

A new Geographical Hydrological Modeling in the Calculation of Infiltration and Runoff: A case Goksu basin

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Abstract: Water is of great importance for all living life in nature, especially for human beings. The world has limited underground-surface fresh water resources. Increasing world population and the need for water use of this population in many areas such as drinking, agricultural irrigation, industry, energy production, etc., is also increasing exponentially. This situation; Human and economic pressures on river basins jeopardize the risk of pollution of the basins and the sustainability of the water potentials of the basins. For these reasons, it is very important to determine infiltration and runoff in any river basin. On these issues; from past to present, hydrological formulas and methods have been developed by many authors such as. However, natural factors are not included in these formulas and methods in a holistic manner. In this study; A new geographic hydrological model has been developed with the help of GIS, AHP, RS and Digitization techniques by taking into account natural factors on infiltration and runoff in the Goksu Basin. In the hydrological modeling process developed; In order to determine the effects of each natural criterion on infiltration and runoff, it was digitized and processed in the AHP model program. As a result of the mathematical formula and calculations developed in addition to all these, a total of 407.1 mm infiltration and runoff were calculated. This result was correlated with a total flow height of 429.2 mm in the basin and a successful result of 0.95 was obtained.

Key words: GIS, AHP, Runoff, Infiltration, Hydrological Model, Goksu Basin.

1. Introduction

Water is an indispensable element for the survival and survival of human beings and other living creatures. Due to the increasing importance of water, studies on the hydrological cycle or water production are also increasing. In the formation of water, evaporation, infiltration and runoff are the basic hydrological cycle parameters. Various hydrological formulas and models have been developed by many authors in hydrology, ecology and other related disciplines from past to present in order to determine the hydrological circulation of water and the factors affecting this process. These formulas and models developed were applied in different parts of the world and the results reached were evaluated within themselves.

When these studies are evaluated briefly; Studies modeling surface and subsurface hydrology [31],[30],[20],[21],[22],[77],[19],[34],[51],[54],[23],[33],[55], integrated surface and subsurface hydrological models [11],[75],[76],[28],[49],[56],[63],[73],[2],[43], basin scale three-dimensional modeling [24],[25],[26] physical, numerical comparative integrated models [80],[10], hydrological prediction simulation and experimental studies [53], the effects of change in field parameters in experimental and simulation studies on hydrological processes [47],[76],[6],[37],[79],[62],[81],[18],[14], models containing transport dynamics and flow media properties [75],[61],[82],[5], the numerical model used in the process-based hydrological model. techniques [3],[8],[42],[57],[48],[49], mass transfer and transport between multiple species and stages in the hydrological model Many models such as experimental, predictive, three-dimensional, integrated and numerical dynamics [72],[46],[60], have been developed.

Again in a similar way here; Studies evaluating parameters such as atmospheric air structures, atmospheric water content, soil and vegetation [44],[36],[45],[66],[13],[27], stochastic and

deterministic models and studies based on rainfall-flow relationship [64],[83],[73], physically based empirical and mathematical models [9],[12],[16],[4],[68],[69], hydrological models based on geographic information systems (Gis) and basin-scale hydrological process simulation studies [41],[59], hydrological studies with the help of geographic information systems based remote sensing techniques [1], studies on geographic information systems (GIS) based, precipitation-lithology-vegetation with remote sensing, and groundwater flow modeling [15],[35],[67], studies that express the shape and hydrographic characteristics[52] of river basins on a mathematical basis various hydrological models for the hydrological water cycle including stochastic, deterministic, empirical and various mathematical formulas such as stochastic, predictive, mathematical etc. have been developed. This improved hydrological models applied in Turkey and evaluated in its river basins in different parts of the world.

However, according to the hydrological models constructed above, all parameters affecting the hydrological cycle process are not included in the hydrological model processes. In these modeling studies, hydrological parameters such as surface and groundwater, evaporation were tried to be calculated with the help of geographic information systems (Gis) based remote sensing techniques, physically based three-dimensional, empirical and mathematical formulas, hydrological process-based numerical techniques. With these methods, only a few hydrological cycle parameters such as precipitation-flow, precipitation-temperature, precipitation-lithology-vegetation were taken into account.

However, not only meteorological factors are effective in the hydrological cycle and distribution of water to the earth, but also geology (lithology-tectonic), topography, soil, vegetation, hydrographic system, human characteristics also have important effects on the hydrological cycle of water [39]. As can be understood from here, natural processes such as lithology, soil, vegetation, and hydrographic system play an important role in the hydrological cycle of water and its distribution to the earth, especially with the parameters of climate (precipitation-temperature etc.). The hydrological models mentioned here are devoid of a geographical point of view and do not have a holistic feature. Therefore, it is necessary to include all components that affect the hydrological water cycle in any river basin in the modeling process.

In this study; Natural factors such as lithology, soil, vegetation, soil cover (ndvi), slope, aspect, as well as meteorological (precipitation-temperature etc.) parameters that play a leading role in the hydrological water cycle are included in the hydrological process. Here, a new geographic hydrological model has been developed using geographic information systems (Gis) based, analytical hierarchy process (Ahp), remote sensing, isohyet and digitization methods and techniques. Here, the following gains were desired to be achieved through hydrological model development processes.

Since meteorological processes such as precipitation-temperature as well as lithology, soil, vegetation and other natural parameters may differ in any river basin, it is very important to create a holistic hydrological model that includes the natural conditions of each basin. Because in the geographic-based hydrological model, the model outputs will be close to reality, as the variability of precipitation-temperature and natural factors will be included in the model processes for each different basin. In addition, infiltration processes of natural static parameters such as lithology, soil, vegetation, hydrographic system and positive processes such as groundwater and aquifer recharge will be able to establish a rational relationship with the earth. Or on the contrary, topographic surface conditions of negative processes such as drought, flood, landslide and erosion can be determined.

Thus, the original model suitable for the climate and natural processes of each river basin studied will be developed. In this way, according to the outputs of each unique model developed, the use of water in drinking, irrigation, energy production, industry and other fields will contribute to its rational and sustainable use.

The main purpose of this study is to determine and simulate the effects of natural conditions such as lithology, soil, vegetation, soil cover (ndvi), slope and aspect on water production with this hydrological modeling. In this way, the effect levels of each natural factor included in the hydrological

process on infiltration and runoff will be revealed. As a result, the success or validity of the developed hydrological model will be determined by comparing the calculated and simulated infiltration and runoff values and natural flow data no.1805 representing the basin. This new geographic hydrological model developed has been applied in the Goksu Basin.

2. Study Area

Goksu Basin (Adana-Seyhan) is an important sub-basin of the Seyhan Basin, most of which is located in the eastern part of the Middle Taurus Orogenic belt within the borders of the Mediterranean Region, Adana part. The basin extends in the northeast-southwest direction and is located between $37^{\circ} 33' - 38^{\circ} 40'$ north latitudes and $35^{\circ} 35' - 36^{\circ} 41'$ east longitudes (Figure, 1).

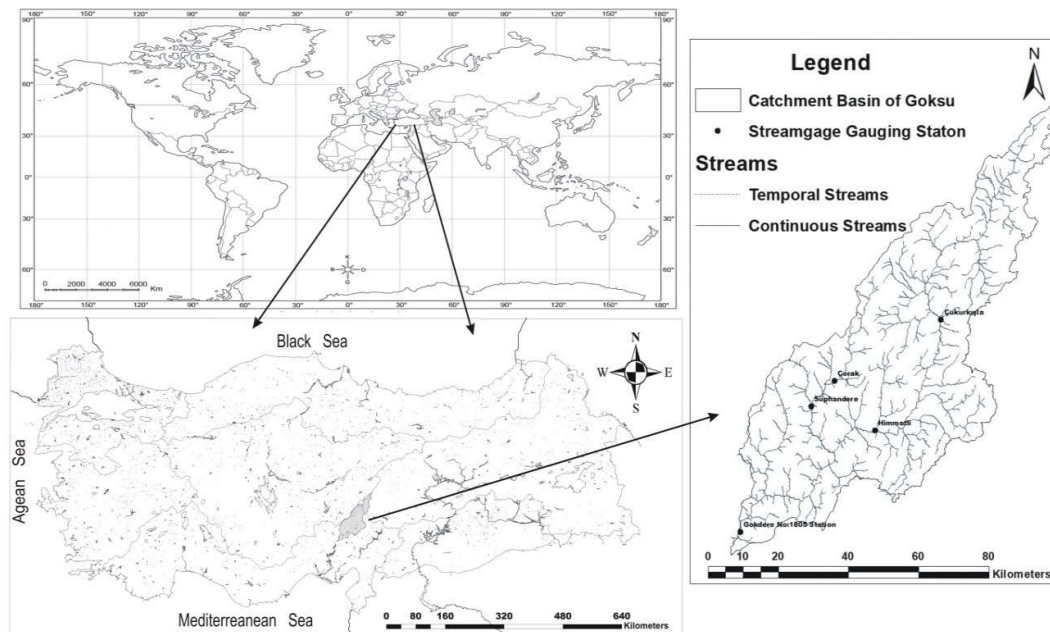


Figure 1: Location of Goksu Basin

The Tahtalı Mountains extending in the northeast-southwest direction in the west of the basin are surrounded by the Dibek mountainous mass extending in the northeast-southwest direction in the east, and the Binboga Mountainous mass in the same mountain unit in the northeast. The basin extends in the northeast-southwest position with an area of approximately 4392 km².

Goksu River springs from Sarlak Springs in the southern part (1900 m) of Govdeli Mountain in the inner part of the Tahtalı mountainous mass in the northeast of the field. The surrounding mountainous area combines with Ataltı, Eskiayla, and Cavlak Springs to form the Sarız Stream. It collects many streams and creeks in the field such as Demircik Stream, Kazan Stream, Saimbeyli Stream, Asmaca Stream, Salam Stream, Kocadere, Balık Creeks and reach the Zamantı River downstream of the junction of the Balık stream.

In the study area, the high slope values due to the relative elevation differences increased the bed slopes of the rivers in the basin and at the same time, having a tectonically cracked and faulted structure contributed to this process and this situation increased the hydraulic energy potential of the rivers flowing in the basin. Therefore, many water structures such as dams, HEPPs, regulators and ponds have been built on the Goksu River and its tributaries. In the basin, rocks of different ages and various lithological characteristics from Paleozoic to Quaternary are found, and consist of rocks with good permeability levels such as marble, dolomite, limestone, conglomerate, reefal limestone,

sandstone, neritic limestone, conglomerate, slope debris and alluvium. These rocks correspond to surfaces where topography is high and karstification is effective. On the other hand, rocks with poor permeability, such as shale, marl, claystone, mudstone, etc., are exposed throughout the basin.

The northern and southern parts of the basin have different climatic characteristics. While the south-southeast of the field reflects relatively Mediterranean climate characteristics in the regions of Feke and Saimbeyli, the influence of terrestrial climate characteristics is observed in the north-northeast of the field, Tufanbeyli and Sarız regions. This situation can be clearly observed in the temperature and precipitation values obtained from the station data in the basin. In the northern parts, there is an increase of 510 mm in the basin bottom and 850 mm in the surrounding mountainous areas. In the southern parts, while precipitation increases in the Feke region compared to the Adana basin, there is a high amount of precipitation of up to 1150 mm on the slopes affected by humid air masses. With the increase in elevation, it shows a decrease of about 140 mm in average annually in Saimbeyli. In the south of the basin, the annual average temperature is about 19 C.

Various large soil groups were formed in the basin due to the main material, climate, topography, vegetation and time in the study area. The humid and temperate climatic conditions in the south and a wide part of the basin provided the forest vegetation to cover a large area. In terms of plant geography, the Upper Seyhan Basin is in the Iran-Turan Region, and the Lower Seyhan Basin is in the Mediterranean Region. In terms of natural vegetation, the basin consists of the Southern Anatolia Mediterranean Plant Community, the Southern Anatolia Cedar-Fir Mountain Forests and the Alpine Plant Communities. The distribution of plant species in the basin, under the control of precipitation-temperature factors, from south to north; It shows distribution in the form of maquis, pinus brutia, pinus nigra, cedrus, abies, juniper and steppe.

3. Materials and Methods

In the research; 30x30 m resolution ASTER-GDEM digital elevation model (DEM) image and slope and aspect data produced from this DEM image with the help of Arc.Map, lithology, soil, land use, soil cover (ndvi) data obtained from USGS landsat-8 satellite images and from various stations in the basin. The obtained rainfall and flow data constitute the basic materials for the study.

In the study; A new geographic hydrological modeling has been developed together with GIS, AHP model program, Izohyet (Co-Precipitation), remote sensing (RS) techniques and Digitization processes in determining the infiltration and runoff of the Goksu Basin (Figure 2).

With this new geographic hydrological modeling, it became possible to calculate the distribution and amount of infiltration and runoff in the basin. In the calculation of infiltration and runoff of the research area; ASTER-GDEM digital elevation model (DEM) with 30x30 m resolution, raster data such as slope, aspect, soil cover (ndvi) and vector data such as geology (lithology), land use cover, soil types constitute the basic materials. The raster and vector data belonging to Goksu Basin are supported with mathematical formulas developed for the purpose by digitizing (Figure 2).

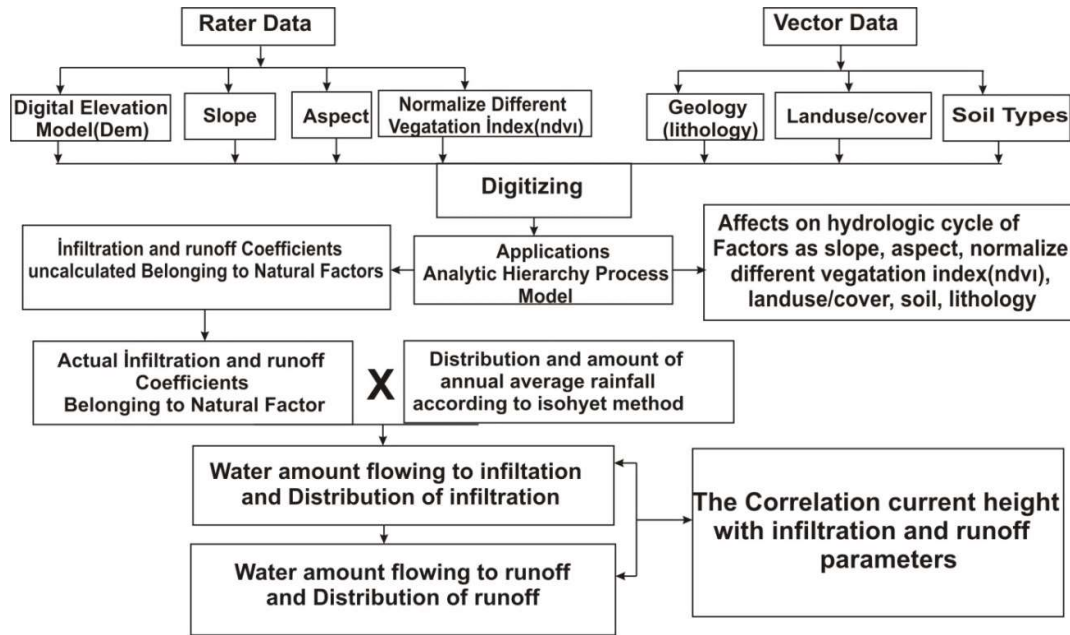


Figure 2: Hydrological Model Flow Developed for Determination of Infiltration and Runoff in Goksu Basin (**Source:** [40], It was benefited from published doctoral thesis)

3.1. Digitization Formula

Sub-alternatives for each natural factor were created according to this digitization formula 1.

$$N_f = \sum_{i=1}^n I_i = 1, N_f;$$

It refers to the natural factor. I_i ; It refers to weighted average. $\sum I_i$; It refers to the sum of the alternatives. Each of these alternatives has been digitized by giving numerical value. The sum of the numerical values given for each natural criterion is provided to be equal to '1'. Thus, the purpose of digitization is that it is suitable for the AHP model program, which is a multiple decision making technique, and it is aimed to be processed here. According to this formula, the high or low numerical values given to the alternatives for each natural criterion are related to the effect levels of these alternatives on infiltration or runoff during the hydrological water cycle process. In other words, if the alternatives have a positive effect on infiltration or runoff, the numerical value of the alternative is high, and if it has a negative effect, the numerical value of the alternative is low. In addition, the engineering studies about each natural factor and the numerical values created as a result of this were always taken into account in the digitization process (Table 1).

Table 1: Infiltration (A) and Runoff (B) Coefficients Formed Regarding the Digitization Process of Alternatives Belonging to the Natural Criteria of the Goksu Basin (**Source:** [40], It was benefited from the published doctoral thesis)

Infiltration Coefficients Created for Digitization of Alternatives Belonging to Natural Factors		
Natural Factors	Alternatives and Coefficients	Total of Weighted Average
Lithology	Limestone, Dolomite, Pebblestone, Brownstone, Conglomerate, Aluvion(0.563),Mudstone, Conglomerate, Schist, Brownstone, Arenite (0.312),Marl, Schist, Argilleceous, Shale (0.125)	1
Soil	Chesnut, Aluvial and Coluvial soils (0.560), Red Mediterranean soils, naked and rocky and talus (0.190), Brown forest and non-calcareous brown soils(0.250)	1
Landuse/Cover	Forest, chaparral bushland areas (0.170), pasture areas (0.130), vinyard and garden (0.230), plantation areas (0.270), naked soil and rocy surfaces(0.110), centre of population (0.090)	1
Soil Cover(ndvi)	Naked surfaces and massive rocky (0.110), vegetation weakness and pasture areeas (0.130), chaparral, brushland, garden, plantation areas (0.240), complex forestry areas (0.250), densely forestry areas (0.270)	1

Slope	% 0-5 (0.400), %5-10 (0.300), %10-30 (0.200), %30 + (0.100)	1
Aspect	Flout areas (0.280), north, northeast, northwest (0.200), south, southeast, southwest (0.150), East (0.170), West (0.200)	1
Runoff Coefficients Created for Digitization of Alternatives Belonging to Natural Factors		
Lithology	Limestone, Dolomite, Pebblestone, Brownstone, Conglomerate, Aluvion(0.125),Mudstone, Conglomerate, Schist, Brownstone, Arenite (0.312),Marl, Schist, Argilleceous, Shale (0.563)	1
Soil	Chesnut, Aluvial and Coluvial soils (0.300), Red Mediterreanean soils (0.140) naked and rocky and talus (0.200), Brown forest and non-calcareous brown soils(0.250), non-calcareous soil (0.110)	1
Landuse/Cover	Forest, chaparral, bushland areas (0.070), pasture areas (0.130), vinyard and garden (0.230), plantation areas (0.090), naked soil and rocy surfaces(0.2300), centre of population (0.250)	1
Soil Cover(ndvi)	Naked surfaces and massive rocky (0.320), vegetation weakness and pasture areeas (0.300), chaparral, brushland, garden, plantation areas (0.150), complex forestry areas (0.120), densely forestry areas (0.110)	1
Slope	% 0-5 (0.100), %5-10 (0.200), %10-30 (0.300), %30 + (0.400)	1
Aspect	Flout areas (0.100), north, northeast, northwest (0.250), south, southeast, southwest (0.190), East (0.180), West (0.280)	1

3.2. Analytical Hierarchy Process (AHP) Model

The Analytical Hierarchy Process (AHP) technique was first introduced in the 1970s by Thomas L. and Saaty, and is one of the multi-criteria decision-making techniques used in the solution of the decision problem. AHP is an objective and subjective decision-making with multidimensional and multi-criteria. It is widely used in complex environmental analysis and across disciplines because it offers the opportunity to combine factors [29]. AHP [62], first proposed by Myers and Alpert (1968) and later developed by Saaty, is a decision-making process based on managerial decision-making by giving relative importance values to decision-makers, decisions, options and criteria[62].

Thus, AHP is expressed as a decision making and estimation method that gives the percentage distributions of decision points in terms of factors affecting the decision in the decision hierarchy. AHP is based on one-to-one comparisons in terms of both the factors affecting the decision and the importance values of the decision point in terms of these factors, using a predefined comparison scale on a decision hierarchy. Consequently, differences in importance turn into percentage distribution over decision points.

In this study; In the Goksu Basin, AHP decision making and estimation method, which is a multiple decision making technique, was used in determining the infiltration and runoff. Accordingly, in determining the natural criteria and the alternatives for these criteria, digitization was made from the actual data of the field. In this digitization; in the process of valuing alternatives; Physical geography factors of Goksu Basin, which affect the hydrological cycle, are taken as basis. In addition, while the numerical values given to the alternatives are supported by various studies, a rational balance has been established between these values by also considering the characteristics of the field (Figure 3).

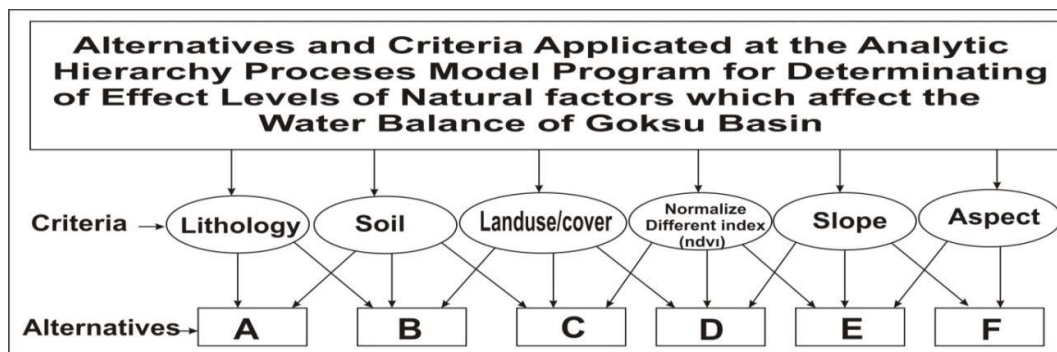


Figure 3: Representation of the Criteria and Alternatives Regarding the AHP Model Application in Goksu Basin (Source: Karosmanoglu, F, 2020, It was benefited from published PhD Thesis.)

3.3. Flow Height Data of Goksu Basin

The Flow height data (Table 2) obtained from the actual hydrological flow data of the basin is very important in terms of testing the consistency or validity of the new hydrological model applied in the field. Because the total infiltration and runoff amount calculated as a result of the model application should be compared with the flow height data. The closer the correlation between the flow height data of the site and the calculated total infiltration and runoff is 1, the more successful the model simulation is.

Table 2: Flow Height Data of Goksu Basin (1966-2017),(Source: [40], It was benefited from Published PhD Thesis)

Streamgauge Gauging Station (SGS(No:1805))													
Months	J	F	A	M	M	J	J	A	S	O	N	D	Annual Average
The Flow Height	13.64	16.51	30.59	38.74	43.00	74.92	87.29	53.80	26.61	17.47	13.98	12.65	429.23
The Flow Height(mm)													

3.4. Conversion of Uncalculated Coefficients of Natural Factors to Actual Infiltration and Runoff Coefficients as a Result of AHP (Analytical Hierarchy Process) Model Application

In the calculation of infiltration and runoff of the basin; The values obtained as a result of the digitization of natural factors obtained by using GIS, AHP and remote sensing (RS) techniques were applied in the AHP model program and the resulting coefficients were used. The coefficients for infiltration and runoff obtained as a result of AHP model program implementation are not calculated since they correspond to 100%. In converting these infiltration and runoff coefficients into actual coefficients; Mathematical calculation was made between the annual average rainfall in the basin and the height of the current and the amount of water corresponding to infiltration and runoff was determined. Provided that the infiltration and runoff elements of the basin are hydrological processes that complement each other, the data of 429.2 mm current height (Table 1) obtained from the streamgauge gauging station (SGS)) numbered 1805 located at the downstream of the basin was taken as basis. The annual average rainfall in the basin is 860.6 mm, which corresponds to approximately half of the amount of precipitation when mathematically calculated (Formula 2). According to formula

2; $R_{(P_a/Q_h)} = \frac{P_a}{Q_h} = \frac{860.6mm}{429.2mm} = 0.50$ P_a ; It refers to the annual average precipitation. Q_h ; It refers to the annual average current height. $R_{(P/Q_h)}$; It expresses the ratio of the annual average precipitation amount to the annual average current height.

Here, its correlation is made according to formula 2. Although the distribution and amount of runoff and infiltration within the basin differ locally; In the temporal course of hydrological processes, it creates a balance with mutually complementary processes such as leaking groundwater flowing back to runoff with springs, and involving re-infiltration processes in surface conditions that change due to lithology, slope, vegetation etc. at the local level. Due to this created balance, a mathematical proportioning of the current height data was made to obtain actual infiltration and runoff coefficients

based on current height data (Formula 3). According to formula 3; $R_{(Q/I)} = \frac{\sum(Q+I)}{2} = \frac{0.50}{2} = 0.25$

, $R_{(Q/I)}$; It refers to the annual average infiltration and runoff rates. Q ; It refers to the annual average runoff rate. I ; It refers to the annual average infiltration rate. $\sum(Q+I)$; It refers to the annual average total infiltration and runoff. Thus, the infiltration and runoff coefficients that were not calculated based on the proportions in formula 3 were converted into actual infiltration and runoff

coefficients(Formula 4, 5). According to formula 4; $I_{(ac)} = \frac{I_{(cc)}}{4}$, $I_{(ac)}$; It refers to the actual infiltration coefficient. $I_{(cc)}$; It refers to the uncalculated infiltration coefficient. According to formula 5; $Q_{(ac)} = \frac{Q_{(cc)}}{4}$, $Q_{(ac)}$; It refers to the actual runoff coefficient. $Q_{(cc)}$; It refers to the uncalculated runoff coefficient. As a result, the actual infiltration and runoff coefficients obtained in the mathematical operations and calculations mentioned above made it possible to calculate the infiltration and runoff in the Goksu Basin.

3.5. Izohyet (Co-Precipitation) Method

In the Isohyet method, isohyets (Congruent precipitation height curves) are drawn that connect points with the same precipitation height. The calculation is made by assuming that the height of precipitation in two consecutive areas is equal to the average of the values of the isolates. Although the isohyets method is not subjective, it provides the most accurate contribution in determining the average precipitation. Because, since the wind direction of movement takes into account the features such as aspect and relief, the Isohyet method enables a wide range of factors (Ward, 1967), (Table 3,

$$P_a = \frac{\sum_{i=1}^n P_i A_i}{\sum_{i=1}^n A_i} = \frac{3780809 \text{ mm}}{4392 \text{ km}^2} = 860.8 \text{ mm}$$

formula 6). According to formula 6; P_a ; It refers to the annual average precipitation. P_i ; It refers to the annual average rainfall rates. A_i ; It refers to the basin areas corresponding to the annual average rainfall. $\sum P_i A_i$; It refers to the annual average total precipitation amount corresponding to the grouped basin areas. $\sum A_i$; It refers to the sum of grouped basin areas.

Table 3: Application A case of Isohyet Method and Formula Applied to Determine the Distribution of Precipitation in Gökusu Basin,(**Source:** [40], It was benefited from Published PhD Thesis)

Isohetes	Annual Precipitation Height (mm) Pi	Ai (Area =Km ²)	Pi Ai
900-1100	1000	146	146000
1100-1200	1100	474.5	521950
1100-1000	1050	1277.4	1341270
850-510	650	1790.1	1163565
850-900	875	618.4	541100
900-660	780	85.8	66924
	Total	4392 km²	3780809 mm

4. Calculation of Infiltration and Runoff by Applying New Geographical Hydrological Modeling Developed by GIS, AHP, UA, Izohyet (Co-Precipitation) and Digitization Processes in Goksu Basin.

Necessary information and explanations were made about the development processes of the new geographic hydrological model developed in the research area. Analysis and evaluation will be made about the model validity and success with hydrological processes such as infiltration and runoff obtained as a result of the application of the hydrological model developed here in the Goksu Basin.

4.1. Calculating the Amount and Distribution of the Infiltration in Goksu Basin with the New Geographical Hydrological Model Application Developed

In calculating the spatial distribution and amount of infiltration belonging to the Göksu Basin, the actual infiltration coefficients of which the classification groups are specified in Table 4 and the precipitation distribution groups mathematically multiplied (formula 7), the distribution of the infiltration in the basin was calculated.

Table 4: Calculation of Infiltration in Goksu Basin with the Help of GIS, AHP, RS Techniques (Source: [40], It was benefited from PhD Thesis)

¹ Uncalculated Coefficient Distribution	² Actual Coefficient Distribution	³ Rainfall Distribution(mm)	⁴ infiltration Distribution(mm)	⁵ Areal Distribution of Basin(km ²)	⁶ Total Amount and Areal of Infiltration
0.545	0.136	510	69.3	493.4	34192620.0
0.705	0.176	685	120.56	1055.4	127390240.0
0.842	0.210	885	185.85	1250.4	232386840.0
0.993	0.248	1085	269.08	1041.4	280219912.0
1.368	0.342	1194	408.34	551.4	225158676.0
				Total: 4392 km²	Total: 899348288 m³
Total Infiltration Amount: 899348288 m³/4392 Km²= 204.7 mm					

According to formula 7; $I_d = I_{cv} \times P_{dv}$, I_d ; It refers to the distribution of infiltration. I_{cv} ; It refers to the actual infiltration coefficient values. P_{dv} ; It refers to the rainfall distribution values. The spatial distribution amounts of the infiltration were calculated as a result of mathematically multiplying the infiltration with the basin areas corresponding to the distribution groups (formula 8). According to formula 8; $I_{ad} = I_d \times B_{ag}$, I_{ad} ; It refers to the spatial distribution amounts of the infiltration. I_d ; It refers to the distribution groups of infiltration. B_{ag} ; It refers to grouped basin areas. As a result of mathematically summing up the spatial distribution of infiltration and dividing it into the total basin area (formula 9), the annual average infiltration amount of the entire basin was calculated. According

$$I_{aa} = \frac{I_{ata}}{B_{ta}} = \frac{899348288m^3}{4392km^2} = 204.7mm$$

to formula 9; I_{aa} ; It refers to the annual average total infiltration amount. I_{ata} ; It refers to the total areal amounts of annual average infiltration. B_{ta} ; It refers to the total catchment area corresponding to the infiltration areas.

With the help of the New Geographical Hydrological Modeling application results, Table 4 and related mathematical formulas (formulas 7, 8, 9), the distribution of the infiltration in the Göksu Basin, its areal amounts and total infiltration amount were calculated(Figure 4). Accordingly, the annual average total infiltration amount in the basin was calculated as 204.7 mm (Formula 9).

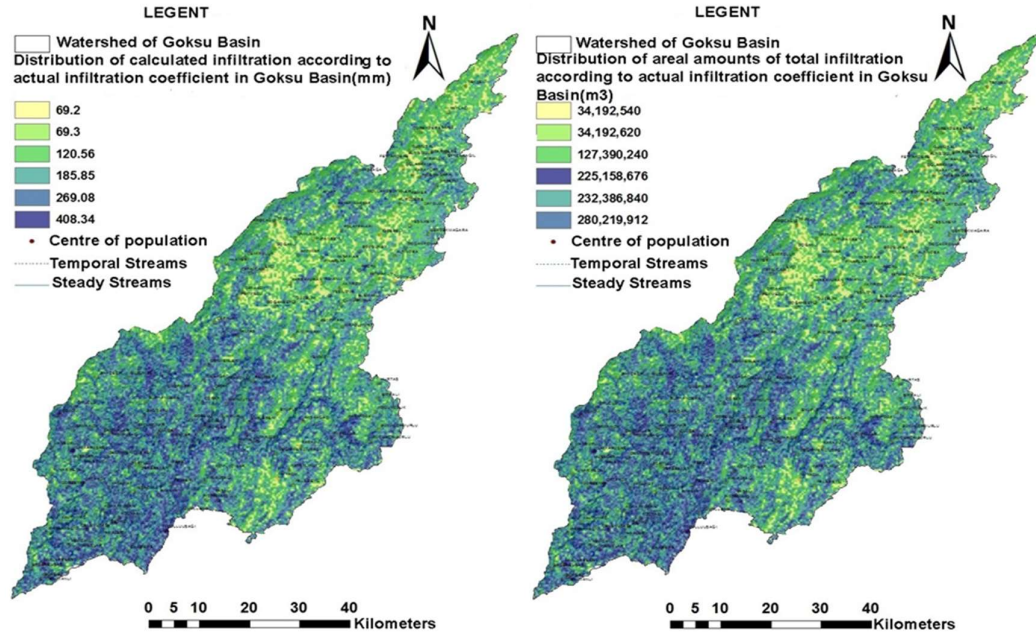


Figure 4: The Distribution of the Infiltration (A) in the Goksu Basin and the Spatial Amounts of the Infiltration (B), (Source: [40], It was benefited from published doctoral thesis)

4.2. Calculating the Amount and Distribution of Runoff in Goksu Basin with the New Geographical Hydrological Model Application Developed

In calculating the spatial distribution and quantities of the runoff belonging to the Göksu Basin, the real runoff coefficients specified in the classification groups in Table 5 and the mathematical multiplication of the precipitation distribution groups (formula 10) has been calculated.

Table 5: Calculation of runoff in Goksu Basin with the Help of GIS, AHP, RS Techniques (Source:[40], It was benefited from published PhD thesis)

¹ Uncalculated Coefficient Distribution	² Actual Coefficient Distribution	³ Rainfall Distribution(mm)	⁴ Runoff Distribution(mm)	⁵ Areal Distribution of Basin(km ²)	⁶ Total Amount and Areal of Runoff
0.525	0.136	510	69.3	493.4	34192620.0
0.683	0.170	685	116.4	1055.4	122848560.0
0.823	0.205	885	181.4	1250.4	226822560.0
0.971	0.242	1085	262.5	1041.4	273367500.0
1.408	0.352	1194	420.2	551.4	231698280.0
				Total: 4392 km ²	Total: 888929520 m ³
Total Runoff Amount: 888929520 m³/4392 km²= 202.4 mm					

According to formula 10; $Q_d = Q_{cv} \times P_{dv}$, Q_d ; It refers to the distribution of runoff. Q_{cv} ; It refers to the actual infiltration runoff values. P_{dv} ; It refers to the rainfall distribution values. As a result of the mathematical multiplication processes (formula 11) with the basin areas corresponding to the distribution groups of the runoff in the basin, the spatial distribution amounts of the runoff are calculated. According to formula 11; $Q_{ad} = Q_d \times B_{ag}$, Q_{ad} ; It refers to the spatial distribution amounts of the runoff. Q_d ; It refers to the distribution groups of runoff. B_{ag} ; It refers to grouped basin areas. As a result of mathematically summing the spatial distribution amounts of the runoff and

dividing it by the total basin area (formula 12), the annual average runoff amount of the entire basin

$$Q_{aa} = \frac{Q_{ata}}{B_{ta}} = \frac{888929250m^3}{4392km^2} = 202.4mm$$

was calculated. According to formula 12; Q_{aa} ; It refers to the annual average total runoff amount. Q_{ata} ; It refers to the total areal amounts of annual average runoff. B_{ta} ; It refers to the total catchment area corresponding to the infiltration areas. With the help of the new geographical hydrological modeling, application results, table 5 and related mathematical formulas (formulas 10, 11, 12), the distribution of the runoff in the Goksu Basin, its areal amounts and the total runoff amount were calculated (Figure 5). Accordingly, the annual average total runoff amount in the basin was calculated as 202.4 mm (Formula 12).

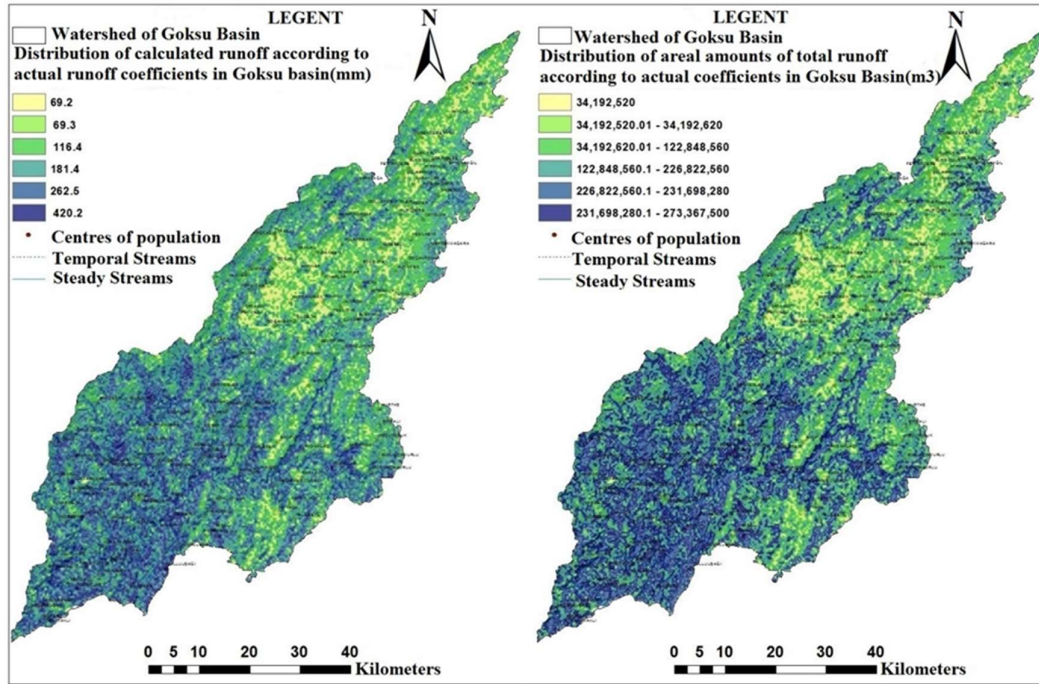


Figure 5: Distribution of Runoff (B) and Spatial Amounts of Runoff in Goksu Basin (A), (Source: [40], It was benefited from published doctoral thesis)

4.3. The Correlation of the Infiltration and Runoff Amounts Calculated in the Göksu Basin with the Current Height by the Application of the New Geographical Hydrological Model Developed

In this chapter; The sum of the annual average infiltration and runoff amounts obtained as a result of the new geographical hydrological model developed was correlated with the current height obtained from the streamgauge gauging station (SGS) no.1805 located downstream of the basin (Table 1, formula 13,14).

The purpose of this correlation is whether the annual average total infiltration and runoff amounts obtained as a result of the application of the newly developed geographical hydrological model meet the current height. If the annual average infiltration and runoff amounts obtained as a result of the model application meet the current height to a large extent, the developed hydrological model means that it is so successful. On the contrary, if the sum of the calculated annual average infiltration and runoff amounts does not give a value close to the amount of current height, the success of the developed model is also insufficient or incomplete. According to the results of the new geographical hydrological model developed above, the sum of the amount of infiltration and runoff calculated in formula 13 was calculated as 407.1 mm. According to formula 13;

$\sum(Q_{ct}I_{ct}) = Q_{ct} + I_{ct} = 202.4 + 204.7 = 407.1mm$, Q_{ct} ; It refers to the annual average calculated total runoff. I_{ct} ; It refers to the annual average calculated total infiltration. $\sum(Q_{ct} + I_{ct})$; It expresses the annual average calculated amount of total infiltration and runoff.

The current height value obtained from the streamgage gauging station 1805 at the downstream of the basin was calculated as 429.2 mm. The calculated 407.1 mm annual average total infiltration and runoff amount was correlated to 429.2 mm current height (Table 1) by performing a mathematical

$$C_r = \frac{Q_{ch}}{Q_{ah}} = \frac{407.1mm}{429.2mm} = 0.95$$

division (Formula 14). According to formula 14; C_r ; It refers to the correlation rate. Q_{ch} ; It refers to the calculated annual average current height. Q_{ah} ; It refers to the actual annual average current height.

5. Findings and Discussion

In this study; The processes regarding the application and results of the new geographical hydrological model developed have been successfully implemented. Accordingly, geographic information systems (Gis) based, analytical hierarchy process (Ahp) model program, remote sensing, isohyet and digitization methods and techniques were specified in the model flow (Figure 2). First of all, the isohyet method (Table 3, Formula 6) was chosen as an appropriate method and successfully applied in the Goksu Basin to ensure accurate and realistic distribution of precipitation values. According to the application result of this isohyet method, the annual average total precipitation amount of 860.8 mm was calculated. In the calculation of both the distribution and the annual amount of precipitation, the actual meteorology station data in the basin were taken as a basis. In addition, the arrival directions of moist air masses were supported by a meticulous field study by establishing their relationship with the existing vegetation.

If a method was chosen that does not take into account the surface conditions of the site in order to determine both the distribution and the amount of precipitation in the basin, erroneous results including the distribution and amount of precipitation in the Goksu basin would have occurred. These erroneous results could also cause serious computational errors on the new geographic hydrological model developed and fail the model. Therefore, it is possible to say that each method and technique to be used plays an important role in hydrological model development processes.

A digitization formula developed for each natural factor to determine the negative and positive effects of natural parameters such as geology (lithology), soil, soil cover (ndv1), land use / cover, slope and aspect on the infiltration and runoff in the basin (Formula 9,12) They are digitized with the help of. In these digitization processes, natural factors that reflect the real surface conditions of the Goksu basin were used. These digitized natural parameters are; In the geographical information systems (Gis) based AHP model program, the coefficients of each natural factor (Table 4, 5) were obtained by running them separately to determine the infiltration and surface flow processes. Especially in hydrological model development, it is important to include parameters including the actual surface conditions of the basin studied. After this stage, a number of mathematical formulas were produced in accordance with the purpose of the model in order to calculate the relationship between the actual flow height (Table 2) data obtained from the flow observation station no.1805 belonging to the basin and the rainfall data in the basin. With the help of these formulas, the real infiltration and runoff coefficients (Table 4,5) were obtained in order to calculate the infiltration and runoff correctly.

Mathematical multiplication of the actual infiltration and runoff coefficients of the Goksu Basin and the precipitation distribution groups calculated 202.4 mm infiltration (formula 9) and 204.7 mm runoff (formula 12). Here, a successful hydrological result has been obtained with a total 407.1 mm of infiltration and runoff (formula 13).

Such conservative results might not have been obtained if the alternatives for each natural factor in the basin had been quantified in a careless way, regardless of the actual field conditions. Erroneous results obtained would have adversely affected the hydrological model developed. Many researchers, who generally work on hydrological issues, have been found to include only one or a few natural factors in hydrological modeling processes, although it is known that natural factors have significant effects on infiltration and runoff. Hydrological models developed in this way may fail to provide the intended accuracy and consistency since all components that affect the hydrological cycle processes are not included.

Therefore, hydrological processes involving such wide and multidisciplinary issues; It leaves the work of researchers working in hydrology, hydrogeology, and other related disciplines incomplete. As a result, in this study, the calculated (formula 13) 407.1 mm total infiltration and runoff amount was correlated with the 429.2 mm flow height data (formula 14) in order to test the developed hydrological model.

6. Conclusions and Suggestions

In this study, the new geographical hydrological model developed has been successfully applied in Goksu Basin. In model development processes; While geographic information systems (Gis) and add-on analytical hierarchy process (Ahp) model program constitutes the basic methods of the isohyet hydrological model, remote sensing, numerical formulas are used as additional mathematical formulas.

In the study, it has been determined that the real field data to be used in these processes affect the success of the model as well as the importance of the model methods and techniques that ensure the correct and complete processing of hydrological processes and the processing of these processes. It has been understood that hydrological processes, which have a highly variable and dynamic structure, and meteorological and natural factors specific to the study area are included in the model building processes, giving successful results close to reality. It is possible to say that the isohyet and digitization method and formula results used in the model processes in the successful calculation of seepage and runoff in the Goksu Basin reflect the real hydrological processes.

Here, the distribution and amount of precipitation, which is the basic element of hydrological processes, were successfully calculated in the basin with the isohyet method and formula. Based on these precipitation values, the distribution and amount of which was calculated, the infiltration and runoff in the basin were calculated with high accuracy with the help of the numerical formula in which the specific natural factors of the basin were included in the hydrological process and additional mathematical formulas.

The 407.1 mm total infiltration and runoff amount obtained as a result of all this application and calculation was correlated with the flow height data calculated from 429.2 mm natural flows. The purpose of this correlation is to determine whether the new geographical hydrological model developed is successful or not. It has been observed that the new geographic hydrological model developed specific to the Goksu Basin has been very successful with a rate of 0.95 as a result of the correlation of the infiltration and surface flow amount with the actual flow height data of the basin.

In all these hydrological model development processes; Whether in creating a water budget or calculating the amount and distribution of hydrological processes of the hydrological water cycle, such as infiltration and runoff, the successful calculation of the distribution and amount of precipitation in the river basin to be studied and the inclusion of the natural parameters of the basin in the model processes are of critical importance. With this study, the importance of adopting a holistic approach in hydrological model development processes in the physical geography perspective has been revealed.

As a result, based on the success of the new geographical hydrological model developed specific to the Goksu Basin, the following can be made that can be a reference to other river basins in both hydrological model development and water budgeting.

- a) First of all, it should be considered whether the underground and surface hydrological processes of the river basin to be studied form a unity.
- b) The actual precipitation-temperature values of the area, which takes into account the prevailing climatic processes of the river basin, should be determined.
- c) The correct method or formula should be chosen to determine the distribution and amount of evaporation or precipitation based on the actual temperature-precipitation values of the basin.
- d) Natural factors such as lithology, soil, vegetation etc. that have an effect on the hydrological water cycle of the river basin should be determined. In hydrological processes, appropriate programs, integrated models or formulas should be selected for the correct and error-free processing of these natural parameters.
- e) A hydrological model flow, which includes all hydrological processes specific to the river basin to be studied, should be created. At the same time, all these models and techniques should be revisional depending on the change in the natural processes of the basin.

By means of hydrological models that can be created from a geographical point of view in river basins, determining the effect levels of all natural factors affecting hydrological processes at the basin scale clearly reveals the following gains.

The degree of influence of each natural criterion such as lithology, soil, vegetation, slope that affect water production can be determined. This situation is on the infiltration or runoff processes of the water in the relevant parts of the basin; While it facilitates the identification of risks such as erosion, landslides and water pollution, it will provide us advantages regarding lithology-soil-vegetation harmony and healthy aquifer nutrition processes. Thanks to these achievements, while it is easier to take measures against the risks that arise especially at the local level in river basins where successful hydrological models are developed, rational plans and projects can be easily produced in areas such as irrigation, drinking water, energy production, etc., based on the advantages of the basin at the local level. As a result, in river basins where a successful hydrological model has been developed, a sustainable basin management with sustainable water potential will be established where sustainable measures are taken against risks, physical and human elements are planned rationally in harmony with each other.

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