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Estimation of inflow discharge to Lake Baikal at upstream section using different satellite-based precipitation and runoff datasets from Upper Angara and Kichera River basins in East Siberia, Russia

Agegnehu K. Yoshe✉[1,3], Ekateria N. Sutyrina[2], Victor R. Chupin[3], Igor Yu. Shelekhov[3]
[1]Arba Minch University, Arba Minch, Ethiopia
[2]Irkutsk State University, Irkutsk, Russia
[3]Irkutsk National Research Technical University, Irkutsk, Russia

Abstract. Accurate basin-level river discharge estimation is of vital importance across various fields, including water resources, climate change, natural hazards, biodiversity, and energy production. Normally, gauging stations are deemed the most reliable data source for measuring river discharge. However, a significant proportion of the world's rivers remain ungauged due to a combination of technical, economic, and political constraints. Encouragingly, recent advancements in remote sensing and satellite observation have opened new avenues for global river discharge monitoring, even in ungauged basins, and the availability of extensive datasets and advancements in computing technologies have facilitated the development of numerous modern data-driven techniques. The general objective of this study is to estimate inflow discharge to Lake Baikal at upstream section from Upper Angara and Kichera River Basins using different satellite precipitation and runoff datasets. According to the calculation result, a higher discharge was observed for the power dataset. The obtained results were used to mitigate floods, droughts, bridge design, manage urban drainage systems, and manage the lake ecosystem.

***Keywords*:** discharge, runoff, runoff curve number, river basin, remote sensing and satellite dataset

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Научная статья

Оценка расхода притока воды в озеро Байкал на участке выше по течению с использованием различных спутниковых наборов данных об осадках и стоке из верховий бассейнов рек Ангара и Кичера в Восточной Сибири, Россия

А.К. Йоше✉[1,3], Е.Н. Сутырина[2], В.Р. Чупин[3], И.Ю. Шелехов[3]
[1]Университет Арба Минч, Арба Минч, Эфиопия
[2]Иркутский государственный университет, Иркутск, Россия
[3]Иркутский национальный исследовательский технический университет, Иркутск, Россия

Аннотация. Точная оценка речного стока на уровне бассейна имеет важное значение в различных областях, включая водные ресурсы, изменение климата, стихийные бедствия, биоразнообразие и производство энергии. Как правило, гидрометрические станции считаются наиболее надежным источником данных для измерения речного стока. Стоит отметить, что значительная часть рек мира остается незаселенной из-за сочетания технических, экономических и политических ограничений. Обнадеживает тот факт, что недавние достижения в области дистанционного зондирования и спутникового наблюдения открыли новые возможности для глобального мониторинга речного стока даже в неисследованных бассейнах, а наличие обширных наборов данных и достижений в области компьютерных технологий способствовали разработке многочисленных современных методов, основанных на данных. Общей целью данного исследования является оценка притока воды в озеро Байкал в верхнем течении из бассейнов рек Верхняя Ангара и Кичера с использованием различных спутниковых наборов данных об осадках и стоке. Согласно результатам расчетов, для набора данных о мощности наблюдался более высокий расход энергии. Полученные результаты можно использовать для смягчения последствий наводнений, засух, проектирования мостов, управления городскими дренажными системами и экосистемой озер.

Ключевые слова: расход, сток, номер кривой стока, речной бассейн, набор данных дистанционного зондирования и спутников

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INTRODUCTION

River discharge measurements are essential for flood management, climate studies, and water resource management. Knowledge of river flow propagation speed, i.e., the time for flows to pass downstream is critical for watershed modeling, flood prediction, and managing reservoirs [1]. Therefore, there is a great need for long-term, continuous, spatially consistent, and readily available discharge data.

River discharges are currently recording at river gauging stations. However, the availability of gauging station records is generally decreasing in most parts of the world, with data for some areas either completely unavailable or difficult to access for timely use in operational flood forecasting and disaster prevention [2].

Inadequate discharge observation has become a major problem in both developing and underdeveloped countries, as a majority of stations are no longer in operation [3].

Due to the existence of stations for water resources assessment worldwide, the commitments of participating countries to initiatives such as the International Hydrological Observations have been seriously decreasing [4].

In addition to the decrease in the number of stations that contribute to the Global Runoff Database, some stations have discontinuous datasets. These data gaps present a challenge for making useful analyses. Furthermore, current data collection efforts are mainly focused on individual development projects in different countries.

This trend has produced a patchwork of datasets that span short periods of time, with restricted spatial coverage and limited availability. The lack of reliable hydrological data is often a limiting factor for irrigation, energy generation, bridges, canals, etc. The management of water resources in these conditions can be difficult or impracticable.

The past few years there was an unprecedented increase in the number of Earth observation satellite missions with free public distribution of data, which has motivated many scientific researchers to use remote sensing data for hydrological applications [5, 6, 7]. These authors and many more have contributed to proposing and implementing new methods to estimate a number of hydrological variables that can greatly help monitoring the fluvial network and its dynamics. In this sense, remote sensing has become an essential tool to systematically monitor water resources in a synoptic manner while reducing the cost and logistics of in situ measurements.

Upper Angara and Kichera River Basins are river basins located at the upstream of Lake Baikal and serve as a source of water to maintain its sustainable water resources and ecological environment. Due to an increase in population, urbanization, and agricultural development, demand for water was increasing, which affected the availability of the water resources and the ecological environment of the lake.

To understand the current condition of the Upper Angara River Basin, hydrological modeling and predictions are playing a key role in the current scenario of climate change, and have an increasing impact on management decisions, planning, and resilience to future possible scenarios. Remote sensing techniques are significantly contributing to the field of hydrological modeling, bringing new possibilities to collect and assimilate data into hydrological models. For Lake Baikal water resource and ecological management, several assessment studies were carried out in different parts of the lake basin, for example, Borisova and Beshentsev evaluated flood hazards on the Upper Angara River [8], Borisov evaluated the natural and anthropogenic risks in Lake Baikal [9], Tatiana Potemkina et al. [10] evaluated the change in riverine sediment load supply into Lake Baikal. Potemkina, Yaroslavtsev, and Petrov evaluated the hydrological and morphological features of the Upper Angara Mouth Area [11]. However, despite the fact that the Upper Angara River Basin is the most flood-prone region and the floodplain surface is swampy, dissected by channels and dead stream channels-lakes [12, 13], extreme hydrological conditions can affect the development of the area, and understanding the discharge rate of the river basin is very essential. According to the published report, significant damages were caused during the construction of the railroad in 1978-1980, not only due to floods but also to catastrophic mudstone mudflows in the Upper Angara River [14].

The 2019 flood caused the residents of Kumora village to be isolated from the mainland by destroying the road and bridge, causing damage to more than 600 people [14]. From the review of past studies, it is clear that no attempts have been made to estimate the discharge rate for the Upper Angara River Basin using different satellite-based precipitation and runoff datasets for sustainable water resource management and hydrologic predictions.

The general objective of this study is to estimate the inflow discharge to Lake Baikal at upstream section from Upper Angara and Kichera River Basins using different satellite precipitation and runoff datasets. To estimate discharge using the precipitation dataset, the highest rainfall runoff was estimated for the study area using the curve number method by integrating land use, land cover data, hydrologic soil group data, and the moisture condition of the study area. Then, from the estimated runoff and remotely sensed runoff, the discharge of the river basin was estimated during the study period. These estimated discharges are crucial for scientific and rational water resource management, decision-making, and the mitigation of drought risks and flood hazards. Based on the result, the estimated discharge using antecedent moisture condition type one demonstrates the discharge rate during the dry condition of the soil, which is essential for drought monitoring, whereas the estimated discharge using antecedent moisture condition type three shows discharge during the wet condition of the soil, which leads to extreme floods and is used for flood forecasting and mitigation. This study also demonstrates the importance of remote sensing and satellite datasets to estimate the discharge rate of the Upper Angara River Basin and suggests that similar methods could be applied across other river basins.

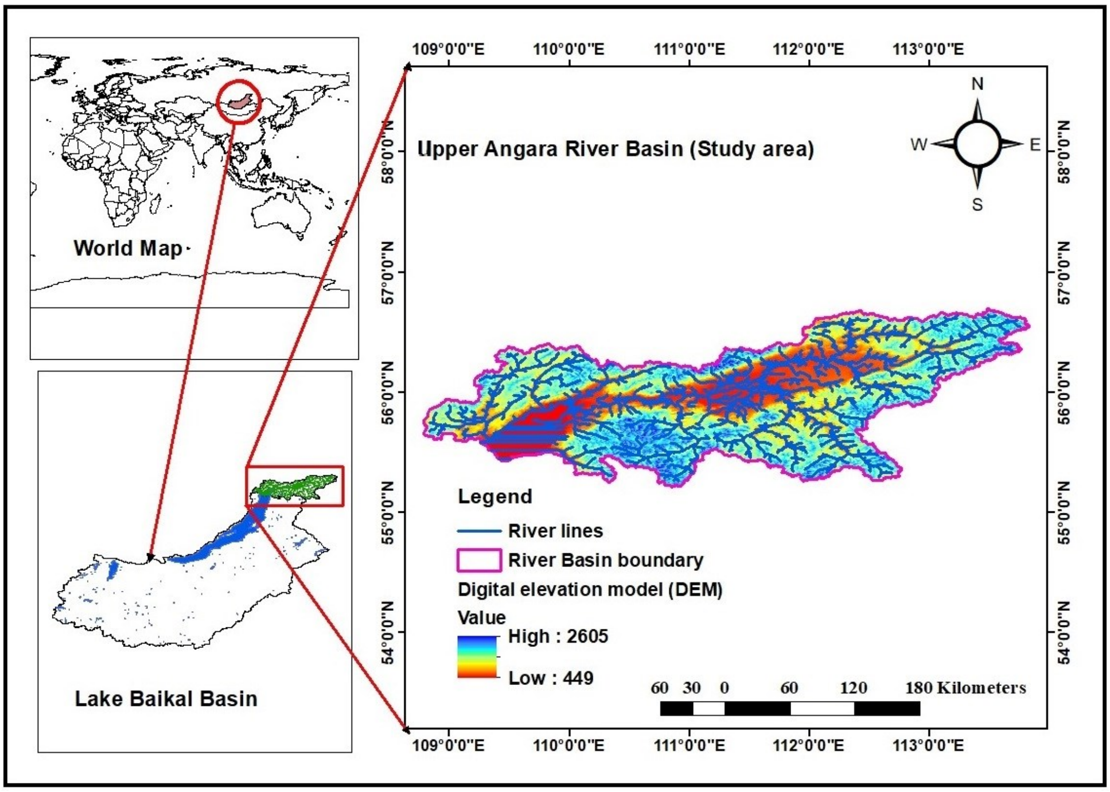

Fig. 1. Study area map
Рис. 1. Карта района исследования

MATERIALS AND METHODS

Description of the study area

The Upper Angara and Kichera River Basins (Fig. 1) are located in Buryatia, Siberia, to the northeast of Lake Baikal, and Upper Angara is the third longest river in the Baikal basin. The length of the Upper Angara River is 438 kilometers, with a drainage area of 27947 square kilometers estimated by using the QGIS model application. It is a vital source of sediment for Lake Baikal Basin and a source of flood for Kumora village and Verkhnyaya Zaimka settlement. It originates at the junction of the North-Muya and Delyun-Uransky ranges at an altitude ranging from 449 to 2605 m above sea level. Kichera River basin and Upper Angara River basin share the same elevation, due to that, in this study, one outlet was considered for the two river basins at the end and its discharge at the outlet point.

The terrain is characterized by mountains in the upstream regions and plains in the lower reaches. The average annual precipitation ranges from 242,6 mm to 744,2 mm; the annual maximum temperature ranges from 23,76 to 30,01 ^{O}C; and the average minimum temperature ranges from -34,64 to -48,66 °C. The interannual distribution of precipitation is uneven and mainly concentrated from May to September. Frequent heavy rain in the summer is the main contributor to flood disasters in the middle reaches of the Upper Angara River Basin.

Data

Different precipitation and runoff data products were collected from various remote sensing and satellite data products. 1. Precipitation and temperature data are collected from the Power-project data products, which provides access to community-based analysis-ready data (ARD) for meteorology and solar-related parameters, specifically formulated for assessing and designing renewable energy systems and water resource monitoring. The data are available at the source models (https://power.larc.nasa.gov/data-access-viewer/) based on the latitude and longitude of any location. The temporal data levels include Hourly, Daily, Monthly, Annual, and climatological ones. 2. For the Water Balance App, different data sets are collected, which includes soil moisture, precipitation, snow water storage, runoff, and evapotranspiration change in water storage. The datasets are available from 2000 to 2022 (https://livingatlas.arcgis.com/waterbalance/). 3. TerraClimate data set is a high spatial and temporal resolution remote sensing data set+. It is a dataset of monthly climate and climatic water balance for global terrestrial surfaces, which includes accumulated precipitation, actual evapotranspiration, temperature, runoff, climate water deficit, soil moisture, potential evapotranspiration, etc. (https://www.climatologylab.org/terraclimate.html). 4. Soil data are collected from Harmonized World Soil Database (DSMW) (https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/). 5. Land use and land cover data was extracted from Sentinel-2 10m Land Use/Land Cover Time series. The map is derived from ESA Sentinel-2 imagery and is a composite of land use and land cover predictions for 9 classes for each year from 2017 to 2021. The datasets are available with cell size of 1010m (https://www.arcgis.com/home/item.html?id=fc92d38533d440078f17678ebc20e8e2). 6. Digital elevation model datasets and slope data was extracted from NASA Shuttle Radar Topography Mission (SRTM) (https://opentopography.org).

Method

According to Borisova and Beshentsev [9], the hydrological study of the Northern Baikal rivers is at a very poor level, with only four hydrological stations, two of which being level gauges. An observation point in Verkhnyaya Zaimka settlement was established in 1932, and others were opened much later during the railroad construction period and are currently inactive. For the purpose of the present study a standard set of various hydrological data sets from different remote sensing and satellite observation datasets were collected using machine learning techniques to process hydrological information for accepted periods of time, methods of analysis, systematization, and geographical generalizations. For river basin delineation, soil map interpretation, land use, land cover development, slope generation, and area calculation, QGIS and ArcGIS application software were used.

Hydrological analysis

The ArcGIS 10.4 software was used to extract a channel network, delineate river basins, and calculate the areas of river basins. First, DEM was uploaded and loaded into ArcGIS, and then to remove sinks in a surface raster, a geoprocessing tool called «FILL» was used to remove small imperfections in the data. Then, a flow direction geoprocessing tool was used to create a raster of flow direction from each cell to its steepest downslope neighbor. Then, a flow accumulation geoprocessing tool was used to create a raster of accumulated flow in each cell. Using the raster calculator algorithm, the logarithm of the river basin area was calculated. Thus, the area of the river basin could be used to set a threshold for channel initiation using the channel network algorithm, and the accumulation of stream lines was evaluated, converted to polylines using conversion tool analysis, and clipped to the area of interest. The basin geoprocessing tool was used to create a raster delineating all drainage basins of the river, and the conversion tool was used to convert the created raster drainage basin to a polygon and clip it to the study area (Fig. 1).

Area calculation

To calculate area of the study basin, the delineated river basin shape file, projection and transformation were carried out from Geographic coordinate system WGS 1984 to projection coordinate system UTM Z48, WGS 84, then combined area for Upper Angara and Kichera River basin was estimated using QGIS 3.26.0. The total area estimated for was 27947000000.000 decimal number (real) or 27947 square kilometers, 27947000000 square meters.

Soil map, land use and land cover, slope preparation

After the river basin was delineated, the composite curve number for the river basin was estimated from soil thematic maps and land use and land cover. The soil data collected from the Harmonized World Soil Database is clipped to the study area using ArcGIS, and then the textural class and hydrological soil group of the study area are identified using Mapwindow software. The study identified two hydrologic groups of the soil (C and D), as presented in Figure 2(C). Land use type is one of the important parameters that affects runoff contribution, and the data on land use and land cover was extracted from Sentinel-2 10m Land Use/Land Cover Timeseries, then clipped to the study area using the ArcGIS application software. The study area of land use/ land cover was grouped into 7 land class types, which include water bodies, trees, snow/ice cover, rangeland, built areas, bare ground, and flooded land surfaces (Fig. 2D). To develop a slope map, the digital elevation model for the study area was extracted using a simple geoprocessing tool that identifies the slope (rate of maximum change in z-value) from each cell. The study area slope ranges from 0,328 to 80,6 percent, which manages the speed of water flow in an area. By integrating the thematic layers, the curve number value for the study area was evaluated.

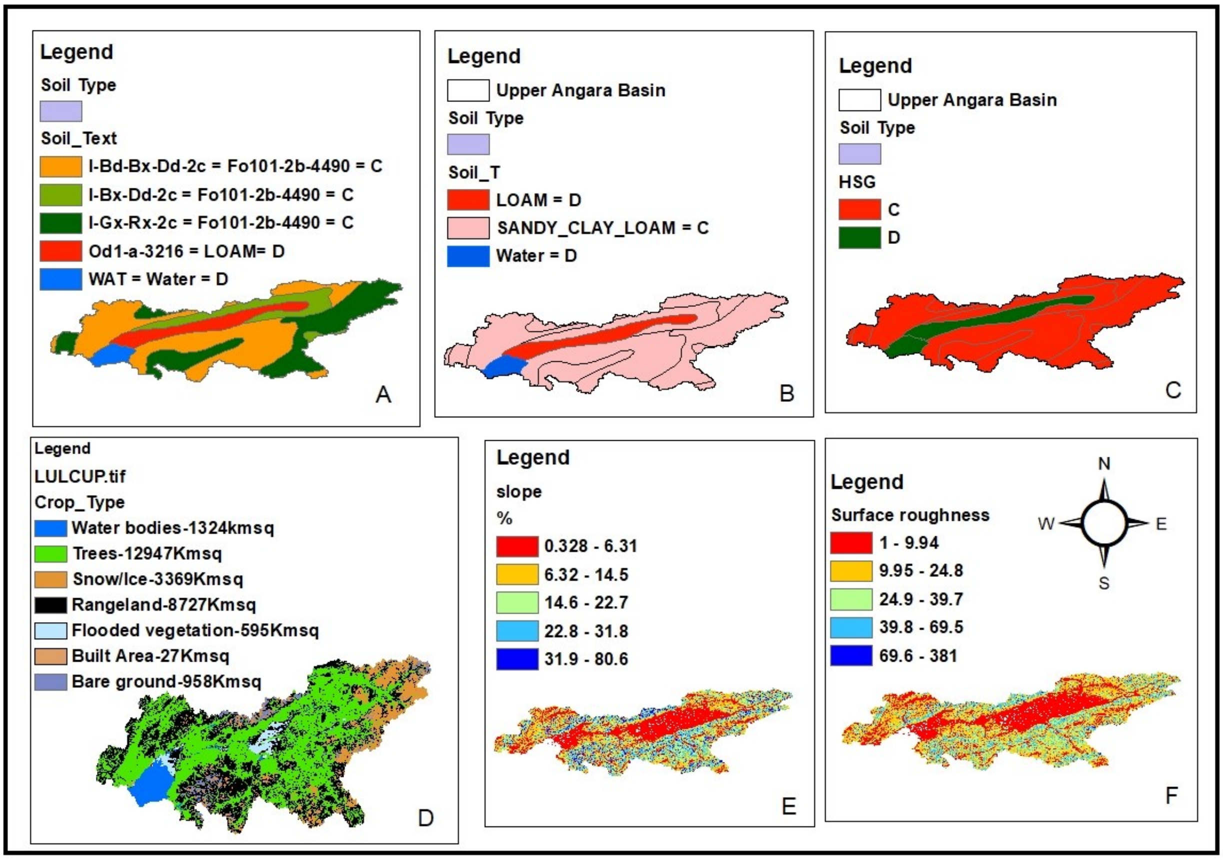

Fig. 2. Different hydrological data sets for the study area: A–C) soil data, D) land use and land cover data, E) slope map and F) surface roughness

Рис. 2. Различные наборы гидрологических данных для исследуемой территории: A–C) данные о почве, D) данные о землепользовании и растительном покрове, E) карта склонов и F) шероховатость поверхности

SCS-CN runoff estimation

Runoff was estimated using the SCS Runoff CN method, which relies on a composite curve number of an average antecedent moisture condition assigned to each sub-basin and rainfall depth in the area. The method incorporated the runoff properties of the catchment by integrating soil and land use information for an average antecedent moisture condition. Determining the Curve Number: for each catchment, the runoff properties were characterized by an empirical curve number derived from the soil and ground cover. The soil parameter was defined by the hydrologic soil group (HSG), determined by the soil texture. The HSG for the different soil textures is presented in Table 1.The curve number for an average antecedent moisture condition for the different soil and ground cover combinations of the study area was determined based on the classifications in Table 2.

Table 1. Hydrologic Soil Group Description [15]
Таблица 1. Описание гидрологической группы почв [15]

Soil Group	Description
A	Sand, loamy sand or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay Loam, silty clay loam, sandy clay, silty

Table 2. Curve numbers for land cover classes and soil groups
Таблица 2. Номера кривых для классов растительного покрова и групп почв

Land Use/ Land Cover	Hydrologic Soil Group Curve Numbers			
	A	B	C	D
Annual Crop	67	78	85	88
Brush/Shrubs	30	48	65	73
Fishpond	99	99	99	99
Built-up	89	92	94	93
Grassland	30	58	71	78
Inland Water	99	99	99	99
Mangrove Forest	98	98	98	98
Marshland/Swamp	72	81	88	91
Open Forest	36	60	79	79
Open/Barren	63	77	85	88
Perennial Crop	45	66	77	83

To determine a composite curve number for each catchment, curve number weighing, the process of summing the product of the curve numbers and its fraction of the total catchment area was performed.

This procedure was defined by the equation [20]:

$$CN_w = \sum_{i=1}^{n} CN_i * \frac{S_i}{S}, \quad (1)$$

where CN_w= weighted curve number,

S_i = area with the curve number, CN_i&,

S= total area of the catchment.

The composite curve number was derived by rounding the CN_w off to the nearest whole number. To calibrate the average condition curve number to a saturated condition, the following equation were used

$$CNI = \frac{4.2 \times CNII}{10 - 0.058 \times CNII}, \quad (2)$$

$$CNIII = \frac{23 \times CNII}{10 + 0.13 \times CNII}, \quad (3)$$

where CNII is the curve number for normal conditions, CNI is the curve number for dry conditions, and CNIII is the curve number for heavy rain and saturated soils.

Table 3. Categorization of antecedent moisture condition
Таблица 3. Классификация предшествующих условий влажности

AMC label	Assessment of soil condition	Total five-day antecedent rainfall(mm)	
		Dormant season	Growing season
I	The soil is dry, not to the point of withering	Less than 13	Less than 36
II	Normal condition	13 to 28	36 to 53
III	Heavy rains and saturated soils	Greater than 28	Greater than 53

Runoff evaluation

The estimating runoff using SCS runoff CN method was calculated using the following equation [15]:

$$Ro = \frac{(P-I_a)^2}{(P-I_a)+R} \quad (4)$$

where Ro = runoff in mm, P = rainfall in mm, R = potential maximum retention in mm, I_a is initial abstraction.

The equation was performed when the precipitation depth was greater than the initial abstraction, otherwise runoff (Ro) was equated to zero.

Initial abstraction (I_a) shows all the losses before the beginning of runoff. It was evaluated through equation as follows:

$$I_a = 0{,}2R \quad (5)$$

where I_a is initial abstraction loss, R is potential maximum retention.

The potential maximum retention R was related to the curve number of the river basin. This relationship was defined by the equation

$$R = \frac{25400}{CN} - 254 \quad (6)$$

where R is potential maximum retention in mm and CN is curve number.

Discharge estimation

Discharge (or flow rate) refers to the volumetric amount of water carried by a body of water per unit of time and is commonly expressed in units of cubic meters per second (cms). Environmental factors such as precipitation, gradient (slope), available groundwater supply, soil type, and vegetation can all affect the magnitude of discharge within a stream or river.

Anthropogenic or human-caused factors that affect discharge include dam installation, water diversion, urban development, groundwater withdrawals, or other land-use practices such as forestry or agriculture. Researchers monitor discharge in streams and rivers for a wide variety of applications that include forecasting extreme weather events (such as floods or droughts) or understanding changes in ecological parameters like water quality or biological habitat. There are different methods used to estimate drainage in a river basin. This study is based on available precipitation and runoff data from different satellite datasets,

$$h = \frac{1000*t*Q}{S} \quad (7)$$

where h is runoff in mm, t is the duration of the calculation period in seconds (if the runoff layer is determined for a year, then this is the number of seconds per year), Q is the average discharge over the study period in cubic meters per second, S is the catchment area in square meters, and 1000 is a multiplier for converting m to mm.

$$Q = \frac{S*h}{t*1000} \quad (8)$$

Results and discussion

In this study, inflow discharge to Lake Baikal at upstream section from Upper Angara and Kichera River Basins in East Siberia was evaluated using different satellite-based precipitation and runoff datasets. To estimate discharge rate analysis of available precipitation, runoff, land use, land cover, hydrologic soil group, slope, surface roughness data sets were processed, made the necessary corrections and integrated together to generate curve number of the study area to develop runoff depth. Based on the finding, the study area has two hydrological soil group (C and D) which covers 79,2 and 20,8 % of total area respectively with the textural class of loam soil, water and sandy clay loam. The land use classification was carried out using supervised classification and the study area has 8 land classes such as water, trees, flooded vegetation, built area, bare ground, snow/ice, and rangeland with percentage area of 4,74, 46,33, 2,13, 0,1, 3,43, 12,05, 31,23 and 31,23 % respectively. Based on soil texture with its land use and land cover, curve number was assigned to each land use type to estimate curve number value for normal condition using equation 1, and the using equation 2 and 3, curve number for antecedent moisture condition for type I and III was evaluated presented in Table 4, according to the estimation of curve number for study area, the value of curve number for antecedent moisture condition type I, II, and III are 56,21, 75,4, 87,6 respectively. The potential maximum retention and initial abstraction losses before the beginning of runoff for each antecedent moisture condition was evaluated using equation 6 and 5 respectively. The result of the potential maximum retention was 197,7, 83,11 and 36,13 respectively, whereas the initial abstraction losses was 39,6, 16,62 and 7,23 respectively for antecedent moisture condition type I, II, and III for the study area. Runoff is the proportion of rainfall that does not infiltrate and is not taken up by evapotranspiration. Precipitation serves as an important source of water and is one of the fundamental components of hydrology. Moreover, rainfall runoff creation is affected by the precipitation in the area. So, when precipitation is high, there is a corresponding increase in surface runoff. However, characteristics of the surface, like land use type and the textural class of the soil, can affect rainfall runoff either directly or indirectly.

For this study, three precipitation data products from power access data source, TerraClimate data source and water balance application precipitation datasets are used to examine runoff and discharge of the study area for the time frame of the study.

Table 4. Characteristics of land cover, hydrological soil group and curve number
Таблица 4. Характеристики растительного покрова, гидрологическая группа почв и номер кривой

Crop type	HSG	Curve Number	Area coverage in Sqkm	% area	CN_i *A_i	
Water	D	80	1324	4,74	105920	**CNI = 56,21** **CNII = 75,40** **CNIII = 87,60**
Trees	C	74	12947	46,33	958078	
Flooded vegetation	D	80	595	2,13	47600	
Built Area	D	80	27	0,10	2160	
Bare ground	D	80	958	3,43	76640	
Snow/Ice	D	80	3369	12,05	269520	
Rangeland	C	74	8727	31,23	645798	
Total area			27947	100,00	2105716	

Runoff estimation from different precipitation datasets

The CN-Rainfall runoff model represents the hydrological modeling that was applied to simulate the runoff from selected precipitation events using different set of hydrologic parameters. For this study, three rainfall distributions from remote sensing and satellite information datasets were used to estimate daily, monthly and annual runoff for the study area and compared with two runoff datasets extracted from different satellite information using machine learning. The result for surface runoff using CN has the potential of runoff estimation. Under the same precipitation condition, low CN value means that the surface has a high potential to retain water, whereas high value means that the rainfall can be stored by the land surface only to a small extent. Therefore, areas with high CN value will produce a large amount of direct runoff and thereby contribute strongly to the flood peak. According to the calculation the estimated runoff using water balance precipitation dataset ranges from 188,6 to 492,7 mm, 265,7 to 593,2 mm and 308,9 to 642,2 mm for dry, normal and wet soil moisture condition respectively with average runoff ranging from 254.4 to 576,0 mm. The estimated runoff using TerraClimate dataset ranges between 165,0 to 374,4, 238,9 to 468,5 mm and 281,1 to 516,0 mm for dry, normal and wet soil moisture condition respectively having an average ranging between 228,3 to 453,0 mm. The result obtained using power dataset was ranging between 102,8 to 550,1 mm, 165,2 to 653,0, 204,0 to 702,6 mm for dry, normal and wet soil moisture condition respectively having an average ranging between 157,3 to 635,22 mm during the study period. The maximum runoff was obtained for power dataset and was recommended for flood monitoring and mitigation. According to Borisova and Beshentsev, the runoff during the high-water period averages 45–55 % of the annual runoff and our finding also agrees with this study [9].

Estimation river discharge from the estimated runoff

In this study inflow discharge to Lake Baikal at upstream section from Upper Angara and Kichera River Basins was estimated using different satellite observation precipitation data sets for Upper Angara River basin in East Siberia region of Russia, using equation 8 from the estimated runoff, using integrated dataset of satellite observations considering three moisture condition of the soil (dry, normal and wet) and presented in Table 6. According to the calculation, the estimated discharge, using water balance precipitation dataset ranges between 91,1 to 487,5, 146,4 to 578,7 and 180,8 to 622,6 in cubic meters per second for dry, normal and wet soil moisture condition respectively, with average discharge ranging from 139,4 to 562,9 in cubic meters per second. The estimated discharge using TerraClimate dataset ranges between 146,2 to 331,8, 211,7 to 415,2 and 249,1 to 457,3 in cubic meters per second for dry, normal and wet soil moisture condition respectively having an average ranging from 202.4 to 401,4 in cubic meters per second. The result obtained using power dataset was ranging between 167,1 to 436,7, 235,5 to 525,7, and from 273,8 to 569,1 in cubic meters per second for dry, normal and wet soil moisture condition respectively having an average ranging between 225,4 to 510,5 in cubic meters per second during the study period.

Table 5. Estimated runoff for Upper Angara River basin
Таблица 5. Расчетный сток для бассейна реки Верхняя Ангара

Year	Runoff from water balance precipitation dataset (RO_1 for AMC-I))	Runoff from water balance precipitation dataset (RO_2 for AMC-II)	Runoff from water balance precipitation dataset (RO_3 for AMC-III)	Runoff from Terra-Climate Precipitation (RO_1 for AMC-I)	Runoff from Terra-Climate Precipitation (RO_2 for AMC-II)	Runoff from Terra-Climate Precipitation (RO_3 for AMC-III)	Runoff from power Precipitation (RO_1 for AMC-I)	Runoff from power Precipitation (RO_2 for AMC-II)	Runoff from power Precipitation (RO_3 for AMC-III)
2000	297,7	386,2	432,4	337,3	42,9	475,8	215,0	295,4	339,5
2001	319,8	410,1	45,7	324,0	414,6	461,3	205,9	285,3	329,1
2002	309,6	399,1	445,5	291,2	370,2	425,2	179,0	254,9	297,7
2003	274,7	361,3	407,0	209,5	289,3	333,2	119,0	184,9	224,8
2004	317,8	408,0	454,5	305,5	394,7	441,1	247,2	331,2	376,2
2005	272,1	358,4	404,0	252,7	337,2	382,3	210,4	290,4	334,3
2006	280,4	367,4	413,2	269,8	355,9	401,4	233,3	315,8	360,5
2007	286,2	373,8	419,7	296,9	385,4	431,5	219,6	300,5	344,8
2008	319,2	409,5	456,1	374,4	468,5	516,0	342,1	434,1	481,1
2009	301,6	390,5	436,8	326,9	417,8	464,5	284,8	372,2	418,1
2010	279,3	366,3	412,1	309,7	399,3	445,7	294,2	382,5	428,6
2011	237,1	320,0	364,7	233,1	315,6	360,2	183,4	259,9	302,9
2012	291,5	379,6	425,6	280,1	367,1	412,9	251,9	336,3	381,4
2013	278,4	365,3	411,0	333,8	425,2	472,1	148,4	219,7	261,2
2014	245,1	328,9	373,8	211,5	291,6	335,5	219,6	300,5	344,8
2015	188,6	26,7	308,9	201,3	280,1	323,8	183,4	259,9	302,9
2016	337,8	429,4	476,4	205,9	285,3	329,1	102,8	165,2	204,0
2017	429,6	526,9	575,2	229,1	311,1	355,6	215,0	295,4	339,5
2018	401,1	496,8	544,7	302,4	391,4	437,6	289,5	377,4	423,4
2019	492,7	593,2	642,2	165,0	238,9	281,1	196,9	275,1	318,6
2020	322,9	413,4	460,1	308,4	397,8	444,2	303,8	392,8	439,1
2021	286,1	373,7	419,6	253,7	338,3	383,5	291,2	379,2	425,3
2022	382,1	476,7	524,4	320,4	410,8	457,4	550,1	653,0	702,6

Potemkina and Potemkin [16] evaluated the sediment load of the main rivers of Lake Baikal in a changing environment. They used the largest rivers by length, water, and sediment load for Selenga, Upper Angara, and Barguzin. According to their report, the discharge rate of the Upper Angara River Basin is 8,44 cubic kilometers per year, which is equal to 267,63 cubic meters per second. Tatiana Potemkina, Ekaterina Sutyrina, and Vladimir Potemkin [17] evaluated the change of the riverine sediment load into Lake Baikal and reported that the annual discharge of the Upper Angara River basin was 8,76 cubic kilometers per year, which is equal to 277,78 cubic meters per second from 1974 to 2011. As presented in Table 6, the obtained result was similar to the findings conducted by Potemkina and Potemkin [16], Tatiana Potemkina, Ekaterina Sutyrina, and Vladimir Potemkin [17] with little variation. The variation of the discharge for this study was due to the area used during the study. The area used by Potemkina and Potemkin [16], Tatiana Potemkina, Ekaterina Sutyrina, and Vladimir Potemkin [17] was 21,400 km^2, but for our study based on the water shed delineation area obtained for Upper Angara, it was 27947 square kilometers. The variation in the result was also due to the uncertainty of the different data sets, including land use and land cover change, soil properties, climatic change, anthropogenic activity, and other water balance components, which were confirmed by similar factors[18, 19, 20]. The study area is also very sensitive to flood hazards. Different extreme floods occurred in 1933, 1936, 1951, 1952, 1956, 1960, 1962, 1977, 1978, 1980, 1982, 1994, 2007, and 2019 and were registered on the right-bank and on the left-bank of the Upper Angara river basin [8, 12, 20]. Accurate river basin discharge estimation is crucial for advancing our scientific understanding of the water cycle and supporting various downstream users and environmental conditions. It is crucial for many activities, ranging from the management of water resources to flood risk mitigation. Due to the limitations of the in situ stations (e.g., low station density, incomplete temporal coverage as well as delays in data access), the river discharge is not always continuously monitored in time and in space. Human-caused climate change is influencing factors that contribute to flood risk such as rainfall extremes and soil moisture, and there is a need for updated flood guidance.

The result for wet soil moisture condition was very essential for flood risk reduction measures which can be exercised through the construction of flood mitigation structures, zoning and development controls, and non-structural measures to better respond to floods and result of dry condition was essential for drought monitoring during dry season.

Table 6. Inflow discharge to Lake Baikal at upstream section from Upper Angara and Kichera River Basins
Таблица 6. Сток притоков в озеро Байкал в верхнем течении из бассейнов рек Верхняя Ангара и Кичера

Year	Discharge from power dataset (Q1)	Discharge from power dataset (Q2)	Discharge from power dataset (Q3)	Discharge from TerraClimate (Q1)	Discharge from TerraClimate (Q2)	Discharge from TerraClimate (Q3)	Discharge (Q1) from water balance	Discharge (Q2) from water balance	Discharge (Q3) from water balance
2000	190,5	261,8	300,9	298,9	380,1	421,6	263,8	342,3	383,2
2001	182,5	252,8	291,6	287,1	367,4	408,8	283,4	363,4	404,7
2002	158,6	225,9	263,8	258,0	336,0	376,8	274,4	353,7	394,8
2003	105,4	163,8	199,2	185,6	256,4	295,3	243,4	320,2	360,6
2004	219,1	293,5	333,4	270,8	349,8	390,9	281,6	361,5	402,8
2005	186,5	257,3	296,2	223,9	298,8	338,8	241,1	317,6	358,0
2006	206,8	279,9	319,4	239,1	315,4	355,7	248,5	325,6	366,2
2007	194,6	266,3	305,5	263,1	341,5	382,4	253,6	331,2	371,9
2008	303,2	384,7	426,3	331,8	415,2	457,3	282,9	362,9	404,1
2009	252,3	329,8	370,5	289,7	370,2	411,6	267,3	346,1	387,0
2010	260,8	339,0	379,8	274,5	353,8	394,9	247,5	324,6	365,2
2011	162,6	230,3	268,4	206,6	279,7	319,2	210,1	283,5	323,2
2012	223,2	298,0	338,0	248,2	325,3	365,9	258,3	336,4	377,2
2013	131,5	194,7	231,5	295,9	376,8	418,3	246,7	323,7	364,3
2014	194,6	266,3	305,5	187,4	258,4	297,3	217,2	291,4	331,3
2015	162,6	230,3	268,4	178,4	248,3	286,9	167,1	235,5	273,8
2016	91,1	146,4	180,8	182,5	252,8	291,6	299,3	380,6	422,1
2017	190,5	261,8	300,9	203,0	275,7	315,1	380,7	467,0	509,7
2018	256,5	334,4	375,2	268,0	346,8	387,8	355,4	440,2	482,7
2019	174,5	243,8	282,3	146,2	211,7	249,1	436,7	525,7	569,1
2020	269,2	348,1	389,1	273,3	352,5	393,7	286,1	366,4	407,7
2021	258,1	336,1	376,9	224,9	299,8	339,9	253,6	331,2	371,9
2022	487,5	578,7	622,6	284,0	364,0	405,3	338,7	422,5	464,7

CONCLUSION

This research investigates inflow discharge to Lake Baikal at upstream section from Upper Angara and Kichera River Basins using different satellite precipitation dataset and surface runoff. A standard set of different hydrological data sets was collected from different remote sensing and satellite observation data sets using machine learning techniques for processing hydrological information for accepted time periods. Methods of analysis, systematization, and geographical generalizations were carried out during the study period. The boundary of the river basin was delineated, and the area was calculated using QGIS 3,26. The drainage area estimated in this study is 27947 square kilometers. The study area for land use and land cover was grouped into water bodies, trees, snow/ice cover, rangeland, built areas, bare ground, and flooded land surfaces, and the slope of the area ranges from 0.328 to 80.6 percent. By integrating the thematic layers, the curve number value for the study area was evaluated. Then the potential maximum retention and initial abstraction loss were estimated. After all, runoff for each antecedent moisture condition and precipitation of the year was evaluated. Finally, the discharge of the river basin was evaluated for the study area from 2012 to 2022.

The average discharge rate for the calculation result of the three precipitation datasets ranges between 139,4–562, 9, 202,4–401,4, and 225,4–510,5 cubic meters per second for the water balance app, Terra-climate, and power data access, respectively.

The estimated result was essential to mitigating floods, droughts, bridge design, urban drainage systems, the lake ecosystem, water resource management, and climatic change.

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Information about the authors

Agegnehu K. Yoshe,
Lecturer, Department of Water Resources and Irrigation Engineering,
Arba Minch University,
21 Post Office Box, Arba Minch, Ethiopia;
Postgraduate Student,
Irkutsk National Research Technical University,
83, Lermontov St., Irkutsk 664074,
Russia,
✉e-mail: kitanbo@gmail.com
https://orcid.org/0000-0002-3792-5854

Victor R. Chupin,
Dr. Sci. (Eng.)., Professor,
Head of the Department of Urban Construction and Economy,
Irkutsk National Research Technical University,
83 Lermontov St., Irkutsk 664074, Russia,
e-mail: chupinvr@istu.edu
https://orcid.org/0000-0001-5460-4780
Author ID: 475565

Ekaterina N. Sutyrina,
Cand. Sci. (Geography),
Associate Professor, Head of the Department of Hydrology and Environmental Management,
Irkutsk State University,
1, Karl Marx St., Irkutsk 664003, Russia,
e-mail: ensut78@gmail.com
https://orcid.org/0000-0001-5743-4596
Author ID: 526672

Igor Yu. Shelekhov,
Cand. Sci.(Eng.)
Associate Professor of the Department of Urban Construction and Economy,
Irkutsk National Research Technical University,
83 Lermontov St., Irkutsk 664074, Russia,
e-mail: promteplo@yandex.ru.
https://orcid.org/0000-0002-7677-3187
Author ID 480140

Информация об авторах

Йоше Агегнеху Китанбо,
преподаватель кафедры охраны окружающей среды, Университет Арба Минч,
г. Арба Минч, Почтовое отделение 21, Эфиопия;
аспирант,
Иркутский национальный исследовательский технический университет,
664074, г. Иркутск, ул. Лермонтова, 83, Россия,
✉e-mail: kitanbo@gmail.com
https://orcid.org/0000-0002-3792-5854

Чупин Виктор Романович,
д.т.н., профессор,
заведующий кафедрой городского строительства и хозяйства,
Иркутский национальный исследовательский технический университет,
664074, г. Иркутск, ул. Лермонтова, 83, Россия,
e-mail: chupinvr@istu.edu
https://orcid.org/0000-0001-5460-4780
Author ID: 475565

Сутырина Екатерина Николаевна,
к.г.н., доцент, заведующий кафедрой гидрологии и природопользования,
Иркутский государственный университет,
664003, г. Иркутск, ул. Карла Маркса, 1, Россия,
e-mail: ensut78@gmail.com
https://orcid.org/0000-0001-5743-4596
Author ID: 526672

Шелехов Игорь Юрьевич,
к.т.н., доцент кафедры городского строительства и хозяйства,
Иркутский национальный исследовательский технический университет,
664074, г. Иркутск, ул. Лермонтова, 83, Россия,
e-mail: promteplo@yandex.ru
https://orcid.org/0000-0002-7677-3187
Author ID 480140

Contribution of the authors

The authors contributed equally to this article.

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