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Impact of LULC Dynamics on Evapotranspiration using GIS : Case Study of Uttarakhand

Ravi Kant Bhardwaj[1]*, Shivangi Sharma[2], Deepak Kumar[3]**

[1]College of Technology, GBPUA&T Pantnagar, India
[2]School of Agro & Rural Technology, Indian Institute of Technology, Guwahati, India
[3]Department of Soil & Water Conservation Engineering, GBPUA&T Pantnagar, India
**Corresponding author, Email address: ravi.kant1441@gmail.com*
***Corresponding author, Email address: shivangi.sharma@iitg.ac.in*

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**Corresponding author,*
Email address:
ravi.kant1441@gmail.com
***Corresponding author,*
Email address:
shivangi.sharma@iitg.ac.in

Abstract

Evapotranspiration is considered as one of the most important components of the hydrological cycle. On the Earth's surface, evapotranspiration plays an important role in context of water-energy balance and irrigation, as well as agriculture practices. In the present study, land use and land cover (LULC) maps of year 2021-2022 of the four districts of Uttarakhand namely, Bageshwar, Pauri Garhwal, Rudraprayag and Chamoli have been comparatively analysed for its impact on evapotranspiration rate. Sentinel-2 imagery has been used to generate LULC maps. From the Uttarakhand administrative map, shapefiles of the four districts were used for processing and analysing. Further, the processed images were used to quantify LULC for the study area. Reclassification of the LULC has been done using eight land classes, namely, water bodies, trees, grass, snow cover, agriculture, scrub/shrubs, build-up area and bare ground. Further, evapotranspiration for the selected districts were analysed. Through comparison of the post-classification data of the LULC, it has been observed that area under tree cover was 52.57%, 61.67% and 43.29% for Bageshwar, Pauri Garhwal and Rudraprayag respectively which is much more than the trees cover in Chamoli district with 35.25%. Also, the bare ground area percent in Bagehswar, Pauri Garhwal and Rudraprayag are 2.65%, 0.032% and 0.36% in respective districts, whereas on the other hand, in Chamoli district, bare land cover was 14.74%. This explained the lowest evapotranspiration in 2021 for Chamoli, which is the largest district area-wise among these districts, with 586.71mm. While the evapotranspiration for the other districts were found to be 737.33mm, 708.64mm and 718.79mm.

1. Introduction

Land use and land cover changes (LUCC) are one of the most hydrologically significant modifications of the Earth's land surface [1]. Climate change and land-ecological interactions are becoming crucial environmental factors and the LUCC strategies provides scenarios at global and regional levels to understand these interactions [2]. For the same reason, LUCC is regarded as a core joint project of the International Human Dimensions Program on Global Environmental Change (IHDP) and the International Geosphere Biosphere Program (IGBP). Number of physical processes occurring on the Earth surface require knowledge of actual data about land use and land change [3] . Hence, these maps are utilized in modelling applications for estimating aerial extents along with locations of different cover classes [4]. In recent years, data based on satellite imagery has become a widely recognized source of generating useful LULC information ([5]; [6]; [7];[8]). Globally, various

methods and techniques LULC change detection and its mapping have been developed and adapted in the last few decades ([9], [10]). Land use and land cover is greatly decided by topographical conditions, geological patterns, institutional and other socioeconomic parameters ([11],[12]). Industrialization, urbanisation and growth population have dramatically altered the LULC ([13]). Although the changes in the land cover are not necessarily indicative of land degradation, they are one of the most vital factors influencing changes globally. Changes in land use and land cover, mostly brought out by anthropogenic activities, such as changes in vegetation types, and evolving land-use practices, can have significant impact on hydrological cycle ([14]). Potential evapotranspiration (PET) is usually considered as the amount of water lost from a land surface to the atmosphere having abundant water supply. The high variability in its spatial-temporal attribute makes it one of the most complex variables along with ecohydrology ([15]). The effects of human influences on the hydrological processes can be gauged by understanding ET, which can further help to improve water use efficiency and strengthen watershed management as well as strategic water use. Evapotranspiration (ET) is simply the combined total evaporation and transpiration as these two phenomena are challenging to isolate for typical land expanses which include evaporation from water bodies, soil and other surfaces as well as transpiration from plants and vegetation. As hydrological processes vary both temporally and spatially, it is common to employ remote sensing (RS) and geographical information system (GIS) tools for better clarity and in order to have an explanation of these phenomena. The state of Uttarakhand which lies in the northern part of India is situated in the Himalayan foothills and majority of the area of the state falls under hilly terrain (about 86%) except for Haridwar, Udham Singh Nagar and some parts of Dehradun district. In hilly terrain of Uttarakhand, the climatic factors like maximum temperature, minimum temperature, humidity etc. are similar which affect the ET, the only variable is LULC pattern. The extent of forest/tree covered area plays an important role in affecting evapotranspiration in the area. In the present study, high resolution (10 m) Sentinel-2 imagery has been used to map the pattern of LULC of the four districts, Bageshwar Chamoli, Pauri Garhwal and Rudraprayag, for the year 2021. The objectives of this study were to: (1) provide a recent perspective on the spatial and temporal LULC patterns; and (2) assess, qualitatively, the impact of land use land cover pattern on the evapotranspiration.

1.1 Study Area

This study was conducted on four districts, namely, Bageshwar, Chamoli, Pauri Garhwal and Rudraprayag, of Uttarakhand state located in the central Himalayan region of India, with a total geographical area of 53,812.47 km^2 as shown in Fig. 1. The Uttarakhand state lies between 77° 34′ E and 81° 03′ E longitudes and 28° 43′ N and 31° 28′ N latitudes with altitudes varying from 145 m to 7796 m above mean sea level (MSL). The state of Uttarakhand shares its boundaries with Himachal Pradesh in the northwest, Uttar Pradesh in South, and with Nepal and China on the southeast and northeast, respectively. The State is divided into two administrative divisions such as (i) Garhwal region including seven districts namely Chamoli, Dehradun, Haridwar, Pauri Garhwal, Rudraprayag, Tehri Garhwal, and Uttarkashi and (ii) Kumaon region including six districts namely Almora, Bageshwar, Champawat, Nainital, Pithoragarh and Udham Singh Nagar (Fig.1.). Uttarakhand is divided into four physiographic zones viz.: (i) Terai (finer alluvium deposits) and Bhabar (a belt of pebbles) region between the elevations of 175 m to 600 m; (ii) Shivalik region between the elevations of 600 to 1200 m; (iii) Lesser Himalaya region between the elevations of 1200 to 3000 m; and (iv) Great Himalaya region between the elevations of 3000 to 7000 m above mean sea level. The State has a temperate climate, except in the plains where the climate is tropical. The temperature in the state

ranges from sub-zero to 43 °C. The annual rainfall varies between 260 and 3955 mm, of which most part (60 to 85% of the annual total) is received during monsoon season (June to September) alone. According to the Indian Meteorological Department, four prominent seasons namely (i) winter (December–February), (ii) pre-monsoon (March–May), (iii) monsoon (June–September), and (iv) post-monsoon (October–November) are dominant.

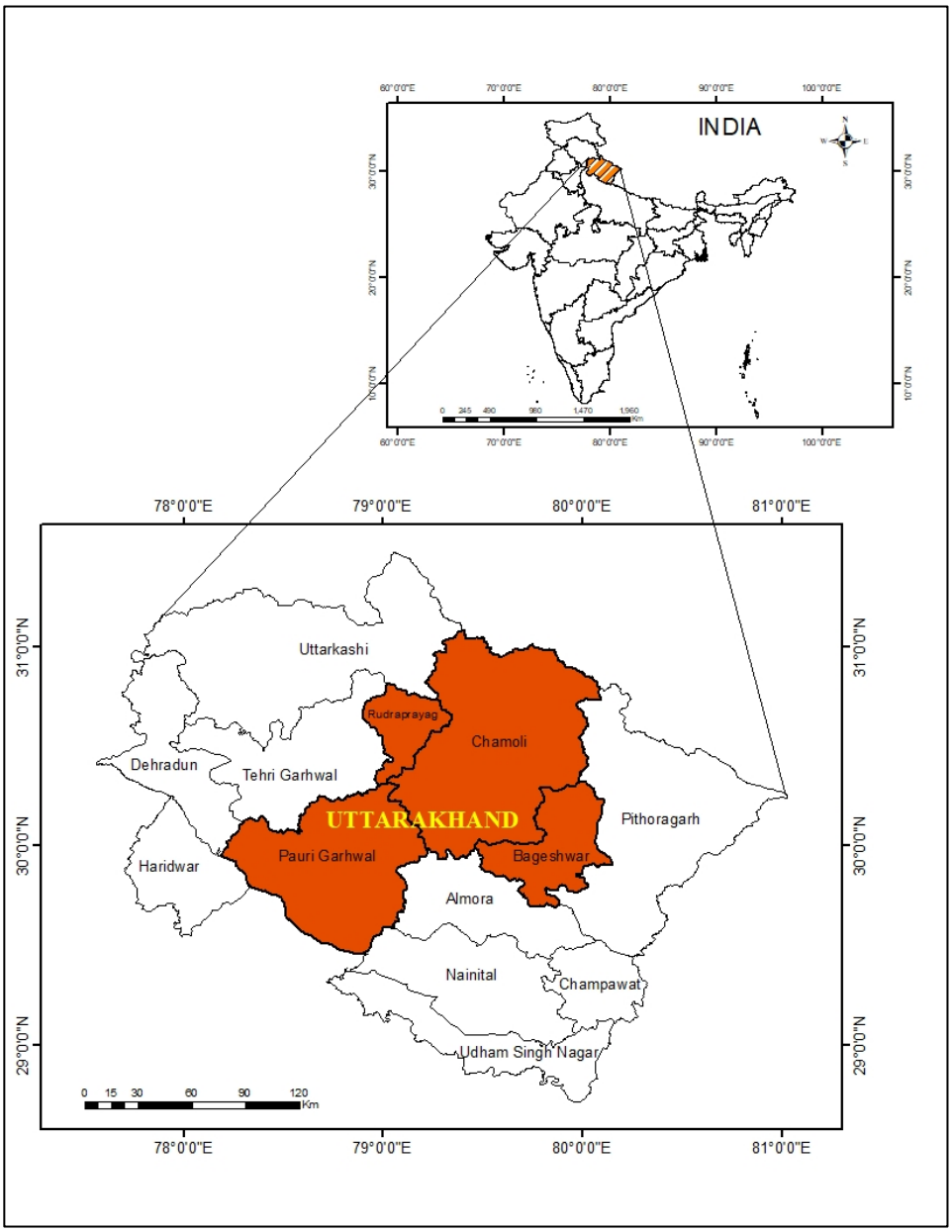

Figure 1. Location map of Uttarakhand state

2. Methodology

2.1 Data Collection

The evapotranspiration data of the four districts for year 2021 have been collected from India WRIS poral (wris.nrsc.gov.in) for a comparative study. High resolution cloud free Sentinel-2 satellite images of 2021 was used for mapping LULC classes of the four districts. The global thematic LC data was accessed and downloaded from Environmental Systems Research Institute, Redlands, California, USA (ESRI) database in the form of GeoTIFF files with Universal Transverse Mercator (UTM) data projection and WGS84 (World Geodetic System 84 coordinate system) mosaic projection. These

scenes tiles are derived from European Space Agency (ESA) Sentinel-2 satellite imagery with 10m resolution land use and land cover 2017-2021 time series dataset. All the images were downloaded from ESRI website. In addition to this, Survey of India, topographic map (1:50,000) was also used to obtain additional information about the area of interest.

2.2 Land-cover classification scheme

To prepare the LULC map from satellite imageries, a classification scheme which defines the LULC classes was considered. According to the requirement of a particular project different kinds of LULC classes are available to incorporate (Saha et al., 2005). For the present work of study, eight major LULC classes were chosen for mapping the entire watershed area viz; water bodies, trees, scrub/shrubs, agriculture, bare ground, snow, built-up area and grass as per the definitions specified in the ESRI database.

2.3 Satellite data and its processing

From the Uttarakhand administrative map, vector data as shapefiles of the four districts were clipped for processing, analysing and visualising the satellite data for quantitatively assessing the LULC pattern for the study area in the Aeronautical Reconnaissance Coverage Geographical Information System (ArcGIS). Identification and reclassification of the original data was then carried out on the basis of these eight major LULC categories. The attribute tables were then utilized to estimate the area (in km^2 and percentage) for the respective land cover areas. These tables were then exported in Microsoft Excel for statistical analysis. Thus, the hydrological data was coupled with thematic satellite images to have a comparative evaluation of changes in land use patterns in these four districts.

3. Results and Discussion

3.1 Land use and land cover classification

Multi-temporal LULC covering eight major classes: water bodies, trees, grass, snow cover, agriculture, scrub/shrubs, build-up area and bare ground of Bageshwar, Chamoli, Pauri Garhwal and Rudraprayag for 2021 are shown in Fig. 2. The spatial distribution pattern of LULC obtained by processing in the attribute tables for the four districts are registered in Table 1, 2, 3 and 4. Results from classified maps indicated that in 2021, area occupied by different classes viz; the percentage of land classes like trees, grass, scrub/shrubs collectively accounted for a total of 86.32%, 35.78%, 64.24% and about 48.68% for Bageshwar, Chamoli, Pauri Garhwal and Rudraprayag respectively, for the year 2021. The area covered by bare ground was obtained highest (about 14.74%) in Chamoli out of the all four districts.

Whereas, the percentage occupied by built-up area was found to be most prominent in case of Pauri Garhwal district. In case of agricultural land, Chamoli constituted an area of about 27.92%, Rudraprayag of about 35.61%; Pauri Garhwal of about 33.04%. In year 2021, the percentage of area covered by water bodies in all four districts remained more or less similar with about less than 2% of the total geographical area of each district, separately.

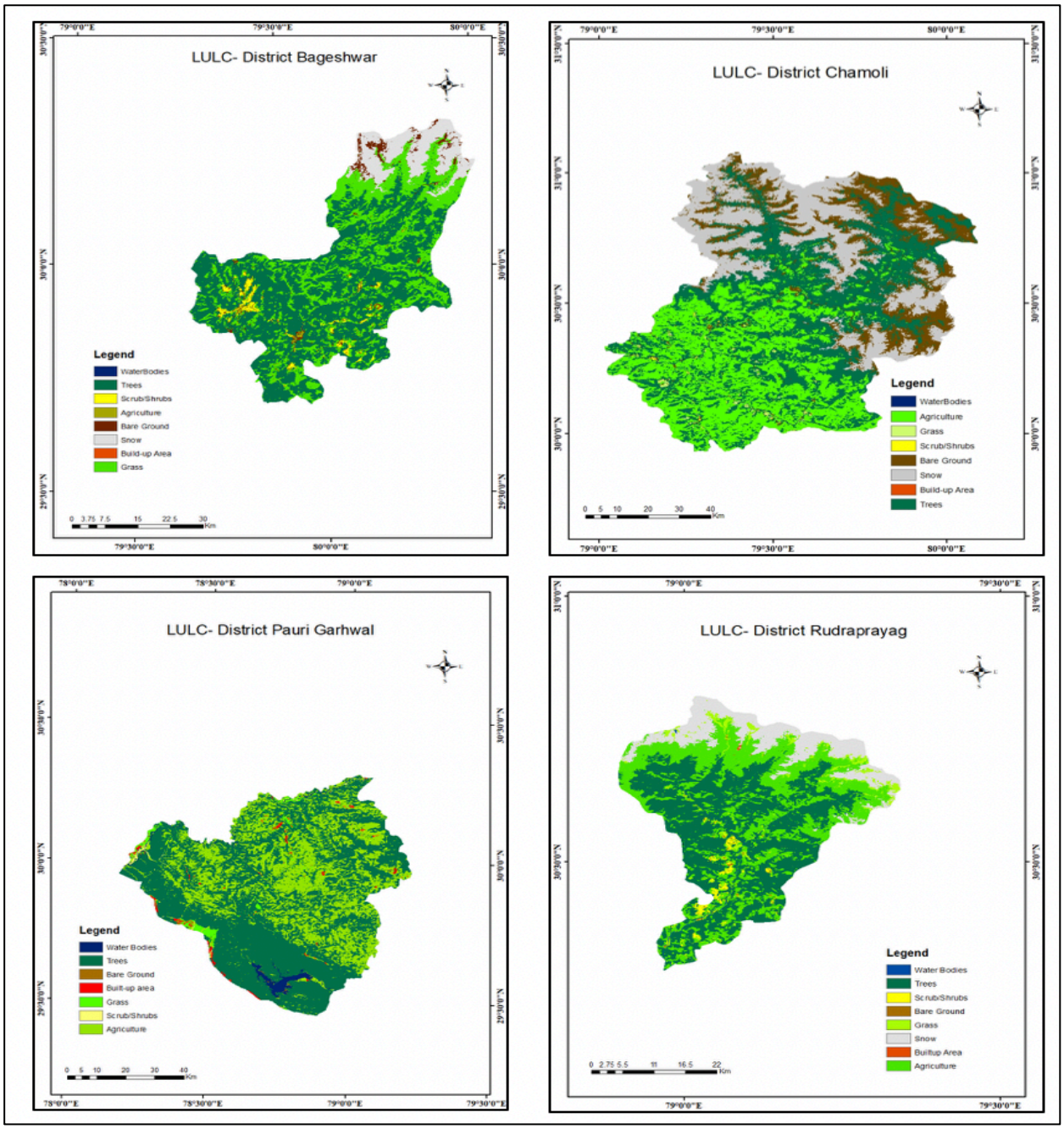

Figure 2. Land use land cover pattern in different categories during year 2021 for: Bageshwar, Chamoli, Pauri Garhwal and Rudraprayag

Table 1. Area covered under different land use in Bageshwar in year 2021

S. No.	Attributes	Area (km^2)	Area (%)
1.	Water Bodies	3.3161	0.145435
2.	Trees	1198.677	52.57055
3.	Scrub/Shrubs	35.3269	1.549336
4.	Agriculture	20.827	0.913412
5.	Bare Ground	60.4841	2.652659
6.	Snow	227.2613	9.967029
7.	Built-up Area	0.0071	0.000311
8.	Grass	734.2312	32.20127
9.	Total Area	2278.1307	100

Table 2. Area covered under different land use in Chamoli in year 2021

S. No.	Attributes	Area (km^2)	Area (%)
1.	Water Bodies	21.1479	0.266811
2.	Trees	2794.1703	35.252455
3.	Scrub/Shrubs	13.8043	0.174161
4.	Agriculture	2213.6884	27.928846
5.	Bare Ground	1168.5052	14.742365
6.	Snow	1685.9668	21.270883
7.	Built-up Area	0.2566	0.003237
8.	Grass	28.6327	0.361242
9.	Total Area	7926.1722	100

Table 3. Area covered under different land use in Pauri Garhwal in year 2021

S. No.	Attributes	Area (km^2)	Area (%)
1.	Water Bodies	96.9664	1.776707
2.	Trees	3365.594	61.66748
3.	Scrub/Shrubs	22.8871	0.419358
4.	Agriculture	1803.724	33.04948
5.	Bare Ground	1.741	0.0319
6.	Built-up Area	49.1205	0.900031
7.	Grass	117.6144	2.155039
8.	Total Area	5457.6474	100

Table 4. Area covered under different land use in Rudraprayag in year 2021

S. No.	Attributes	Area (km^2)	Area (%)
1.	Water Bodies	3.6666	0.302007
2.	Trees	525.5572	43.28852
3.	Scrub/Shrubs	13.4928	1.11136
4.	Agriculture	432.3308	35.60976
5.	Bare Ground	4.448	0.366368
6.	Snow	181.969	14.98822
7.	Built-up Area	0.5992	0.049354
8.	Grass	52.0161	4.284406
9.	Total Area	1214.0797	100

The district Chamoli, having the largest geographical expanse (about 7926.1722 km^2) out of the four districts, constituted of about 27.92% share from agricultural land; bare land covered about 14.74% (most prominent in terms of all districts under the year of study); and area covered under trees was found to be 35.25% (lowest in terms of all districts under the year of study). The values are indicated in Tables 1-4.

3.2 Evapotranspiration data

The daily time series data of evaporation for the four districts, namely, Bageshwar, Chamoli, Pauri Garhwal and Rudraprayag is shown in the figure below (Fig. 3.). The results of the study entail that, mean daily and mean monthly evapotranspiration recorded in Bageshwar for the year 2021 were 2.03 mm/day and 61.44 mm/month. Similarly, for Chamoli were 11.16 mm/day and 48.89 mm/month, for

Pauri Garhwal were 1.95 mm/day and 59.05 mm/month and for Rudraprayag were 1.98 mm/day and 59.90 mm/month. The maximum monthly evapotranspiration for Bageshwar was recorded 110.19 mm in month of July 2021, for Chamoli 86.75 mm in May, for Pauri Garhwal 120.84 mm in August and For Rudraprayag 107.34 mm in May.

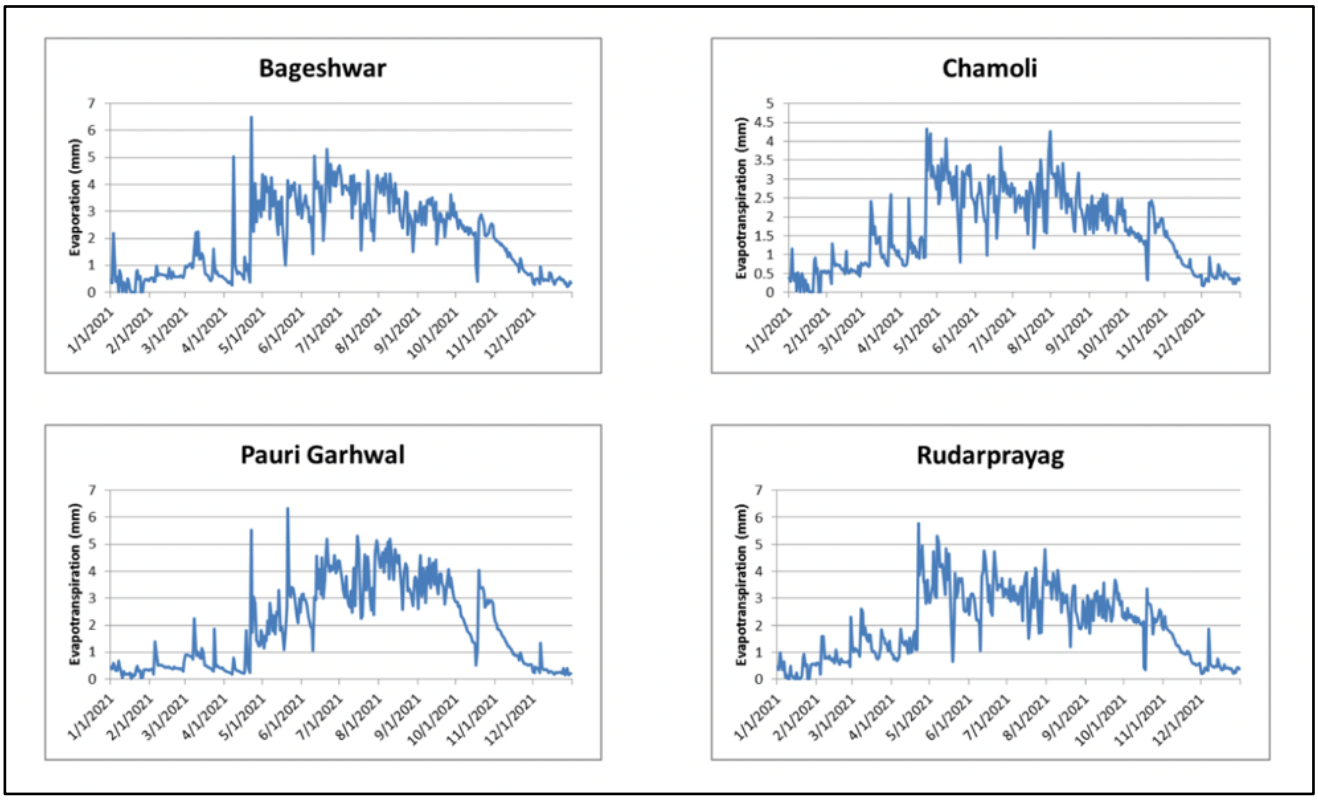

Figure 3. Time series data of evapotranspiration for 2021 for Bageshwar, Chamoli, Pauri Garhwal and Rudraprayag

Table 5. Mean daily and monthly evapotranspiration

S. No.	District	Daily mean (mm/day)	Monthly Mean (mm/month)
1.	Bageshwar	2.031267218	61.44333333
2.	Chamoli	1.616363636	48.89333333
3.	Pauri Garhwal	1.952121212	59.05416667
4.	Rudraprayag	1.980055096	59.89833333

3.3 Relationship between LULC classification and variation in evapotranspiration

The LULC classification of the area plays a vital role in hydrology of that area. Fig. 4. shows the comparison of the evapotranspiration in the four districts of the study area in 2021. The aggregate evapotranspiration in Chamoli was the lowest among these districts with 586.71 mm while the area of Chamoli is the highest with 7926 km^2. While the other three districts, Bageshwar, Pauri Garhwal and Rudraprayag, with significantly lesser area, that is, 2278 km^2, 5457 km^2 and 1214 km^2 had evapotranspiration 737.33 mm, 708.64 mm and 718.79 mm respectively.

With climatic conditions almost identical and the districts belonging to hilly terrain, the only factor that would explain this anomaly is the variation in land use land cover classification. The percent area covered under trees/forest in Chamoli is the lowest with 35.25% of the total area while the bare land

accounts for 14.74% of the area, that is, 1168.50 km^2 of its total geographical area. This bare ground area can be the land cleared for construction purpose or waste land, both the cases it will affect evapotranspiration. On the hand, the area percent under trees in other three districts are more with 52.57%, 61.67% and 43.29% in Bageshwar, Pauri Garhwal and Rudraprayag respectively and bare ground is comparatively very less as compared to Chamoli in former districts with the percentage area being 2.65%, 0.032% and 0.36% respectively.

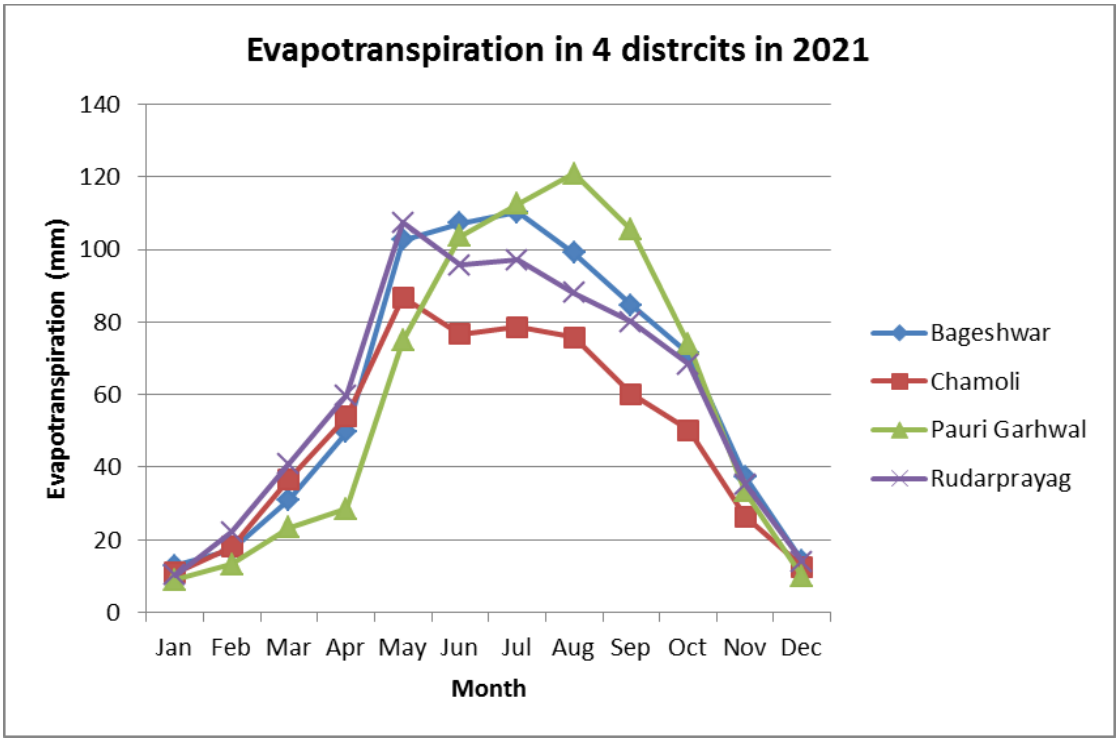

Figure 4. Monthly variations in evapotranspiration in four districts for the year 2021

Table 6. Annual evapotranspiration (in mm) in the four districts for the year 2021

S. No.	District	Evapotranspiration (in mm)
1.	Bageshwar	737.33
2.	Chamoli	586.71
3.	Pauri Garhwal	708.64
4.	Rudraprayag	718.79

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