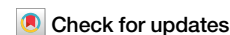


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Diverse wildfire impacts on river flows across the globe



Manolis Grillakis^{1,2} & Apostolos Voulgarakis^{1,2,3}

Forest fires can significantly impact the hydrological regime of river basins, affecting short-term flood propensity and long-term water resource availability until vegetation is reestablished. While basin-level studies have extensively investigated these impacts, regional and global-scale assessments remain limited. Here we use a comprehensive global dataset of river discharge observations to systematically assess the hydrological response to wildfires for a range of hydrologically homogenous world regions and biomes. Our analysis reveals contrasting hydrological impacts by region, with high-latitude discharge ratios declining by 7.5% and 16% in the first and second year after wildfire, respectively, while Northern mid-latitude regions showing a marginal 3.3% median increase in discharge ratio the first-year post-fire. Sub-tropical and equatorial regions display negative and positive effects, respectively. We further discuss how potential ecological and hydroclimatic factors, along with human river and watershed management, shape these diverse hydrological responses per hydroclimatic region.

Wildfires disturb the land cover of a region, at least temporarily, given that an ecosystem can usually recover through its ecological memory¹. Wildfire-driven land cover and soil property changes alter major water fluxes, ultimately affecting river discharge. In the first few months following a wildfire, deposited ash on the soil and soil hyper-drying caused by intense heat¹ can induce temporary water repellency², reducing soil infiltration capacity³. Those factors can increase concentration time and water volume, potentially triggering flash floods, soil erosion⁴, sedimentation, degradation of river habitats⁵, networks, or coastlines⁶. Over months to years, the partly or entirely destroyed vegetation as well as its regrowth, alter soil depth and structure, rainfall interception and evapotranspiration^{7,8}, ultimately modifying river discharge⁷. From a water resources perspective, changes have been shown to increase runoff by up to 30%, for as long as 6 years after the wildfire event⁹ in the water-limited Western US. However, these effects may vary significantly in magnitude and direction across different climatic zones. For example, in boreal regions, wildfire heat and increased solar forcing from reduced canopy shade can increase the hydrologically active layer depth, altering flow paths and hydrological fluxes. These changes often decrease river discharge^{10–12} that may need several years to return to pre-fire conditions^{10–12}. These effects are more pronounced when forest fires are accompanied by smoldering ground fire¹³. However, a study in the boreal catchment in Alaska found that burning increases flow connectivity and enhances soil drainage¹⁴. In contrast, studies in temperate regions have shown that fire activity can reduce flow, likely due to increased vegetation growth and enhanced evapotranspiration¹⁵.

Quantifying the wildfire-induced hydrological impacts is challenging, since post-fire weather variability can largely obscure any potential fire-related effects on the hydrological regime¹⁶. Additionally, direct human interventions affecting river flows like dam construction alter the global flux of water from continents to oceans¹⁷ and hence the potential signal of the wildfire effect. Most commonly, changes in the hydrological regime are quantified using hydrological models that simulate the discharge of the affected region, with and without wildfire effects on vegetation and water flux dynamics^{18,19}. Alternatively, these impacts can be estimated using parsimonious regression approaches to assess the counterfactual hydrological response in the absence of a wildfire^{9,15}. A key challenge for large-scale comparative studies is the limited data on wildfire extent and severity. Although remotely sensed data have been available since the early 1980s, near-global coverage with reliable meta-data such as burned land cover types has only been consistently available since 2001.

With recent increases in wildfire-burned areas globally^{20,21}, and projections of increased wildfire danger²², understanding wildfire impacts on water resources is increasingly important for both water management and eco-environmental perspectives. Advancing this understanding can enhance prognostic tools such as hydrological and land surface models. This study contributes by systematically assessing the effects of forest fires on the basin-scale discharge ratio, which is the fraction of the precipitation water that leaves the watershed. We use remotely sensed burned area data for forest land cover types between 2001 and 2018 from Collection 6 MODIS²³

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and observed river discharge data from Global Streamflow Indices and Metadata (GSIM)²⁴.

Results

The effect of the largest wildfire event in terms of Burned Area on the discharge ratio for the first year after the wildfire is shown in Fig. 1. We analyzed only watersheds with at least 5% of their area being burned (average burned area equals 11.6%—for burned area distribution also see Fig. S1). The comparison is performed against a counterfactual discharge ratio estimated for the years after the wildfire with multiple linear regression, using as predictors the annual total precipitation, mean temperature, and mean potential evapotranspiration at a watershed level (see “Methods”).

Results show a general decrease in the discharge ratio in northern high latitudes (mainly of Canada) and a general increase in the temperate zone (mainly the USA territories). The subtropical regions (represented mainly by the southern Amazon region and India) tend to exhibit a decrease in discharge ratio, while African tropics exhibit an increase (based, however, on a small sample of basins).

By aggregating results across contiguous regions with uniform hydrological and thermal patterns, referred to as hydrobelts²⁵, we identify consistent changes primarily within the first years following the wildfire events. Figure 2 presents an area-weighted annual average difference between the observed discharge ratio and its counterfactual estimate. In high latitude regions such as Canada and Sweden, the median discharge ratio shows an estimated decrease of -7.5% . In the second year, the variability in the change increases, but also the median change becomes even more negative (-16%). In the third year, the majority of the basins exhibit an increase, with a median of 6.5% .

The northern mid-latitude watersheds (mostly US and Iberian Peninsula) exhibit a 3.3% increase in the median in the first year after the fire, and similarly for the second and third post-fire year. Dry regions (mainly southwest/central US) exhibit a significant increase in the variability towards positive and negative values, with an almost zero median in the first year. In the second and third year the changes become positive. Equatorial regions (mainly the Amazon, the Congo basin, the west Indian coast) exhibit

a strong increase in the discharge ratio in the year after the wildfire, while it was found to become negative in subsequent years. Northern subtropical areas (mainly India, southeastern US, Niger basin), tend to exhibit a negative effect of -5.8% . The southern subtropics (mainly southeast Brazil) exhibit a similar pattern to the northern subtropics, with a median decrease in the discharge ratio. For the subtropics, this decrease is attributed to an immediate decrease in actual evapotranspiration in response to wildfire, (5% reduction in median for Northern subtropics, 18% reduction for southern subtropics), followed by a subsequent increase over the next nine months (averaging 11.7% and 4.7% for Northern and Southern subtropical regions, respectively) (see Methods). For all regions, the directions of change are confirmed by a sensitivity analysis between burned area and discharge ratio—see Methods.

The size of wildfires is influenced by various factors, including the meteorological conditions during the time of the wildfire itself. However, it is also important to analyze the antecedent weather conditions. Here we focus on precipitation, temperature, and potential evapotranspiration (Fig. 3). It is shown that, across all regions, the year preceding a major wildfire event typically experiences a negative precipitation anomaly. This anomaly varies across watersheds with a median reduction of -3% in northern mid-latitudes and -14% in northern dry regions, making precipitation the most consistent climatological driver amongst those tested. Notably, the median reduction is statistically significant (at a 95% significance level) for the boreal, northern dry, and north subtropical regions. In addition, most Northern Hemisphere regions show a reduction in precipitation also for the second year prior to wildfire. On the other hand, in the first year before the wildfire, temperature and potential evapotranspiration were found to be higher compared to the climatological values for the boreal regions ($+0.28^\circ\text{C}$, $+2\%$), northern mid-latitudes ($+0.05^\circ\text{C}$, $+2\%$), northern dry ($+0.09^\circ\text{C}$, $+6\%$) and subtropics ($+0.12^\circ\text{C}$, $+11\%$) (medians not significant in the 95% confidence interval).

To investigate how post-wildfire discharge ratios are influenced by meteorological drivers, we conducted a main effects analysis for the discharge ratio changes in the first year after the wildfire. The drivers examined include the 2001–2018 averages of precipitation, potential

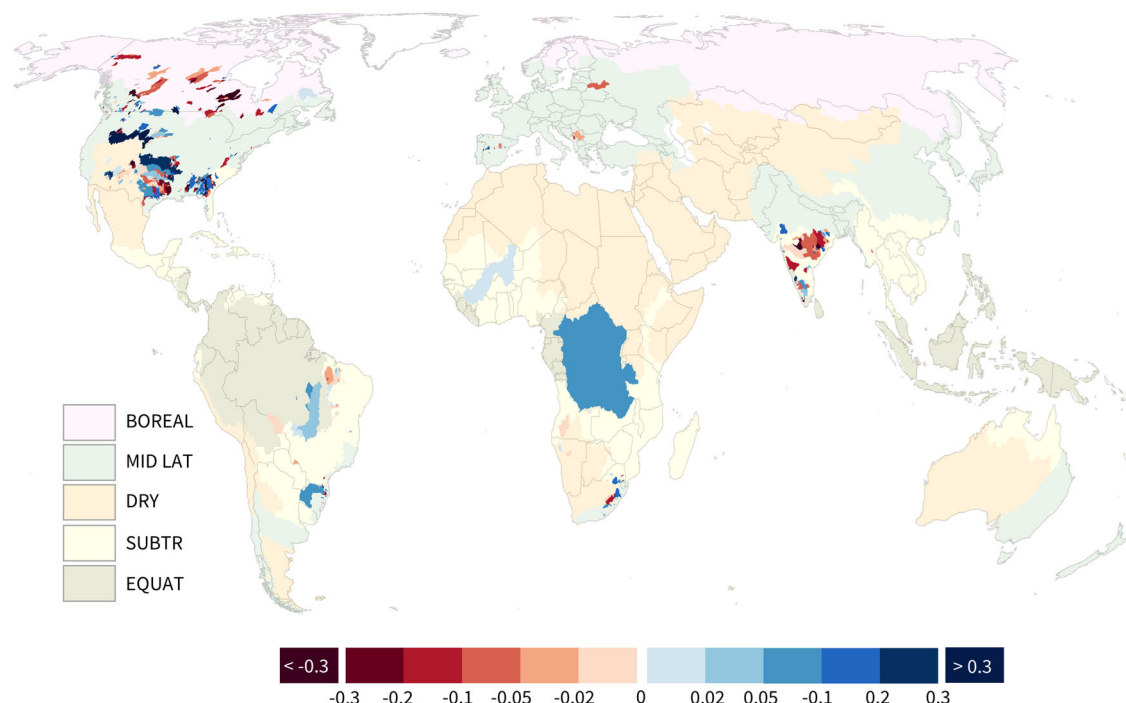


Fig. 1 | Changes in the discharge ratio for the 1st year after a large wildfire, for watersheds with sufficient data availability. Red to blue colors denote the degree of change in the discharge ratio. The background colors indicate the broad hydrobelts

defined for our study: BOREAL for boreal, MID LAT for mid-latitudes, DRY for dry regions, SUBTR for sub-tropical regions and EQUAT for equatorial regions. MID LAT, SUBTR, and DRY regions exist both in the north and south hemispheres.

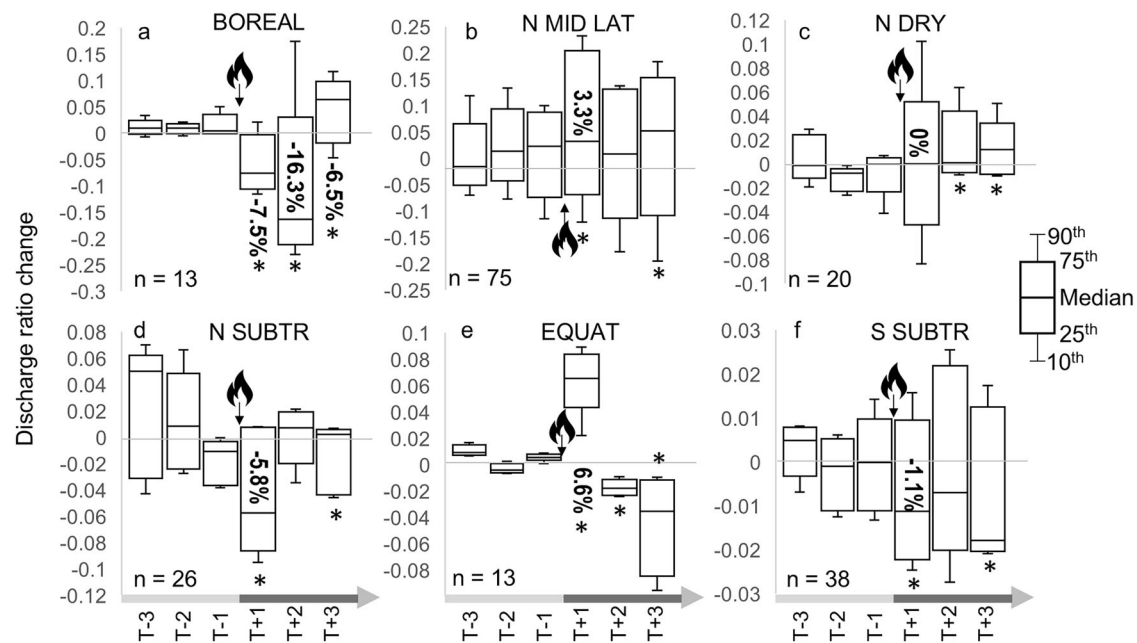


Fig. 2 | Area-weighted annual average discharge ratio changes due to wildfires for the 6 hydrobelts (defined in Fig. 1), for three years before and three years after the largest observed wildfire in each watershed contained within each hydrobelt. The boxes represent 50% of the data (interquartile range), whiskers represent the 10th and 90th percentiles, and the horizontal line represents the median value. The value of n represents the sample size (number of watersheds) analyzed in each region.

Information about the area weighting is provided in the Methods section. The asterisk denotes post-fire distribution with a different median compared to the 3-year pre-fire period, according to the Wilcoxon rank-sum test ($\alpha = 0.05$), see Methods. Panels **a–f** refer to the different hydrobelts: **a** boreal, **b** mid-latitudes, **c** north dry regions, **d** north sub-tropical regions, **e** equatorial regions, and **f** for south sub-tropical regions.

evapotranspiration, air temperature, topsoil temperature, and discharge ratio. In addition, the meteorological drivers of the year preceding the wildfire event and the burned area fraction were examined. The results are shown in Fig. 4. The effect of burned area fraction (BA) varies across different hydrobelts, agreeing with the findings discussed earlier, with the exception of a negative effect for the northern dry regions. Notably, high climatological discharge ratios exhibit an opposite effect on the discharge ratio after the wildfire compared to the effect of BA. Climatological precipitation exerts a negative influence in all regions, except for the subtropics. In contrast, potential evapotranspiration (PET) has a positive effect in all regions, excluding the subtropics. Temperature negatively impacts most regions, with exceptions in the mid-latitudes and dry regions. Regarding the meteorological factors in the year prior to the wildfire, precipitation anomaly seems to mainly affect the northern mid-latitudes, northern dry regions, and northern subtropics. Conversely, a PET anomaly in the year before wildfire has a positive effect in the boreal and north sub-tropical regions but a negative effect in the northern dry region, equatorial region, and southern subtropics. Temperature anomaly in the year before wildfire negatively impacts the boreal region and has a positive effect on the southern subtropics and northern dry regions. It is worth noting that most of those effects are not statistically significant at a 95% confidence interval. Burn severity is shown to have the same sign of effect with the burned area fraction, except for Boreal regions, where the signal is opposite, i.e., the severity has a positive effect on the discharge ratio, however, with a greatly limited sample of 5 boreal watersheds with available data for burn severity. Regarding the region-specific parameters, in the boreal region, soil temperature is found to have a positive effect on the discharge ratio change. This indicates that lower upper-layer soil temperatures that reflect a higher presence of permafrost are linked to a more pronounced reduction in the discharge ratio after a wildfire. For the northern mid-latitudes, it is also shown that within each watershed, dams' capacity exhibits a negative effect on the post-wildfire discharge ratio change, estimated at -0.1% per 1000 Mm^3 of water stored. The same result is drawn when analyzing the percentage of the watershed being irrigated, as a proxy for the management/

regulation intensity of the water resources (estimated effect -0.1% for a 12.8% increase in the irrigated area fraction). The watershed impoundment ratio²⁶ was also considered, but no signal was detected. Dam capacity could not be considered for other regions since the number of watersheds considered in the analysis with any dam capacity available was limited (see “Methods”). The watersheds' irrigated fraction was analyzed only for the northern mid-latitudes, similarly to the dam capacity.

Discussion

The assessment of forest wildfire effects on runoff is challenging due to the dominant influence of weather in driving flow variability. This study aimed to comprehensively quantify the watershed hydrological responses to wildfires across diverse hydroclimatic regimes, identify differences in the direction of change, and delve into the underlying mechanisms that drive those changes. Analysis of wildfire events from 2001 to 2018 revealed that all cases were preceded by at least one year of precipitation deficit, accompanied usually by a warmer-than-usual year and larger potential evapotranspiration rates. In boreal regions, wildfires appear to reduce discharge ratios, a pattern that contrasts with the observed increase in runoff following forest disturbances, typically observed under long-term permafrost thawing conditions^{27–29}. This phenomenon is likely linked to enhanced water retention in the thawed soil, as increased connectivity between surface water and groundwater alters post-fire hydrological pathways³⁰. The role of permafrost dynamics is critical here, as lower upper-layer soil temperatures—indicating permafrost presence—are associated with stronger declines in discharge, consistent with findings from Hou et al.¹¹ and Li et al.¹². While previous studies have suggested that permafrost thawing can lead to higher runoff in the long term^{27–29}, our findings emphasize a different mechanism, in which soil moisture retention increases after a wildfire, leading to short-term reductions in streamflow. The duration of this response in this study remains uncertain, as long-term observational studies indicate that soil temperature disturbances may persist for years or even decades^{11,12}. The mechanism behind reduced discharge following wildfire has been proposed before³¹, but supported by limited observational data. In the

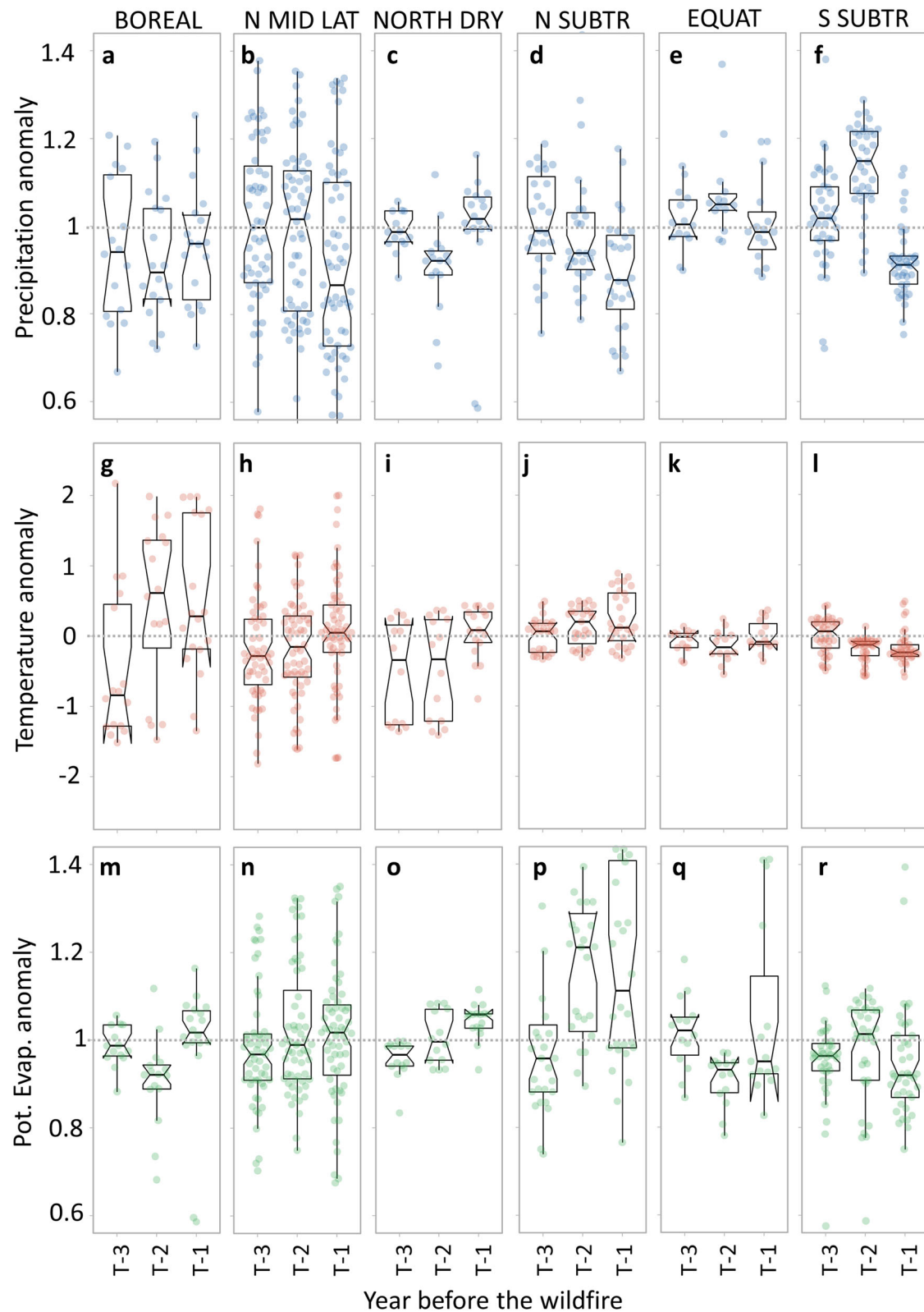


Fig. 3 | Mean annual meteorological anomalies for the 3 years preceding each watershed's largest wildfire. Boxplots of the anomalies (ratio with respect to the 2001–2018 climatology) of mean annual meteorological forcings for 3 years before the largest wildfire event observed in each watershed, for precipitation (upper, panels a–f), temperature (mid, panels g–l) and potential evapotranspiration (lower, panels m–r), for the six regions studied (boreal—panels a, g, m, northern mid-latitude—panels

b, h, n, northern dry—panels c, i, o, north subtropics—panels d, j, p, equatorial—panels e, k, q, and south subtropics—panels f, l, r). The boxes represent the IQR, whiskers show the range of values that are within 1.5*IQR, and the horizontal line denotes the median. The notches represent the 95% confidence interval (approximated by $1.58 \cdot \text{IQR} / \sqrt{n}$) of the median value²⁶.

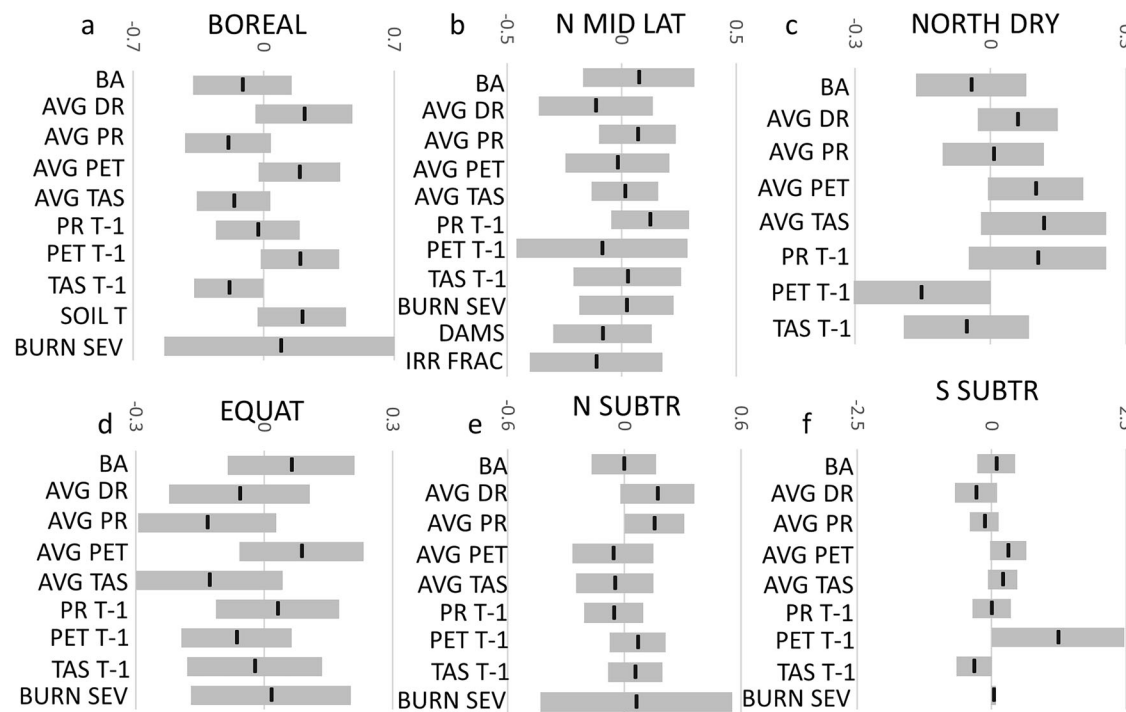


Fig. 4 | Main effects (black lines) and the 95% confidence range (gray stripes, 2-sided test) for the discharge ratio of the first year after the wildfire. The effects are estimated individually for the following driver variables: fraction of the burned area relative to the total watershed area (BA), climatological average discharge ratio (AVG DR), precipitation (AVG PR), potential evapotranspiration (AVG PET), temperature above surface (AVG TAS), precipitation anomaly the year before the wildfire (PR T-1), potential evapotranspiration anomaly (PET T-1), temperature anomaly (TAS T-1) and burn severity (BURN SEV). For the North Dry regions, burn severity was not available for the analyzed events/watersheds. For the boreal region,

the climatological average upper soil temperature (SOIL T) was analyzed, and for northern mid latitudes, the dam capacity (DAMS) and the fraction of watershed being irrigated (IRR FRAC). The horizontal axes represent the estimated effect magnitude. The confidence intervals are estimated using the *t*-statistic for each variable to test the null hypothesis that the corresponding effect is zero against the alternative that it is different from zero. *P*-values are provided in the Supplementary Information. Panels a–f refer to the different hydrobelts: a boreal, b mid-latitudes, c north dry regions, d north sub-tropical regions, e equatorial regions, and f for south sub-tropical regions.

northern mid-latitudes, wildfire impacts on discharge are characterized by increased variability rather than a uniform directional change. While the median discharge ratio exhibits a modest increase, consistent with the well-established mechanism of reduced water transpiration and percolation following a wildfire^{10–12}, greater variability above the median suggests that post-fire hydrological responses are highly heterogeneous. To this end, the role of watershed management was explored in the regions of continental USA and Western Europe that are characterized by a very high degree of regulation^{32,33} (see “Methods”). Dam capacity per watershed and the fraction of irrigated land within a watershed both show a tendency to mitigate post-wildfire increases in discharge, though their effects are not statistically significant, while the impoundment ratio²⁶ does not exhibit a clear influence. These findings align with the broader literature on the role of reservoirs and irrigation infrastructure in buffering hydrological changes^{34,35}, suggesting that water management may dampen the immediate impacts of wildfires on river flow. Similarly, in the northern dry regions, the analysis reveals increased variability in discharge ratio, both positive and negative, during the first year after a wildfire, with a predominantly positive trend persisting into the second and third years. This suggests that wildfires may have a net positive impact on the discharge ratio. This is in line with the findings of Biederman et al.³⁶ that detected contrasting streamflow responses to wildfire, affected by elevation and season, for two watersheds in the Lower Colorado River Basin. In the equatorial zone, wildfires are associated with a significant increase in the discharge ratio, a pattern that contrasts with the subtropical response. In subtropical watersheds, particularly those in the Indian subcontinent and South America, wildfires tend to reduce discharge in the first year after a wildfire. For the Northern Hemisphere, this change is found to be more pronounced. However, it seems to affect only the first year after the wildfire. This immediate response is attributed to a combination of

impaired infiltration due to fire-induced soil hydrophobicity and the increase in evaporative demand after a 3-month lag, due to the abrupt increase in vegetation growth¹⁵. In summary, this global analysis provides comprehensive insights into the effects of forest wildfires on runoff across diverse hydroclimatic settings. The results align with the existing body of literature, which highlights distinct mechanisms and outcomes in different regions and emphasizes the complex interplay between climatic and non-climatic factors in post-wildfire runoff dynamics. Moreover, indications of anthropogenic influence on the wildfire–discharge response are provided, demonstrating that water damming—and water management more broadly—may mitigate the wildfire-induced increase in discharge ratio in mid-latitude regions. One of the incentives of this study is to aid the validation of processes in land surface models that integrate hydrological and wildfire dynamics. It also paves the way for global studies that involve the integration of information that derives from field measurements and from remote sensing, to enhance the understanding of complex mechanisms of wildfire effects across diverse environmental conditions. In this context, this study provides multi-source indicators of the mechanisms affecting discharge ratio change—primarily in the first three years after a wildfire—rather than robust predictive relationships, due to the dominating role of large uncertainty sources. A major source of uncertainty lies in the fact that we designated the largest observed wildfire event (in terms of burned area fraction) as the representative wildfire event for which we performed the analysis, while other significant wildfire events may have been overlooked, or considered as a climatology period, which might lead to a diminution of the estimated wildfire effect on discharge. Another significant source of uncertainty is the formulation of the counterfactual discharge ratio (see “Methods”). Furthermore, some regions are underrepresented or unrepresented in the analysis, mostly due to the availability of discharge data during the period of

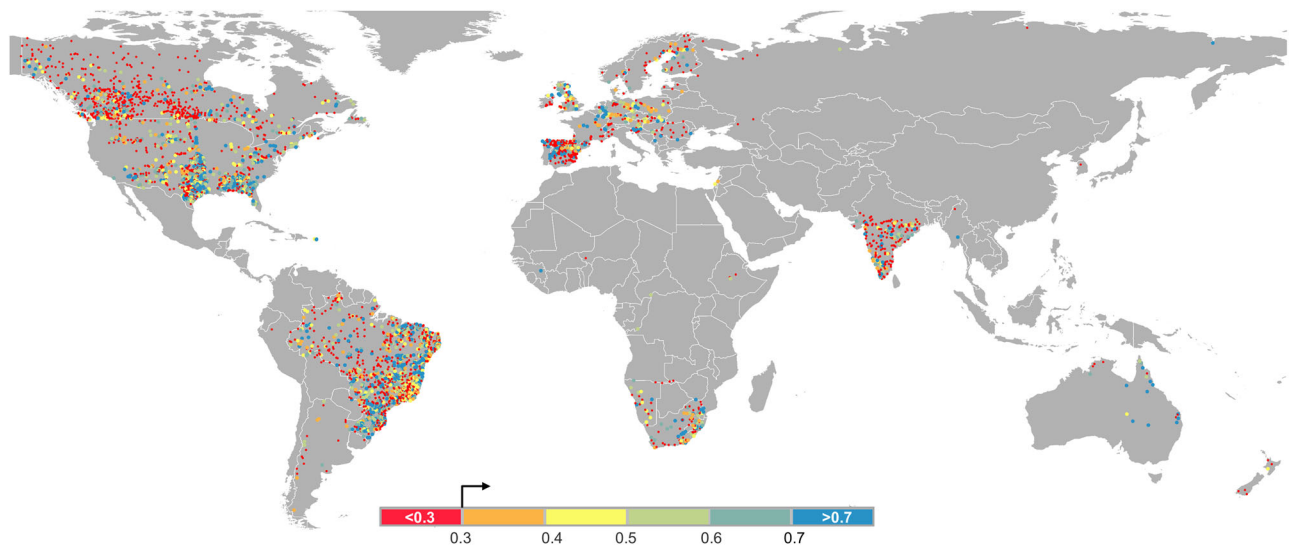


Fig. 5 | Coefficient of determination for the trained discharge ratio model at a watershed scale. The Coefficient of Determination (R^2) of observed and estimated discharge ratios for the training period based on Equation 1. Each dot represent one watershed where the regression model was trained.

the analysis. Additionally, wildfire effects on the discharge can be modified by fire-induced changes in geomorphology due to debris flows^{37,38}, or even channel routing, overbank flooding, flood wave attenuation, and the degree to which convective precipitation events within large watersheds coincide with burned areas. Moreover, uncertainties in precipitation estimates and discharge measurements may affect the accuracy of discharge ratio changes. Finally, the analysis of the watershed management mitigation of discharge ratio changes provides an indication of the effect, however, this finding is based on a limited sample and in a limited region and should therefore be interpreted with caution.

Methods

Data

The 2001–2018 burned area data from Collection 6 MODIS (MCD64CMQ)²³ were used. This data is available at a 0.25° spatial resolution and a monthly time step. Only forest-burned areas (i.e., evergreen and deciduous, needleleaf and broadleaf forests, as well as mixed forests) were considered for the analysis. Precipitation data were obtained from MSWEP³⁹ (V2.8). This precipitation product was selected as it merges gauge, satellite, and reanalysis data to obtain precipitation estimates at a 0.1° resolution. Temperature, potential and actual evapotranspiration, and soil temperature data were obtained from the ERA5 dataset⁴⁰ (source: Copernicus CDS). The observed flow data were obtained from various sources, which are USGS data for the United States⁴¹, GRDC, Environment Canada⁴² and Camels BR⁴³, as well as the Global Streamflow Indices and Metadata (GSIM) database²⁴. The GSIM archive provides a wide range of time series at a monthly time resolution, which were computed from daily average values after an automated quality control (i.e., detection of outliers that were set to missing prior to computation). Watershed boundaries were also obtained from the GSIM database²⁴.

Counterfactual discharge ratio estimation

The discharge ratio was estimated at the watershed level using the watershed monthly average precipitation from MSWEP³⁹ and the observed flow data. The discharge ratio for all the available years between 2001 and 2018, before the wildfire event and for 3 years after it, was used as a predictant to train multiple linear regression equations at a watershed level, using as predictors precipitation, temperature, and potential evapotranspiration (Eq. 1). A threshold of at least 6 years of available data was used.

$$DC_{\text{counterfactual}} = \alpha + \beta * TAS + \gamma * PR + \delta * PET \quad (1)$$

In Eq. 1, α , β , γ , δ are the regression coefficients, TAS is the mean annual temperature, PR is the total annual precipitation, and PET is the mean annual potential evapotranspiration. The integration period for the climate variables to annual was defined by the timing of the wildfire event. The calibration objective function was the Coefficient of Determination. The estimated discharge ratio for the training years is compared to that estimated using the observed data. The Coefficient of determination is shown in Fig. 5. Watersheds with a Coefficient of determination less than 0.35 were excluded from further analysis.

Weighted percentiles in Fig. 2 are computed by assigning each value the weight of the corresponding watershed area. This approach considers each value to be repeated a number of times equal to its weight, enabling the calculation of percentiles based on this weighted distribution⁴⁴. This was implemented by Matlab code of Durga Lal Shrestha (2024), retrieved from MATLAB Central File Exchange (<https://www.mathworks.com/matlabcentral/fileexchange/16920-returns-weighted-percentiles-of-a-sample-accessed-13/10/2023>). The Wilcoxon rank-sum test (also known as the Mann–Whitney U test) presented in Fig. 2 was performed for each individual post-fire year, against the 3-year pre-fire period, combined.

Discharge data

The discharge data were available for a total number of 5353 watersheds. Of those, 7.5% exhibited a burned area larger or equal to 5% between 2001 and 2018, and simultaneously, discharge data were available for at least 6 years within 2001–2018 with a maximum 3% of missing observed discharge data. The 5% threshold for the fraction of drainage area being burned was chosen considering the existing literature^{9,16,45–48}, that suggests detectable streamflow changes from a similar (6%) burned area fraction. This threshold was lowered to increase the number of basins that were included in our analysis. Beyond 5%, the number of basins that comply with the criteria reduces drastically (see Fig. 6—histogram).

Main effects analysis parameters selection

The main effects analysis was performed in order to examine, in parallel to the BA, other potentially affecting parameters of the discharge ratio. The set of variables is a combination of the major meteorological parameters that affect the hydrology of a region (precipitation, temperature and potential evapotranspiration), both as an average climatology (AVG PR, AVG TAS, AVG PET), as well as the year just before the major wildfire event (PR T-1, TAS T-1, PER T-1). Added to those, we analyze the climatological value of the discharge ratio (AVG DR), as a measure of the importance of the watershed's hydrological regime. We analyze burn severity (where available)

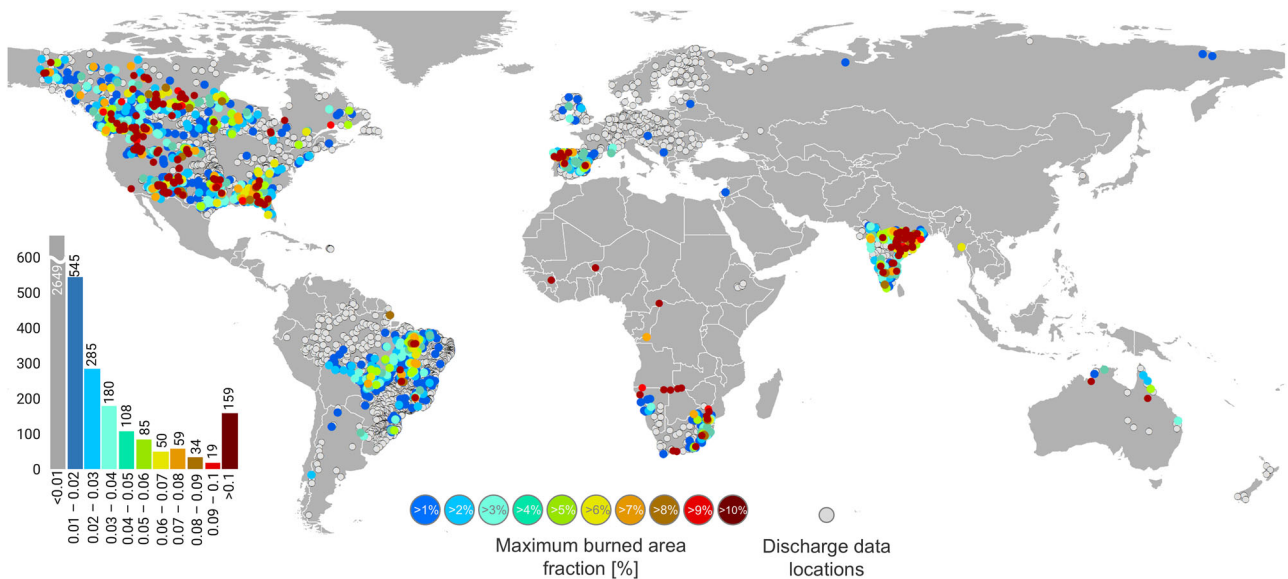


Fig. 6 | Burned area per watershed and histogram of their distribution. Maximum burned area observed per watershed, as it is reported at the watersheds' discharge gauging locations. At the bottom left corner, a histogram of the number of watersheds per burned area fraction is provided.

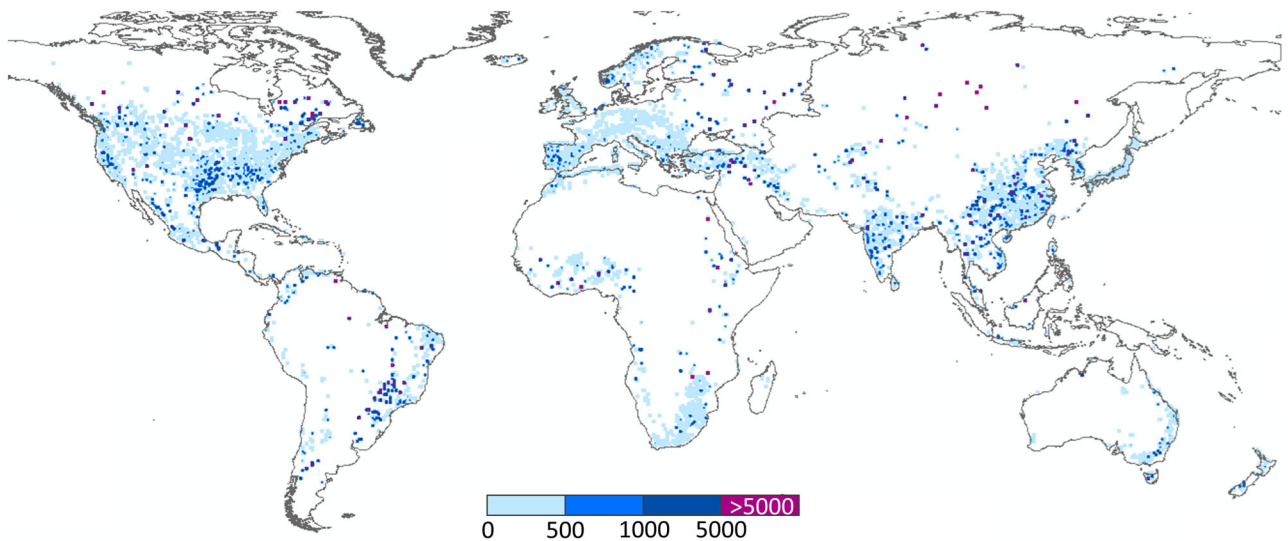


Fig. 7 | Dam capacity in mm^3 . Gridded distribution of total dam storage capacity (Mm^3) at 0.5° resolution, based on ISIMIP dam data. Dam capacities were summed within each 0.5° grid cell.

as an affecting variable since it has been found to affect the hydrological changes in wildfire events⁴⁹. Region-specific parameter selection is discussed in the main text.

Dam capacity

The level of river regulation at a watershed level was quantified by the total combined storage capacity in water dams³³. The data were obtained from the ISIMIP repository⁵⁰. The dam capacity was summed at a 0.5° resolution grid (360×720), to form the Fig. 7 gridded dataset. Figure 7 shows the capacity of dams in mm^3 at a spatial resolution of 0.5° . The number of dams for each hydrobelt analyzed is 3, 31, 6, 2, 4, 10, for boreal, mid-latitudes, dry regions, northern subtropics, equatorial regions, and southern subtropics, respectively. To investigate the potential influence of water regulation on post-fire hydrological response, changes in discharge ratio during the year following the wildfire event were compared against dam-related metrics (Fig. 8). These included (a) the total dam capacity in the affected watershed (mm^3), (b) the dam capacity normalized by watershed area (mm^3/km^2), (c) the dam capacity per km^2 multiplied by average watershed precipitation (mm), (d)

the dam capacity relative to average annual discharge volume, and (e) the fraction of irrigated area in watersheds with at least 1% irrigation coverage (see Fig. 9). Watersheds with dam capacities between 0 and 800 mm^3 were considered. The negative correlations observed were weak and statistically insignificant, with p -values of 0.44, 0.68, 0.56, 0.96, and 0.43 for cases (a) through (e), respectively.

Irrigated fraction

The percentage of irrigation area per watershed was estimated based on the Global Map of Irrigation Areas—version 5.0⁵¹. This dataset shows the fraction of area equipped for irrigation around the year 2005 as a percentage of the total area. The gridded data was aggregated at a watershed level by averaging the values within the watershed.

Burn severity

We use the global burn severity database—MOSEV⁵², which is based on Moderate Resolution Imaging Spectroradiometer (MODIS) surface reflectance and burned area (BA) products from November 2000 to 2020. This

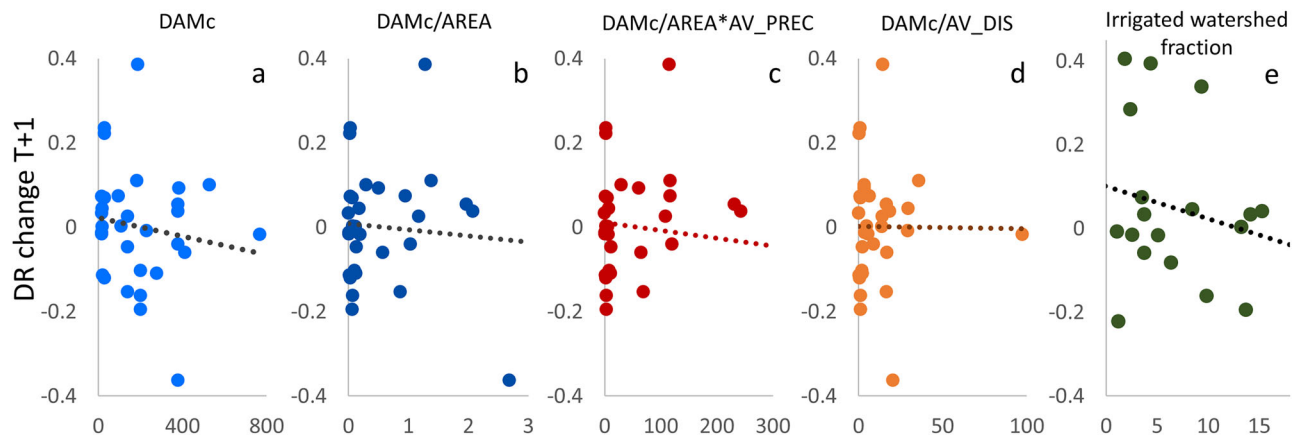


Fig. 8 | Discharge Ratio vs. Dam Capacity and Irrigation Indicators in the Year Following Wildfire. Discharge ratio change during the year after the wildfire event (y -axis) correlated to **a** the total dam capacity in the affected watershed in the x -axis (mm^3), **b** the total dam capacity per square Km of watershed, **c** the total dam capacity per square Km of watershed, multiplied by the average precipitation (in mm) of the

watershed, for the northern mid-latitudes region, **d** the total dam capacity divided by the average annual discharge volume, and **e** the irrigated watershed fraction for watersheds with at least 1% of area irrigated. Dam capacities between 0 and 800 mm^3 were considered. The p -values of the negative correlations estimated are **a** 0.44, **b** 0.68, **c** 0.56, **d** 0.96, and **e** 0.43.

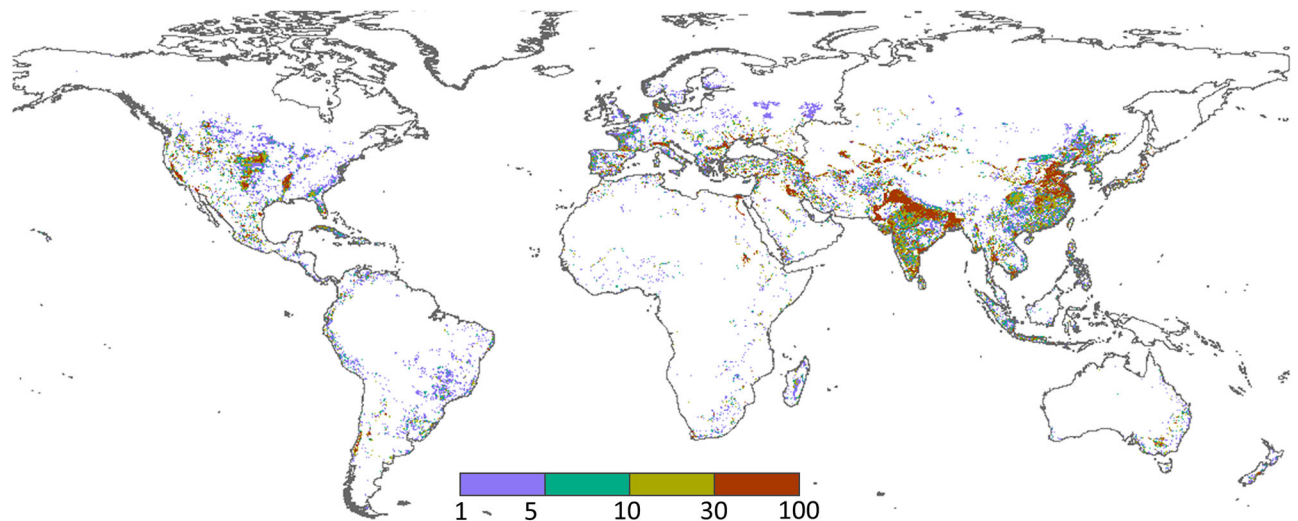


Fig. 9 | Irrigation fraction (%), for regions with at least 1% of irrigation. Percentage of irrigated area per watershed, based on the Global Map of Irrigation Areas v5.0. The dataset represents the fraction of land equipped for irrigation (circa 2005) as a percentage of total area.

dataset is available at the tiling system of MODIS (sinusoidal tile grid). The extraction of burn severity was performed through a multi-step process that included merging of MODIS sinusoidal projection tiles, and a two-step reprojection process from MODIS Sinusoidal projection to Goode Homolosine projection and finally to WGS 1984 projection.

Subtropics actual evapotranspiration anomaly after wildfires

The change in the actual evapotranspiration relative to the climatology is shown for four trimesters after the wildfire, for the north and south tropics (Fig. 10).

Discharge ratio sensitivity on burned area fraction

The effect of burned area magnitude on discharge ratio was analyzed at a regional level for the first year after the wildfire. Two different methodologies were used, the first was to regress the discharge ratio change with the BA fraction, for each region using Theil–Sen regression, while the second was to split the watersheds of each analyzed region into two equally sized samples—the one with the smaller BA fractions, and the other with the larger BA fractions. Both methods' results are shown in Fig. 11. The Theil–

Sen slope regressions for all regions show a consistent sign of change to those reported in Fig. 2 (for the first year after the fire). This implies that the higher the burned area fraction, the more pronounced the detected effect. The same conclusions are drawn from the split-sample analysis per region, apart from the North Subtropics region that exhibits an opposite signal (i.e., while the effect in the discharge ratio for the first year after the wildfire is negative (Fig. 2) and the same tendency is acquired from the Theil–Sen regression, the split sample median is shown to increase as we move from the low BA fraction to the high BA fraction sample).

Discharge data autocorrelation

To maximize the dataset used, nested watersheds were also considered for the analysis. This may have induced spatial autocorrelation in the regression analysis. To assess the level of autocorrelation in the nested watersheds and compare it to independent watersheds, we estimated the Pearson's correlation coefficient of the discharge data from 164 nested watershed pairs and the 231 watersheds with their closest independent watershed. Nested watersheds were defined as those whose delineated upstream area was fully or partially contained within a larger watershed upstream of another

Fig. 10 | Changes in the actual evapotranspiration for the northern and southern subtropical regions for the four trimesters (months 1–3, months 4–6, months 7–9 and months 10–12) after the wildfire occurrence. Changes were assessed as ratios to the climatological averages for the 2001–2018 period, with a three-year period after the wildfire being excluded in the calculation of the average.

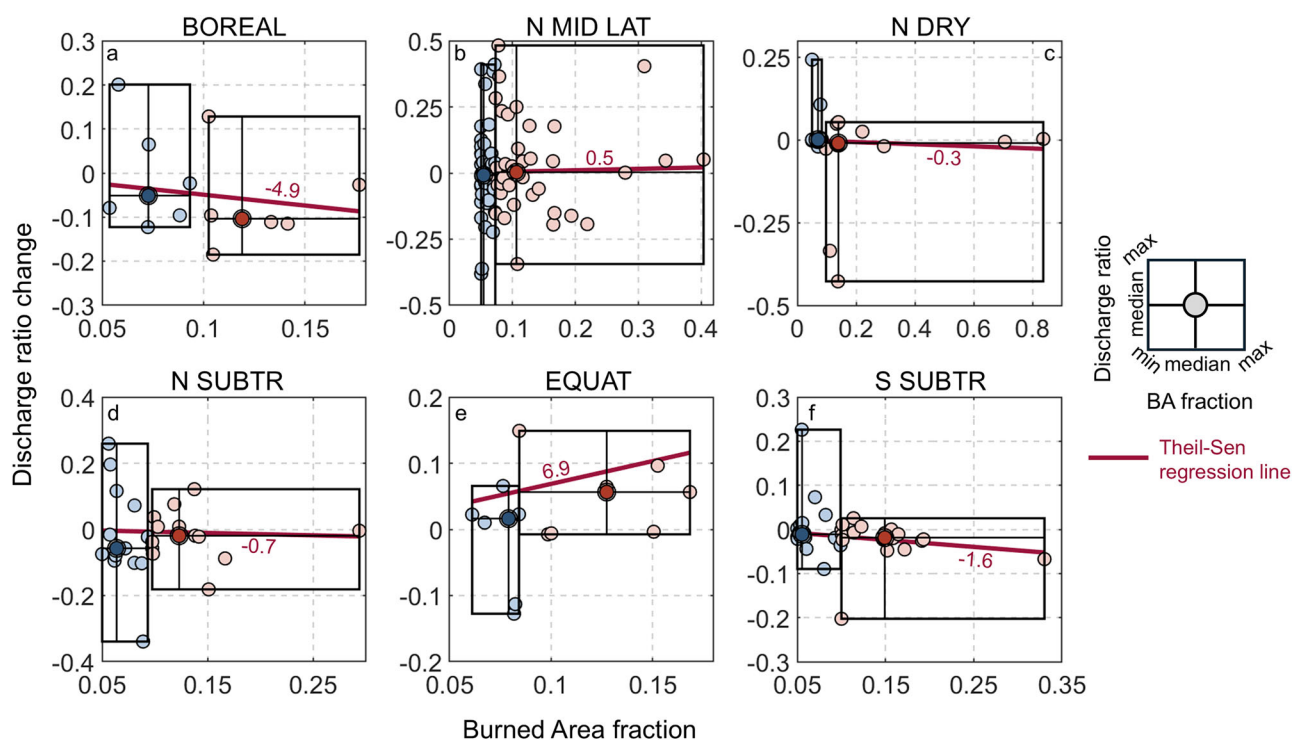
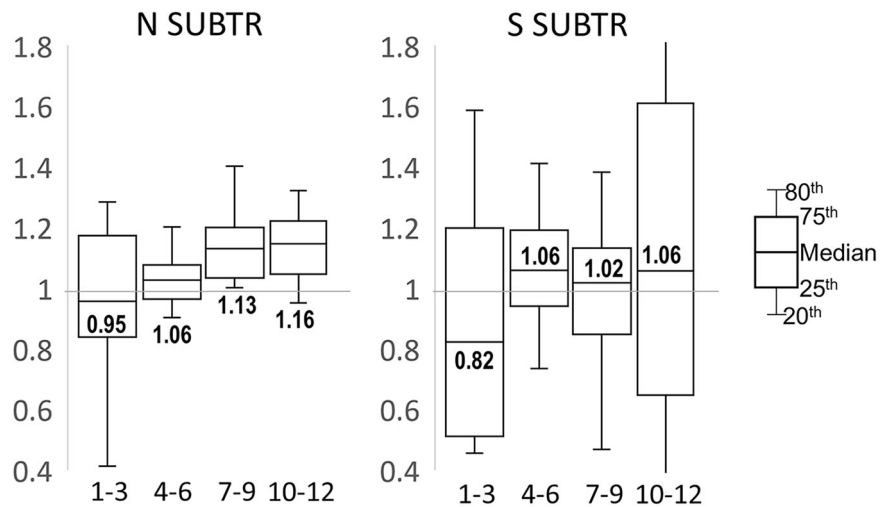


Fig. 11 | Theil–Sen regression lines (red) for the watersheds analyzed for each region. The red and blue points represent the datapoints on which the regression was performed. The slope of the regression is mentioned in red text. For each region, the watersheds' sample was split into two sub-samples according to the median burned area fraction. The smaller BA fractions are represented with blue and the larger ones with red color. The crossed boxes represent the bounds (min and max of

the sample) of the burned area fraction (vertical lines of the boxes) and the discharge ratio change (horizontal lines of the boxes). The cross in the box represents the median values of burned area fraction and discharge ratio change. Panels a–f refer to the different hydrobelts: **a** boreal, **b** mid-latitudes, **c** north dry regions, **d** north sub-tropical regions, **e** equatorial regions, and **f** for south sub-tropical regions.

discharge gauge, based on the shapefile geometry. The selection of the nested and independent pairs was made on the basis of the closest (Euclidean distance) discharge location (i.e., discharge gauging point). For example, a given watershed may be nested within one or more larger watersheds; in such cases, we selected the larger watershed with the closest gauging point. Similarly, when a watershed had several nearby independent watersheds (whether or not they shared a boundary), we selected the closest one based on the distance between gauging points. The results are summarized in Fig. 12. Figure 12a, d shows histograms of the Pearson's correlation coefficient (r) for discharge time series between each watershed and its nearest independent (12a) or nested (12d) neighbor. Figure 12b, e presents

scatterplots of Pearson's r against the distance between watershed mouths, illustrating that, as expected, correlation generally decreases with distance—more markedly so for independent watershed pairs. Figure 12c, f displays boxplots of Pearson's r for independent (12c) and nested (12f) watershed pairs, grouped into five distance classes: <40 km, 40–80 km, 80–120 km, 120–200 km, and >200 km. The comparison reveals that nested watershed pairs tend to maintain higher correlations at greater distances compared to independent ones. Finally, Figure 12g summarizes the overall Pearson's r values for all independent and nested watershed pairs. A two-sample Kolmogorov–Smirnov test was applied to the Pearson's r values (from Fig. 12c, f) to assess whether the distributions of correlation coefficients for

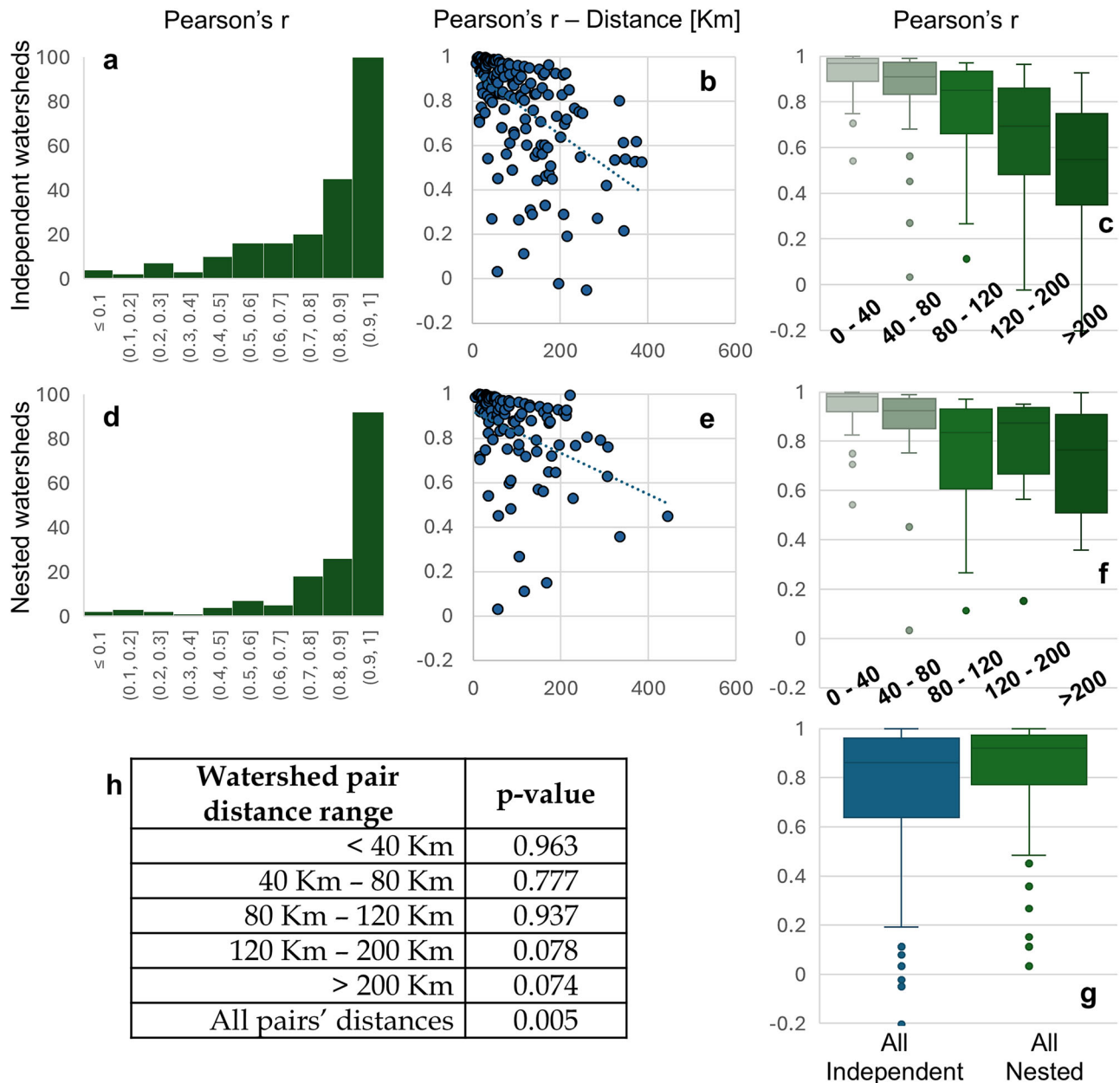


Fig. 12 | Spatial autocorrelation statistics of the discharge data used in the analysis. Histogram of the attained Pearson's r , among the discharge time series of the nearest independent (a) and nested (d) watersheds. Panels b, e are scatterplots of the Pearson's r with the watershed mouths' distance. Panels c, f shows boxplots of the Pearson's r for the independent (c) and the nested (f) watershed pairs, for five different ranges of watershed mouths' distances (i.e., watershed pairs with distance under 40 km,

distance from 40 to 80 km, distance from 80 to 120 km, distance from 120 to 200 km, and distance over 200 km). Panel g shows the summary boxplots of Pearson's r for all independent and nested watersheds together (panels c and f, summarized). **h** p -Values of the two-sample Kolmogorov-Smirnov test on the Pearson's r samples for different watershed pair distances.

independent and nested watershed pairs differ significantly. The resulting p -values are shown in Fig. 12h. At the 95% confidence level, no distance group showed a statistically significant difference. However, at the 90% confidence level, the 120–200 km and >200 km distance categories did exhibit significant differences. When all pairs were compared together (Fig. 12g), the p -value was 0.0046, indicating a statistically significant difference in Pearson's r distributions. Overall, this analysis indicates that while spatial autocorrelation is present in the dataset, it is primarily driven by geographic distance rather than watershed nesting. Furthermore, it is confirmed that correlations do not differ to an extent that including nested watersheds may lead to significant additional spatial autocorrelations. It is important to note that this assessment was based on the entire discharge time series, not limited to years surrounding wildfire events.

Data availability

All the data used is publicly available. The 2001–2018 burned area data from Collection 6 MODIS (MCD64CMQ)²³ can be found in the secure FTP: <sftp://fire.burnt@fuoco.geog.umd.edu/> /data/MODIS/C6/MCD64CMQ. MSWEP³⁹ Precipitation data can be requested for research purposes from <http://www.gloh2o.org/mswep/>. The ERA5⁴⁰ temperature, potential and actual evapotranspiration, and soil temperature data can be obtained with registration from <https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels-monthly-means?tab=overview>. The observed flow data were obtained from USGS data for the United States⁴¹ (<https://waterdata.usgs.gov/>), the Global Runoff Data Center—GRDC, Environment Canada⁴² (<https://collaboration.cmc.ec.gc.ca/cmc/hydrometrics/www/>) and Camels BR⁴³ (<https://zenodo.org/records/3964745>), as well as

Global Streamflow Indices and Metadata (GSIM) database²⁴ (https://store.pangaea.de/Publications/GudmundssonL-etal_2018/GSIM_indices.zip).

Code availability

The code used in the data processing for this study is available upon request.

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Author contributions

M.G. and A.V. conceptualized the study. M.G. and A.V. developed the methodology and conducted the data analysis. M.G. curated the dataset and created the figures. M.G. first draft of the paper, M.G. and A.V. contributed to reviewing and editing the final version. A.V. supervised the project and acquired funding.

Competing interests

The authors declare no competing interests.

Inclusion and ethics

Both authors of this study fulfill the criteria for authorship required by Nature Portfolio journals and have been included as authors, as their participation was essential for the design and implementation of the study. Roles and responsibilities were agreed upon ahead of the research. This work does not include findings that are locally relevant. This research was not severely restricted or prohibited in the setting of the researchers and does not result in stigmatization, incrimination, discrimination or personal risk to participants. Local and regional research relevant to our study was taken into account in citations.

Additional information

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