. Due to abundance of clay content in Ergene River Basin, soil in alfisol group prevents permeation. Spreading on the low slopes of mountainous areas and downstream of Ergene River, this soil supports surface runoff in these areas (Figure 6). A similar situation is valid for vertisols that cover large areas towards the upstream of Ergene River. Mollisols that completely cover mountainous areas and entisols found in valley floors also establish the foundation that allows permeability with their soft texture and porous structures. This situation creates a relative disadvantage for areas such as Istranca Mountains and Işıklar Mountain slope which host favorable conditions for the increase of surface runoff. However, as it will be discussed later, shallow soil strata in these parts and the fact that they are limited with impermeable units that are located right below decrease the negative impact of this disadvantage.

The fact that slope directly affects runoff velocity and runoff velocity affects amount of permeation makes the distribution and degree of topographic slope significant in the study area. Ergene River, which separates Istranca range in the north and Işıklar range in the south, is surrounded by slopes from both mountainous areas with decreasing attitude towards the river bed (Figure 7). The slope of these mountain hillside is directly proportional to elevation. Especially the areas to the north of Kırklareli-Vize that correspond with the core of Istranca Mountains consist of the sections where slope values reach the highest levels due to abrasion resistance and abrasion types of resistant lithological units at basin scale on the floor. Slope levels that also increase towards the high areas in the vicinity of Işıklar Mountain present a softer, plainer and still relief in conformity with the abrasion of Neogene deposits composed of detritic material in a manner that cannot present sharp lines and decreased energy of the rivers in the areas in central parts of the basin. Slope values of Ergene River Basin are classified as 5% segments. Accordingly, the most available conditions for surface runoff are found in high mountainous areas and the most negative unfavorable can be observed in valley floors and interflow areas. Therefore, higher parts of the basin strengthen the expectations that with their structure that allows them to flow before finding an opportunity to permeate, meteoric water that reach the surface would increase surface runoff potential in these areas.

Another factor that affects the surface runoff distribution design of Ergene River Basin is soil texture. Depths of soil that cover the ground and the type of soil directly affect amount of permeation and period of saturation. Since soil is the decomposed state of the bedrock, its porosity is relatively higher and when its depth increases, the amount of water that it permeates and stores also increases. In terms of texture, the soil in the study area is classified in five classes as rocky and devoid of soil, very shallow (0-20cm), shallow (20-50cm), medium depth (50-90) and deep (90cm +) (Figure 8). While deep soil is mostly found in the central parts of the basin, shallow soil and rocky surfaces are generally observed in high mountainous areas and slopes where slope value is higher. Valley slopes located especially in the upstream of rivers, tectonic lines and valley floors overwhelmed by current alluviums can be defined as unfavorable areas for the formation of deep soil texture. In this sense, since soil texture becomes shallow in areas where elevation and incline increases for Ergene River, the shallow soil texture will have less water holding capacity and therefore surface runoff will increase.

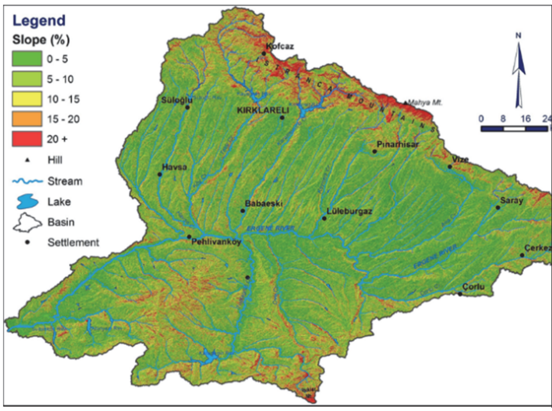

Figure 7. View of Ergene River Basin in terms of slope values.

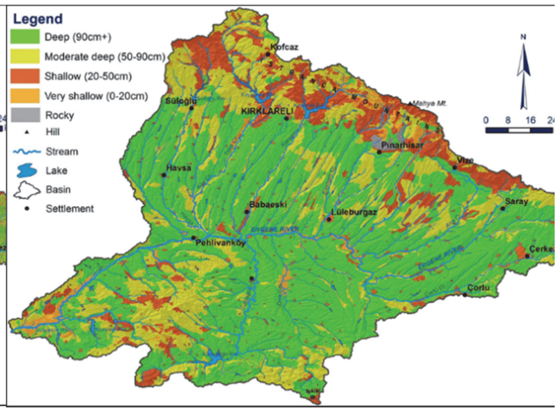

Figure 8. Ergene River Basin soil texture map.

Seven main parameters listed above which shaped the surface runoff distribution design in Ergene River Basin were composed of units revised with multiplier coefficients based on their impact rates. These units corresponded to pixel based numerical expressions and were analyzed to present the digital surface runoff distribution design map of the basin determined according to all these factors by applying the weighted overlay method (Esri, 2017). The map obtained as a result established a surface runoff distribution design that reflected the foreseen impact of each unit in initial interpretations (Figure 9). The digital surface runoff distribution map, the output, included pixel based values that changed between 144 and 414720. These values were visualized as quantities between 1 and 5 via reclassification. However, in order to save sensitivity in calibration procedures that would follow, minimum value, intermediate value and maximum value were assigned as 144, 207288 and 414720 respectively. At this point, although the mentioned map was not calibrated yet, it presented a clear view of surface runoff distribution design. As expected, it can be observed that surface runoff was stronger along Istranca mountainous mass and in areas closer to Işıklar Mountain and on the other hand it weakened in areas towards the valley floor. Since this view was designed by taking all specific conditions of each point in the basin into consideration and did not rely on generalizations, it corresponded to a distribution model that expressed separate realities for each pixel. Therefore, values that will be obtained after calibration are also specific for each point.

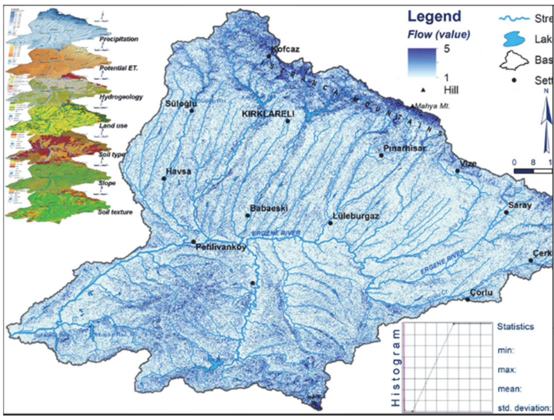

Figure 9. Compounds that affect surface runoff distribution in Ergene River Basin and surface runoff distribution design.

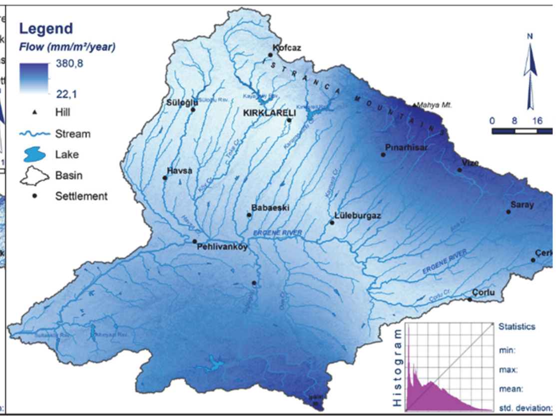

Figure 10. Surface runoff distribution map of Ergene River Basin generetaed according to Thornthwaite method and interpolation of climatic data points.

In order to comprehend the level of compatibility between surface runoff distribution map of Ergene River Basin and the real land conditions and how far the findings were from generalization, it would be useful to make comparisons with the runoff distribution map interpolated according to Thornthwaite water balance measurement. Thornthwaite runoff accounting based on the relationship between precipitation and potential evapotranspiration is listed at the top of the methods widely used today since it provides rather realistic results with almost 90% confidence interval at some areas (Calvo, 1986). However, whether results obtained for climactic data points can be representative for areas with no data or not and the results obtained after evaluating surface runoff based only on these point data can clearly be observed in runoff distribution map generated in this framework (Figure 10). It is evident that amount of surface runoff observed in rather low values especially to the north of Kırklareli-Süloğlu line does not correspond with the data obtained from the parameters that affect surface runoff in the basin. Also, as befitting the logic of interpolation, an imaginary transition occurs between Istranca and Işıklar ranges that represent high values and the central parts of the basin that correspond to relatively lower values. Therefore, areas outside of climactic data points are completely represented according to homogeneous surface and based on only estimated and generalized data. In this sense, the usability of data obtained according to this method will be ruled out for sub basins where especially climactic data is very few or nonexistent. Despite the fact that the design that is presented offers an unrealistic design in terms of surface runoff distribution; minimum (22.1mm), maximum (380.8mm) and intermediate (128mm) flow depth are important data that can be used to calibrate digital runoff distribution map devoid of the units generated in this study.

Intermediate surface runoff values (128mm) obtained for the basin via Thornthwaite method were used for the calibration of the map generated in this study and obtained the following values after reclassification: maximum 5, minimum 1 and intermediate 1.57 unit values. Maximum, minimum and intermediate runoff values (mm) obtained via Thornthwaite method were assigned for the maximum, minimum and intermediate values in the unitless digital surface runoff distribution map in this study. The calibration provided a surface runoff distribution model with actual units that reflected maximum 400mm, minimum 80mm and intermediate 126.5mm surface runoff values (Figure 11). Compared to the imaginary distribution mode obtained via Thornthwaite method, this model is more realistic and free from generalizations. Also, it can ensure 90% confidence interval for each point of the basin while Thornthwaite method can present this rate only on the basis of climactic data points.

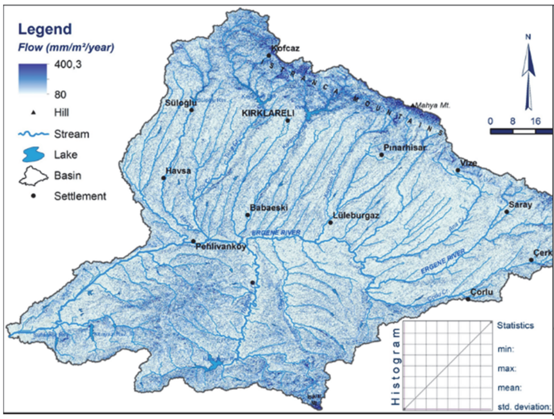

Figure 11. Surface runoff distribution map of Ergene River Basin calibrated according to Thornthwaite (Thornthwaite and Mather, 1957) method.

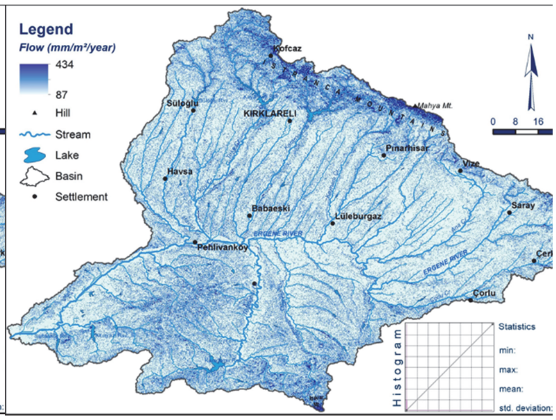

Figure 12. Surface runoff distribution map of Ergene River Basin calibrated according to Turc (1954) method.

Calibration similar to the one used in Thornthwaite method can be undertaken with the results of other methods with the potential to provide the most appropriate and realistic results. Thus, it would be possible to ensure flexibility and independency from the outcomes of only one method. In this framework, another calibration was implemented by using 139mm intermediate runoff value obtained via Turc (1954) method with extensive use (Figure 12). The maximum 434mm, minimum 87mm and intermediate 137.6mm values obtained via reference runoff of the Turc method are quite close to values obtained via Thornthwaite method. In this respect, Thornthwaite and Turc methods can be used to corroborate and verify one another. An imaginary surface runoff distribution design similar to the design in Figure 10 is obtained In Turc method, as in other methods using climactic data points as the basis. Hence, the disadvantages expressed for the distribution design obtained via Thornthwaite method are also valid for Turc method as well as other point data abased methods.

One of the reference values used in the calibration of surface runoff distribution map generated in this study for Ergene River Basin is the intermediate runoff volume of 118,5mm obtained via Langbein (Langbein et al., 1949) method. Maximum 370mm, minimum 74mm and intermediate 117mm flow depth for m²/year were observed in the calibration undertaken for Ergene River Basin based on this value (Figure 13). As in Thornthwaite and Turc methods, close but lower values were obtained in this surface runoff model which focuses directly and solely on climactic parameters. It can be argued that Langbein's disregard for sheetflow and his sole focus on rivers that provide on river channel included runoff while calibrating his own method played a role in this outcome (Langbein et al., 1949). Even so, it is clear that his model correspond to a rather consistent surface runoff amount from the angle of the two previously mentioned methods. In this case, it is observed that methods that aim to calculate surface runoff based on similar parameters arrive at approximate conclusions and therefore they are similar in regards to successful aspects as well as errors. However, it should be remembered that what is calculated in the framework of these theoretical methods is the surface runoff fed with meteoric water. Hence, underground water and sources, composed of water that do not permeate surface runoff, should be added to the amount of surface runoff while calculating the total basin discharge. On the other hand, it should also be remembered that while theoretical methods include sheetflow, empirical methods are more attuned to the flow that arrive at the river bed.

Different from the Thornthwaite, Turc and Langbein methods, it would be wise to address the revised and developed SCS-CN (Soil Conservation Services-Curve Number) (USDA, 1986) method which adopted the view that ground parameters should be taken into consideration while calculating surface runoff. Due to its simplicity, this method which evaluates the characteristics related to the ground such as hydrologic soil groups and flora along with climactic data together has become prominent as one of the most widely used methods to determine surface runoff. When calibration was undertaken via 339,1mm intermediate runoff value obtained with SCS-CN method, the amount of surface runoff in Ergene River Basin was calculated as maximum 1085mm, minimum 217mm and intermediate 343,1mm (Figure 14). Compared with models designed only with climactic data, these values are equivalent to three times more runoff volume and reflect the fact that evapotranspiration is not given enough space in the equation. These values are also clear indicators that differences in methods can create such significant differences in the calculation of the amount of surface runoff.

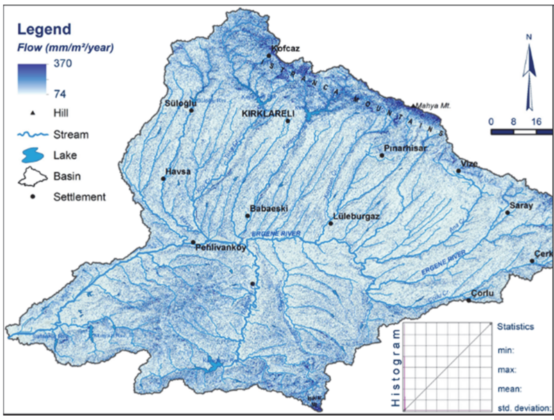

Figure 13. Surface runoff distribution map of Ergene River Basin calibrated according to Langbein (Langbein et al., 1949) method.

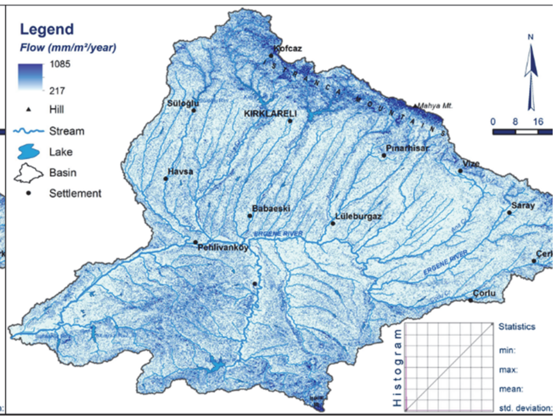

Figure 14. Surface runoff distribution map of Ergene River Basin calibrated according to SCS-CN (USDA, 1986) method.

In addition to previously mentioned methods that should be regarded as theoretical although they have some empirical foundations, use of more data obtained according to outcomes of measurement and observation during calibration will pave the way to make interpretations with wider perspectives by presenting differences. In this framework, in order to present more systematized work and generate a confidence interval, this study selected the empirical data used as the basis of calibration in a manner that would determine the lower and upper limits of the surface runoff amount in Ergene River Basin. Without doubt, the upper limit is defined via calibration based on average precipitation depth of the basin because such a calibration means that the entirety of the meteoric water transforms into surface runoff., i.e. possible maximum surface runoff value can be reached in this manner. The following values were obtained for Ergene River Basin as a result of the calibration by taking 581,4mm intermediate flow depth as reference according to precipitation distribution map of the study area: maximum 1817mm, minimum 363mm and intermediate 574,1mm volume surface runoff values (Figure 15). While these values are far from the real runoff volume of the basin, they are significant since they express the maximum runoff volume. As a result, it cannot be expected for annual surface runoff amount in Ergene River Basin to surpass 574,1mm/m² level.

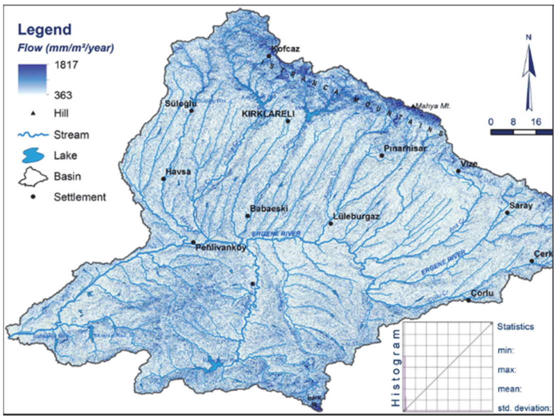

Figure 15. Surface runoff distribution map of Ergene River Basin calibrated according to annual intermediate precipitation depth.

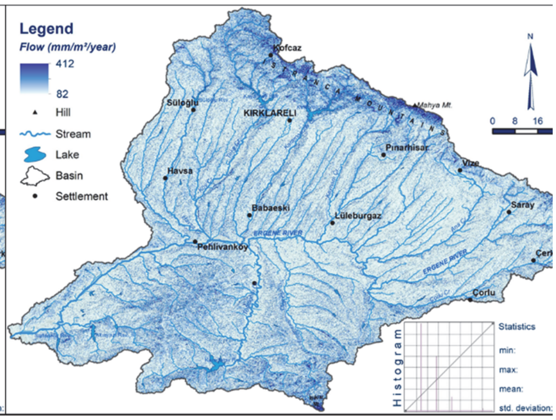

Figure 16. Surface runoff distribution map of Ergene River Basin calibrated according to flow of Ergene River at the mouth.

Another data that can be addressed in terms of empirical data is related to flow data of the main river provided by the stream gauging stations. It is already known that amount of flow presented by surface data can be compared with data obtained by flow observation stations at the basin estuary to look for compatibility (Arnold et.al., 2000). At this point, calibration that will be undertaken based on the average of flow observations conducted at the mouth of the main river in the basin will reflect minimum values for the basin since it is based on the amount of water that leaves the basin after all losses. Ergene River's surface runoff distribution map calibrated over 132mm (EİE, 2008; DSİ, 2017) of annual average runoff based on flow values obtained from No. 12 SGS (Stream Gauging Station) just before the discharges Meriç River provided the following values: maximum 412mm, minimum 82mm and intermediate 130,1mm (Figure 16). These values are average minimum surface runoff values that reach the river channel in Ergene River.

Flow observation data for some sub basins that may be exposed to human intervention at lower levels compared to flow at the main river downstream were also used during the calibration of Ergene River Basin surface runoff distribution map. In this framework, in different parts of the basin, according to surface runoff distribution map with 1.57 average pixel value, a separate calibration was done for each of these sub basins and only included these sub basins-titled SGS 108 with 2,13 average pixel value; SGS 110 with 1,81 average pixel value and SGS 111 with 1,45 average pixel value. Average runoffs calculated as 138mm, for SGS 108, 109mm for SGS 110 and 102mm for SGS 111 (EİE, 2008) were taken as reference and surface runoff distribution maps whose average pixel values were calibrated provided the following results: maximum 323mm, minimum 64mm, intermediate 141,9mm for SGS 108; maximum 301mm, minimum 60mm, intermediate 109,4mm for SGS 110 and maximum 351mm, minimum 70mm, intermediate 102,6mm for SGS 111 (Figure 17). These volumes are unique to these specific sub basins, but they can also be regarded as reference values for flow data based flow depth for relatively small areas in different parts of Ergene River Basin.

As expressed, it is possible to generalize the flow observation data obtained from some streams in different parts of the basin to represent the entirety of the Ergene River basin. The runoff volume in the digital surface runoff distribution map calibrated by taking 118m flow depth, the product of average runoff of the three sub basins that were mentioned, as reference, were found for the whole basin as maximum 375mm, minimum 75mm and intermediate 118,6mm (Figure 18). Compared to the map (Figure 16) calibrated according to mouth discharge of Ergene River, these values correspond to lower values. Therefore, the fact that average flow values are lower in the sub basins -which are thought to be exposed to less human interventions- than the average flow level at the mouth level points to high level of water losses as a result of storage and use of the water for irrigation in these areas which are expected to have higher runoff volumes since they are positioned relatively at the upper course. This situation can be regarded as an indication that higher volumes are possible in areas with completely wild flows. However, the fact that these results represent volumes under actual values since they do not include sheetflow water that does not reach the main channel support the view that flow depth that should be valid for the basin corresponds to higher volumes.

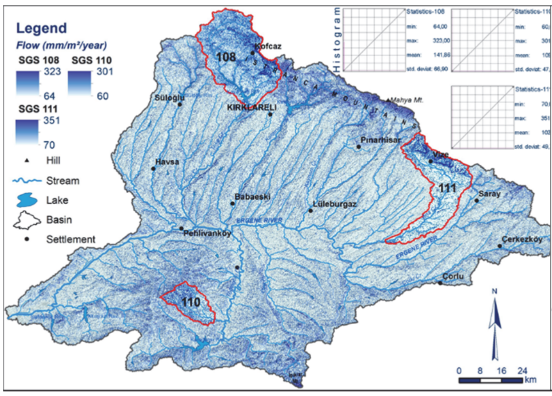

Figure 17. Surface runoff distribution map of Ergene River Basin calibrated according to flow rates recorded in basin estuaries of some sub basins.

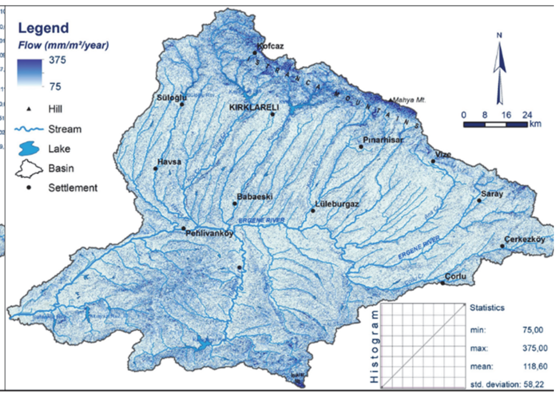

Figure 18. Surface runoff distribution map of Ergene River Basin calibrated according to the average flow depth in No. SGS 108, SGS 110 ve SGS 111 sub basins.

Almost nonexistent human intervention in Ergene River Basin and the existence of at least 15-year flow observation data for some of the sub basins that can be defined as wild flowing makes it possible to undertake calibration based on empirical data free from anthropogenic impact. At areas where such opportunities do not exist, it is still possible t arrive at base data by conducting flow observations for at least a year and correlating these records with the long term records found in nearby observation stations.

The average flow records that were taken as reference for the calibration based on flow observations in the basins that correspond to drainage areas of No.13, 52 and 69 SGS's in different parts of the Ergene River Basin where human intervention to natural conditions is almost nonexistent were as follows: 216mm for SGS 13, 215mm for SGS 52 and 351mm for SGS 69 (DSİ, 2017). Relevant basins were removed from the digital runoff distribution map with 1,57 average pixel used as distribution map for all three basins in question and the following average pixel values were calculated in the next weighted pixel distribution: 2,31 for SGS 13, 1,69 for SGS 52 and 2,74 for SGS 69. Representative results for basins were obtained as a result of calibrating these values with the average flow data measured in each basin. Accordingly, the runoff volumes obtained are as follows: maximum 467mm, minimum 93mm, intermediate 223,4mm for SGS 13; maximum 636mm, minimum 127mm, intermediate 218,4mm; for SGS 52 and maximum 640mm, minimum 128mm and intermediate 383,3mm for SGS 69 (Figure 19). Coordination with the total basin was ensured in this manner and average pixel based surface runoff distribution weighted value was obtained from any part of the basin by averting the mistake of generalizing the regional conditions to the whole basin with the help of flow measurement average assigned according to average pixel value in the basin whose calibration was undertaken. Hence, it was possible to obtain runoff data directed towards the general. Therefore, it was possible to attain the position where it was sufficient to take the average value as reference by only using the accurate runoff distribution map regardless of which part of the basin was used for calibration.

In addition, the fact that average runoff volumes in SGS 52 and SGS 69 were very close as if to confirm one another and higher than that of SGS 13 indicated that surface runoff was much higher in the northern sector of the basin. It is possible that this result is related to the factors such as abundance of rain received on the slopes of Işıklar Mountain that face the north, impact of fohn winds and lack of moisture in the air masses that come over Marmara compared to air masses coming over Black Sea. On the other hand, these flow depths calculated according to flow that arrive the river at the mouth of each sub basin ignore flows with sheetflow character that do not reach the river channel even though they are very small basins. Hence, while it is possible to reach the most realistic volumes with the help of this calibration done according to flow data obtained from areas that are isolated from direct anthropogenic impact to a large extent, it can be argued that the surface runoff that is discussed may be a little bit under the actual value.

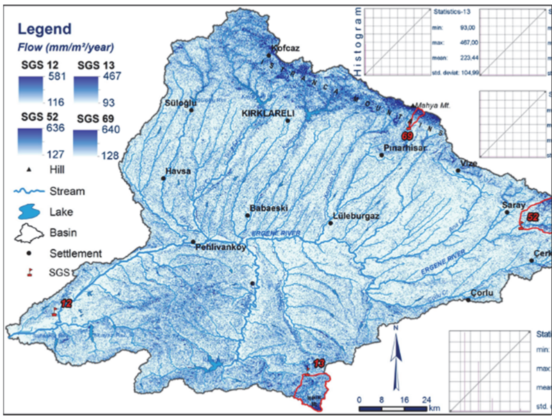

Figure 19. Surface runoff distribution map of Ergene River Basin calibrated according to the amount of average precipitation in sub basins with wild flow.

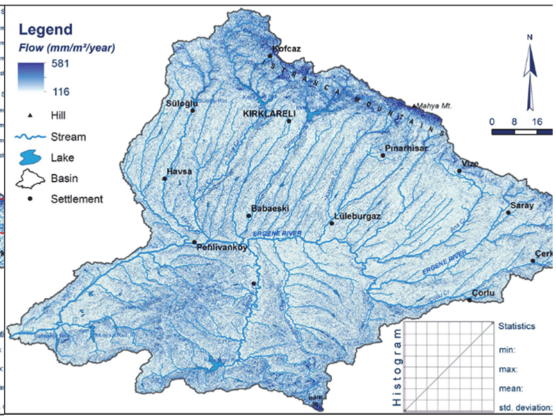

Figure 20. Surface runoff distribution map of Ergene River Basin calibrated according to average flow depth product in sub basins with wild flow.

The digital surface runoff distribution map of Ergene River Basin with 1.57 average pixel value calibrated during the last phase of calibration process by taking 182,55mm average runoff value as reference which was the product value of average runoff volume in the three basins with wild flows provides the following values for the entirety of the basin: maximum 581mm, minimum 116mm and intermediate 183,45mm flow depth (Figure 20).

This value corresponds to a runoff where error margin based on basin sector is decreased by taking different parts of the basin into consideration and which is comprehensive enough to represent the whole basin. Therefore, it is possible to claim that the amount of surface runoff in Ergene River Basin whose natural course is minimally disrupted is an average of 183,45mm and final surface runoff volume including the direct and indirect impact of the calculable and incalculable stakeholders and factors takes place at a higher level with an option between 2% and 5%.

The calibrations with different characteristics that were applied in the study clearly demonstrate that surface runoff amount in Ergene River Basin can be calculated in a manner that will correspond to highly various values. At this point, it can be argued that a serious conflict exists as to which expression is more accurate. However, when all data are evaluated in conjunction with each other, it can be clearly understood that some expressions related to flow depths cannot be accurate (Table 2). A comparison is necessary and even compulsory to reach a definitive conclusion as to the degree of accuracy of the results for Ergene River Basin obtained by different methods. However, it is certain that assessments that will be undertaken in this regard will be specific to Ergene River Basin and very different conditions may apply for another basin because degree of proximity to accuracy in each method can show differences from basin to basin.

Table 2
Some Values Obtained For the Runoff in Ergene River Basin as a Result Of Calibrations Conducted in Digital Runoff Distribution Maps Based on Different References

Calibration	**Max. Runoff** *(mm/year/m²)*	**Min. Runoff** *(mm/year/m²)*	**Intermediate Runoff** *(mm/year/m²)*	**Average Output** *(l/sn/km²)*	**Average Flow** *(m³/year)*	**Ratio to Precipi-tation** *(%)*	**Ratio to Flow** *(±%)*
Thornthwaite	400	80	126,50	4,01	1395605497	21,75	-2,91
Turc	434	87	137,56	4,36	1517416451	23,64	+5,57
Langbein	370	74	117,02	3,71	1291196108	20,12	-10,17
SCS-CN	1085	217	343,14	10,88	3786580500	59,00	+163,44
Precipitation	1817	363	574,13	18,21	6337649900	98,76	+340,92
Flow	412	82	130,13	4,13	1437369252	22,40	0
Sub basin average	375	75	118,60	3,76	1308869600	20,65	-8,93
Mini SGS Average	581	116	183,45	5,82	2024554200	31,94	+40,85

Note.Total amount of precipitation for Ergene River Basin 6417544360m³/year (Turkish State Meteorological Service, 2016), basin area 11036km² and Ergene River mouth discharge 132mm/m²/year (EİE, 2008; DSİ, 2017).

First of all, all "flow" referenced output that corresponds to flow values measured at the mouth of Ergene River channel should be regarded as having the lowest volumes that can represent the whole basin since they take the water existence in the river channel as the basis despite all anthropogenic impact and water losses due to consumption. On the other hand, the fact that calibration conducted according to sub basin averages stays under this value is a result of low flow measured in the sub basins especially located in the east and south and it points to the reality that intervention to surface water in these regions is above basin average and/or water used for irrigation, industry and daily use are recharged to the channel as recycled water from the downstream of Ergene River. This once again reminds us that any generalization for the basin cannot be representative for many sub basins even though they are located in the same main basin. Although it is an agreed matter that there is contributions form groundwater existence, and as explained before, there is no problem to cite these type of contributions while calculating the amount of surface runoff. However, these empirical references that ignore water included in the surface runoff but does not reach the main channel due to their sheetflow character will definitely correspond to higher volumes once sheetflow water is included. Hence, there will be no inconveniency in using volume obtained as a result of calibration conducted according to flow values as surface runoff ground values. At this point, the fact that methods such as the widely used Thornthwaite method, Langbein method and calibrations conducted according to sub basin averages due to the reason cited above generate volumes that are under referenced runoff values show that these methods produce misleading results for Ergene River Basin and are far from usability. It is once again comprehended that while methods with wide use such as Thornthwaite and Langbein methods provide very reliable outputs in different parts of the world, they will not produce the best results everywhere every time.

On the other side of the issue lays the impossibility of expecting meteoric water runoff to exceed the 50% rate in Ergene River Basin that can be defined as a subhumid steppe field where high evapotranspiration values prevail (Koçman, 1993; MGM, 2017) and where high permeability is experienced with a plain relief. Also, since calibrations conducted based on flow observation data take into account the flow that reaches the stream gauging station rather than the river channel itself, it is believed that surface runoff that cannot reach the stream gauging station constitutes a significant ratio considering many reservoirs, agricultural fields that cover wide areas and the population that is close to 1 million (Çevre ve Şehircilik Bakanlığı, 2017) (Figure 21). Also, releasing an annual 255 million m³ discharge water, from domestic an industrial sources, 20% of which consists of groundwater, to Ergene River (DSİ, 2016) and the existence of reservoir volume exceeding a total of 500 million m³/year, out of which only the reservoirs built in the last five years is close to 100 million m³/year volume

(Çevre ve Şehircilik Bakanlığı, 2017) provides some ideas as to the degree of representation of basin surface water in flow observations. In addition to all this, it is known that the amount of water discharged with surface runoff in 37,12% as average in Turkey (DSİ, 2018). Hence, it is clearly seen that SCS-CN method is far from usability in Ergene River Basin while it is designed according to the assumption that meteoric water will flow at the rate of 98,76% and points to 59% surface runoff even though it is highly below the precipitation-referenced calibration that expresses maximum runoff volume for the basin. On the other hand, it should be remembered that contributions from groundwater that is not included in the amount of surface runoff support just the opposite. Possible contributions from the sources that will be reflected in the observations of the main channel have the effect to carry the value obtained as a result of calibration to a higher level than the real amount of surface runoff. While it is probable to calculate major sources to subtract them from the total flow, it is not possible to calculate groundwater transitions such as feeding from the river bed. Actually, the most accurate approach to be adopted at this point, as mentioned before, is to assess contributions from groundwater along with surface water because even though underground water is part of underground flow for a while, it eventually comes to surface and can be used as surface water. Therefore, increase in volume based on feeding from underground water in the river bed will directly cause an increase in surface water potential and it will be a part of surface runoff. Hence, calibrations that take flow observation data into consideration attain a different dimension as calculations that pay regard to the water in this scope.

In the light of all this information, it can be claimed that the surface runoff volume that is realized in Ergene River Basin is between the minimum value of 1437369252m^3/year and maximum value of 2535059960m^3/year which corresponds to 40% of meteoric water. None of the results obtained with existing surface runoff calculation methods are included in this range. So, improbable results will be obtained and the risk of miscalculating the water potential will increase regardless of the method used to calculate surface runoff in Ergene River Basin. Since this case can be replicated in other basins in different manners, the road will be paved for dire errors unless calibration and confidence interval are not identified similar to the one presented in this study. Following these assessments, it is possible to cite a rather high value based on information obtained in terms of Ergene River Basin, impressions and expert views on the field. This value is about 2100000000m^3/year ±2% level as the volumetric expression of average surface runoff amount in Ergene River basin. Therefore, it is possible for a flow to materialize in the basin, a runoff other than the ones foreseen by other methods.

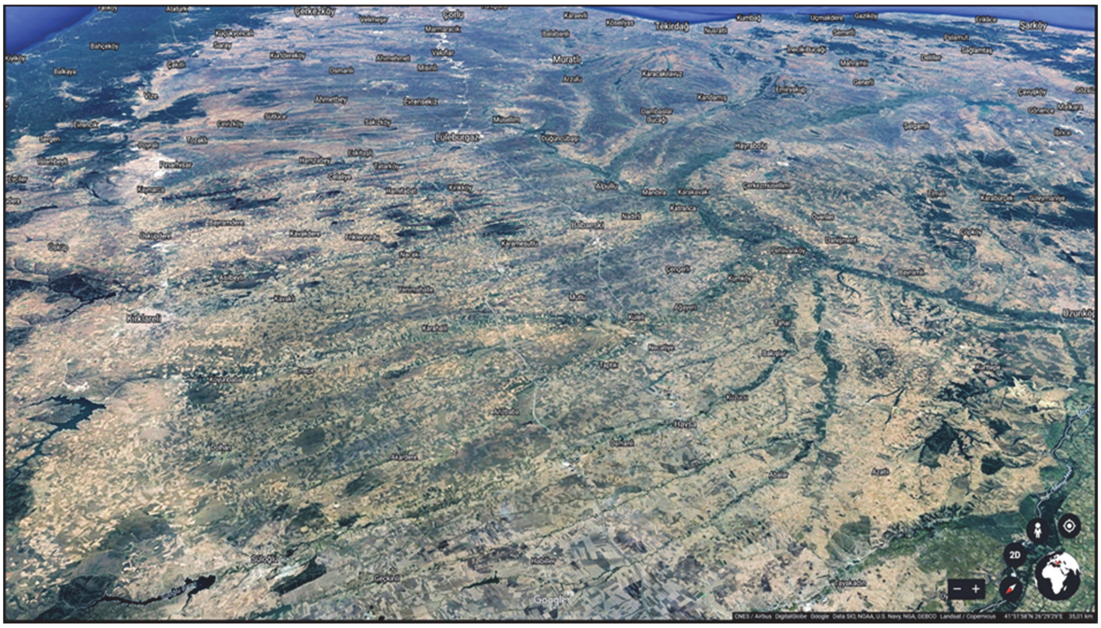

Figure 21. Google Earth image demonstrating the density of agricultural areas and distribution of reservoirs in Ergene River Basin.

The different surface runoff models led by commonly used SCS-CN and Thornthwaite methods, which can be defined as rather reliable methods when evaluated separately, provide such different results when assessed together that it is probable some of these results are inaccurate. This situation should be regarded in a manner that one should not regard these methods as wholly erroneous but take it as the variance in success based on the existence of different conditions that affect the method. Hence, as it was initially expressed, defining existing methods in a manner far from flexibility and comprehensiveness that is necessary for adaptation to all conditions is anything but a reality found in the results of this study. All analyses and comparisons undertaken in the framework of this study have strengthened the opinion that modeling a surface runoff distribution calculation method and calibrating it with the appropriate reference values based on the necessary conditions of the field will create a useful route to obtain data with fewer errors.

Discussion and Conclusion

The fact that small differences in the calculation process of the methods that are used can generate significant fluctuations in the obtained ruoff volume was clearly observed in the results attained from the methods utilized for Ergene River basin. At the same time, another interesting finding is the fact that none of the results were found similar to the results obtained as a result of calculations according to direct flow measurements and they even pointed to volumes much higher or lower values with significant differences. The point that should be strictly emphasized here is the fact that it is not possible to express surface runoff amount which is shaped under the impact of many variables -that may or may not be calculated- as a precise numerical value but at the same time, a sound volume value robust enough to be used in planning can only be obtained by preparing a surface runoff distribution map well with a narrow range and by calibrating it based on real flow data obtained from parts of the filed far from interventions. There is at least a 27% (Turc) or more difference in the runoff volume obtained in this manner and by using other methods in Ergene River Basin. Such a high error margin is outside of acceptable limits. Hence, there is no doubt that existing methods provide erroneous results that cannot be tolerated and there is a dire need for a more reliable and consistent surface runoff calculation method.

The model proposed in this study adopted a new approach that supported benefiting from advantageous aspects of all categorical approaches and sorting out the disadvantageous aspects related to the issue. As a result of the efforts to develop a surface runoff distribution map, a model was created that is flexible enough to include specific parameters such as frost period, interception and water infrastructures in the equation and comprehensive enough to take into consideration the impact values of many variables that are impossible to calculate via calibration conducted according to real flow values. As a matter of fact, it is a reality that let alone calculating the factors that affect hydrodynamic process; we do not even know their names. Hence, while it was possible to present a statement broadly at the end, it was decided that the only way to obtain the closest value to real runoff was to interpret the accurate runoff distribution design based on real field data in their natural forms. Also, with the help of the model, it was possible to make alternative selections in a manner that the final goal would pay a determinant role in calibration and it became possible to separate different runoff characteristics such as sheetflow and channel flow. Calibrations based on flow observation data facilitated this separation.

Even when an average value comprehensive of the total basin was identified at the final point, pixel-based detailed data were used. In this way, it was possible to reflect the data of more than one variable on each pixel and average expressions were opened to specific assessment and analyses through the parts of a whole. Also, while a distinct expression was highlighted as an average value at the end of all analyses, possible lower and upper limit values were identified with the confidence interval of this numerical expression narrowed as much as possible. Hence, representative weakness that would be caused by a single numerical expression was discarded and average flow data were supported by determining maximum and minimum flows over the maximum and minimum values of hydro-meteorological input. In addition, calibration was undertaken according to both empirical and theoretical data sets and in a manner, verification of outputs obtained via different methods was ensured. At this point, it was once again observed that the success rate of models may change under different conditions and each specific variable may cause a model to generate reliable or unrealistic results. Therefore, following the route of identifying the maximum and minimum runoff range by developing the runoff distribution model of the area instead of following a single model or method and therefore getting rid of models that present unrealistic results was regarded as an undoubtedly accurate preference.

In the framework of the results obtained about the study area, total surface runoff volume of Ergene River Basin was calculated as 2100000000m^3/year ±2%. This is a reliable value that can be used to express the general condition of the basin and none of the methods implemented in this study generated a result that would correspond to this value. Hence, the current methods widely used for Ergene River Basin are far from generating reliable results. This finding points to the reality that it is inevitable to face different versions when the basin and conditions change. Therefore, without doubt, the route followed in this study will maximize the chance of success in obtaining the most reliable runoff value. Also, it is evident that runoffs that are lower and higher than the values identified for Ergene River Basin occur in the sub basins of different parts of the basin and it should be regarded as a natural phenomenon. That's the reason why this model becomes more significant with its ability to enable identification the surface runoff amount for of all desired points as specific to this point or area by allowing separate runoff values for all pixels at the rate of data resolution used in the map that represents the surface runoff distribution model.

Acknowledgement

This work was supported by Marmara University Scientific Research Coordination Unit with Project Number: SOS-A-250816-0422. Maps in the study were prepared by ArcGIS® software developed by Esri. Digital elevation model ASTER GDEM, used in mapping and analyses, is a product of METI and NASA.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Akarsu Havzalarında Yüzeysel Akış Dağılış ve Miktarının Belirlenmesi: Ergene Nehri Havzası

Akışa etki eden parametreleri temelde yağışın tipi, yoğunluğu, miktarı, dağılışı, süresi, fırtına istikameti, yağışa bağlı toprak nemi, sıcaklık, rüzgâr, bağıl nem ve mevsim gibi meteorolojik faktörler ile arazi kullanımı, bitki örtüsü, toprak türü, drenaj alanı, havza şekli, yükselti, eğim, topografya, bakı, drenaj şebekesi ve rezervuarlar gibi fiziksel faktörler olarak sınıflandırmak mümkündür. Bunlara toprak tekstürü, yeraltı su tablası ve yeraltı suyu derinliği ile kar yağışı, biriken kar, kar erimesi ve gerçek evapotranspirasyon gibi özel koşullara ait verilerin de eklenmesi mümkündür. Bütün bu klimatik ve yüzeysel verilerin coğrafi bilgi sistemleri marifetiyle bir arada değerlendirilmesi sayesinde, yüzeyde karmaşık bir desen ortaya koyan akışın dağılış özelliklerini belirleme imkânı söz konusu olabilecektir. Her türden problemin varlığına rağmen üzerinde akım ölçümü yapılmayan havzaların çokluğu ile birlikte akış modellerinin yüzeysel akış, toprak nemindeki değişiklikler, evapotranspirasyon ve yeraltı suyu beslenim-boşalım değerleri gibi birçok konuda akarsu akım ölçümlerine göre daha isabetli veriler üretmesi şeklinde sıralanabilecek sebepler bu modellere bağımlılığı artırmaktadır. Sonuçta akım gözlem istasyonlarının sayısını çoğaltmanın yanında mevcut model ve hesaplamaların geliştirilmesi, yenilerinin üretlmesi ve var olan modellerin uygulamalarının kolaylaştırılması amacıyla bilgisayar yazılımlarının oluşturulması gibi birçok alternatif ortaya konulmaya ve ilgi görmeye devam etmektedir.

Mevcut yüzeysel akış belirleme yöntemlerinin yetersizliği konusunda vurgulanması gereken ilk başlık hesaplama yöntemlerinin veya modellerin neyi amaçladıkları meselesidir. Bu noktada tarımsal su ihtiyacını belirlemeye yönelik modeller ile yeraltı suyu beslenimini tespite yönelik olanlar veya yağış sonrası taşkın riski ile su bilançosu ortaya koymayı hedefleyenler aynı yol ve yöntemleri belirleyip aynı sonuçlara ulaşamayacaklar, dolayısıyla da aynı problemi çözerek aynı amaç için kullanılamayacaklardır. Aynı şekilde model veya hesaplamalarda dikkate alınan periyodun farklı oluşu da çalışmaların ayrışmasına sebep olan bir diğer alandır. Yağış-akış denklemlerinde araştırılan yağışın akabinde ortaya çıkan akış tamamen spesifik bir hadise olup, sadece hesaplamanın yapıldığı zaman ve yer için geçerlidir. Böyle bir verinin genellenmesi ciddi hataları da beraberinde getirecektir. Bu durumu, iş yükünü artırarak geniş alanlarda çalışmayı olanaksız kılan günlük klimatik verilere dayanan modeller ile aylık verilere dayanan modeller arasında da gözlemlemek mümkündür. Günlük veriler ile aylık veriler arasında çok belirgin anomaliler olabileceği gibi, planlama çalışmalarında esas olan da aylık veriler yani yıllık ortalamaların rejimidir.

Verilerin süre bakımından farklılıklarına dair sonuçları alansal farklılıklarda da görmek mümkündür. Bu durumun en önemli sebebi neredeyse hiçbir havzada akışın homojen dağılmamasıdır. Modele konu her noktanın, her pikselin benzersiz koşulları olduğu bir kenara bırakılarak, noktasal boyutta elde edilen verilerinin bütün alanı veya havzayı kapsıyormuşçasına yorumlanması vahim bir yanılgıdır. Çünkü her bir nokta modele konu parametreler bakımından kendi koşullarını haiz olup parametrelerin etki değerleri ölçeğinde yüzeysel akış ile farklı bir ilişki seviyesini yansıtmaktadır. Dolayısıyla hemen her yerde heterojen koşullar sergileyen akış dağılış deseninin doğru tespit edilmesi havza ya da alanın hem geneli için hem de bölüm veya alt birimleri için spesifik akış dinamiklerinin ortaya konulmasına imkân sağlayacaktır. Bu noktada etken parametrelerin belirlenmesi ve etki değerlerinin kararlaştırılması hayati öneme sahiptir.

Şüphesiz akış dinamikleri açısından benzersiz hidrolojik birimler olarak kabul edilmesi gereken havzalar, kendi özel koşulları içerisinde akış dağılış desenine şekil veren birçok özelliği barındırırlar. Bunların bazıları daha baskın ve ana paterni belirleyici nitelikte iken bazıları nispeten düşük etki kapasitesine sahiptirler. Örneğin litolojik açıdan homojen alüvyal dolgu sahasından ibaret olan bir havzada akış desenini belirlerken sahanın litoloji verilerini dikkate almak gereksiz bir işlem olacaktır. Dolayısıyla her çalışma alanı açısından akış desenine yön veren parametreler arazi koşullarına göre farklıklar arz edecektir. Bu çalışmada ortaya konan metodoloji örnek havza olarak belirlenen Ergene Nehri Havzasında uygulamalı bir şekilde açıklanmıştır. Ergene Nehri Havzasında yüzeysel akış dağılış desenine şekil veren yedi ana parametre (yağış, potansiyel evaotranspirasyon, hidrojeolojik yapı, arazi örtüsü, toprak türü, eğim ve toprak dokusu) etki oranları nispetinde çarpan katsayılarla revize edilen birimlerden oluşmaktadır. Bu birimler piksel bazlı sayısal ifadelere karşılık gelmekte olup, ağırlıklı çakıştırma işlemi uygulanarak havzanın bütün bu faktörlere göre şekillenen sayısal yüzeysel akış dağılış deseni haritasını ortaya çıkaracak şekilde analize tabi tutulmuşlardır. Sonuçta elde edilen harita herbir birimin ilk yorumlamalarında öngörülen etkisini yansıtacak şekilde bir yüzeysel akış dağılış deseni teşekkül ettirmiştir. Çıktı niteliğindeki sayısal yüzeysel akış dağılış haritasında piksel bazlı değerler 144 ila 414720 arasında değişen değerler arz etmektedirler. Bu değerler yeniden sınıflandırılarak 1 ila 5 arasında değişen nicelikler şeklinde görselleştirilmişlerdir. Ancak daha sonra yapılacak kalibrasyon işlemlerinde verilerdeki hassasiyetin azalmaması için taban değer 144, ortaç değer 207288 ve tavan değer de 414720 olacak şekilde işlem görmüştür. Bu noktada sayısal akış dağılış haritası henüz kalibre edilmemiş olsa da yüzeysel akış dağılış deseni açısından net bir görüntü ortaya koymaktadır. Beklendiği gibi yüzeysel akışın Istranca dağlık kütlesi boyunca ve Işıklar Dağı'na yaklaşılan kesimlerde güçlendiği, buna karşılık havza tabanına doğru olan kesimlerde zayıfladığı net bir şekilde izlenebilmektedir. Bu görüntü aynı zamanda bir genellemeden ibaret olmayan ve havzadaki herbir noktanın bütün özel koşulları gözetilerek dizayn edildiği için her piksel için ayrı ayrı gerçeklik ifade eden bir dağılış modeline karşılık gelmektedir. Dolayısıyla kalibrasyon sonrasında elde edilecek değerler de her nokta için özel olan değerlerdir.

Ergene Nehri Havzasının bu çalışma kapsamında elde edilen yüzeysel akış dağılış haritasının arazinin reel koşulları ile ne derece uyumlu olduğu ve genellemeden uzak bulunduğunu anlamak için Thornthwaite su bilançosu hesaplaması, Turc, Langbein ve Soil Conservation Services-Curve Number gibi teorik yöntemlerin yanı sıra; akış yüksekliği, ortalama ana akarsu akımı, alt havzalar bazlı ortalama akım ve vahşi akışa sahip akarsu havzaları ortalama akımı gibi ampirik veriler, bu çalışmada üretilen ve yeniden sınıflandırıldıktan sonra en çok 5, en az 1 ve ortalama 1.57 birim değerlerine sahip olan haritanın kalibrasyonu için kullanılmıştır.

Sonuç olarak Ergene Nehri Havzasında gerçekleşen yüzeysel akışın hacminin taban değer olan 1.437.369.252m³/yıl ile tavan değer olarak kabul edilebilecek, meteorik suların %40'ına denk gelen 2.535.059.960m³/yıl arasında olduğu söylenebilir. Mevcut yüzeysel akış hesaplama yöntemleriyle elde edilen sonuçlardan hiçbirisi bu aralıkta yer almamaktadır. Bu değerlendirmelerden sonra Ergene Nehri Havzası açısından edinilen bilgiler, izlenimler ve saha hakkındaki uzman görüşü ışığında kesinliği oldukça yüksek bir değerin zikredilmesi mümkündür. Bu değer Ergene Nehri Havzası ortalama yüzeysel akış miktarının hacimsel ifadesi olarak 2.100.000.000m³/yıl ±%2 seviyesindedir. Bu değer havzanın genel durumunu ifade etmek için kullanılabilecek güvenilir bir ifade olup, bu çalışmada uygulanan yöntemlerin hiçbirisi söz konusu değere tekabül edecek bir sonuç üretememiştir. Yani Ergene Nehri Havzası için günümüzde yaygın olarak kullanılan yöntemler güvenilir bir sonuç vermekten uzaktır.