

## Effect of Wildfire on Water Quality of Closed Inland Freshwater Systems in Udaipur, Rajasthan, India

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### ABSTRACT

Wildfires are becoming more frequent all over the world each year. Altered climate and land use patterns are the key causes of unnatural wildfires. They affect terrestrial as well as nearby freshwater ecosystems. After wildfires and consequent removal of forest vegetation, increased water flow and soil erosion amplify the transfer of nutrients, pollutants, and sediment to the freshwater bodies. Water quality of closed lake ecosystems is significantly altered in such circumstances. The present study is an attempt to explore the responses of wildfire on water quality of two inland lakes of Southern Rajasthan, one charred with severe wildfire while another with no recent wildfire incidence. For this purpose, two lakes were seasonally evaluated in terms of water quality responses after the wildfire. They are closed inland freshwater systems with no direct inputs of freshwater other than rainfall. Both the lakes have some resemblance in their sizes, for being less disturbed by direct human activities and having forested catchments, although the topographical and hydrological conditions vary to some extent. Although post-monsoon water quality varies with pre-monsoon conditions due to sediment and mineral transport to lakes with rainwater runoff, fire enhances this impact as vegetation cover is burnt and removed. We observed a range of parameters like pH, TDS, EC, total hardness, alkalinity, nitrate, phosphate, DO, BOD, and DOC in both of the lakes seasonally. The water quality responses were found to have a substantial influence of wildfire in Lake Baghdara. The degree of divergence of impact between the two lakes may be attributed to the presence and severity of wildfire in the catchment of Baghdara Lake. The present investigation will help in analysing the impact of forest fires on closed inland freshwater tropical lakes with forested catchments.

**Key words:** Wildfire, Tropical lakes, Closed lake system, Forested catchments, Water quality, Nutrients

### INTRODUCTION

Fire is a natural factor that has both beneficial and harmful impacts on an ecosystem. It depends on the frequency and severity of the fire and the type of ecosystem. The impact of fire on soil and water may be direct or indirect, affecting the microclimatic level to the ecosystem-level environment. Frequency and intensity of wildfires depend on weather (Wotton et al. 2010), climate (Ryan 1991), vegetation composition (Taylor and Skinner 2003), soil and topography of the watershed (Ranalli 2004), and also on human activities (Krishna and Reddy 2012, Lasslop and Kloster 2017). The area burnt depends on land use patterns (Rego 1992) along with the precipitation regime and drought conditions of the region (Chen et al. 2014). In many regions, a low-intensity forest fire proves to be useful for the forests, as it removes debris from the forest floor, nourishes the soil, opens up the forest for sunlight, creates new habitats, helps seed germination, and controls pathogens. However, manmade wildfires are more

frequent and deleterious in many areas of the world now. Global warming, or climate change, has alarmingly accelerated the fire frequency and the size of the impacted area in many regions (Flannigan et al. 2000, Abatzoglou and Williams 2016). Consequently, fire has been damaging ecosystems like tropical rainforests, which are fire-independent (Juarez-Orozco et al. 2017, Kraus and Goldammer 2007). At the same time, the forest fires also contribute to climate change through both negative and positive feedback mechanisms (Oris et al. 2014). Forest fires are the major cause of degradation of Indian forests, and the foremost cause is human involvement (Roy 2005, Singhal et al. 2014). More than half of India's forest cover is prone to forest fires (Singhal et al. 2014). Indian forests, particularly tropical deciduous forests, are facing frequent fires in many areas. In India, the highest number of fire incidents occurs from February to May (chiefly March and April), known as the fire season. That is because of less humidity (Ahmad and Goparaju 2019). Andhra Pradesh, Chhattisgarh, Madhya

Pradesh, Maharashtra, Telangana, Odisha, Punjab, and the north-northeast states (due to shifting cultivation) have comparatively very large numbers of incidents of forest fires every year. An immense number of fire incidents in protected areas is also a cause of concern in India (Reddy et al. 2017). The southern part of Rajasthan, comprising the Aravalli hills, is highly prone to forest fires. A significant part of the forests, scrubland, and grassland of the Aravalli hills faces recurrent fires in southern Rajasthan (Krishna and Reddy 2012).

Wildfires affect the ambient environment, including soil, air, and water. Increasing incidents of forest fires are posing a threat to freshwater lakes, especially the closed ones with forested catchment, as the water quality gets degraded and the lake ecosystem is impaired. Wildfire enhances water repellence of soil, reduces soil infiltration capacities, and increases soil erosion and sediment transport (Shakesby and Doerr 2006). Runoff losses are also enhanced after wildfire. As a result, the amount of runoff entering a water body is increased considerably (Horwitz and Sommer 2005). High-magnitude events, such as floods (Papathanasiou et al. 2012), landslides (Rengers et al. 2020), and debris flows (Parise and Cannon 2011), may arise due to an increased runoff in the burnt areas. The elements and compounds originated by wildfire, deposited on surface soil directly or through atmospheric deposition, and are transported to water bodies (Meneses et al. 2019). The mobilization, along with the transport of sediments and chemical compounds, depends on the type of watershed and nature of the fire (Nunes et al. 2018). Post-fire impacts on water quality include an increase in nutrient levels, hazardous chemicals (Fe, Cu, Pb, and Ar), and changes in physical parameters like turbidity, pH, conductivity, and temperature (Teclé 2006, Teclé and Neary 2015). Excess amounts of nutrients can cause eutrophication of lakes (Bladon et al. 2014, Yang et al. 2008). Due to biomass burning, reactive compounds are emitted into the atmosphere, and from there they fall into the water bodies with rain, causing their acidification, especially in poorly buffered lakes (Roser 1997). As a result of such impacts, the treatment of the inland water bodies for community water supply requires high costs and facilities (Smith et al. 2011, Bladon et al. 2014).

Forest fire affects lake biota for many years (Bixby et al. 2015, Martens et al. 2019). The habitat of aquatic organisms is mainly affected due to increased sedimentation with ash and other debris accumulation (Neary et al. 2003). The present study focuses on the impact of wildfire on freshwater inland lake water quality, and the findings help explore the consequent changes.

## MATERIAL AND METHODS

### Study area

The study was performed at two isolated, closed freshwater lakes near Udaipur city. Udaipur has a sub-humid climate with distinct seasonality and temperatures ranging from about 3 to 46°C. The average rainfall of Udaipur is less than the average rainfall of India. In a recent study, the average monsoon season rainfall in the area was found to be 558.72 mm with a standard deviation of 203.8 (Deoli and Rana 2019). The rainfall pattern is almost similar for both lakes, as they are located within a few kilometres of each other.

**Lake I (Badi):** Lake Badi (control) is a closed water body, situated about 10 km away from Udaipur city (24.61605° N latitude and 73.622127° E longitude), surrounded by hills covered by vegetation. The lake has a surface area of 1.25 km<sup>2</sup> with a maximum depth of 23 m.

**Lake II (Baghdara):** Lake Baghdara (fire affected) is an enclosed water body, situated about 20 km southeast (24°31'N latitude and 73°48'E longitude, 582 m above msl) of Udaipur city in the midst of dry tropical deciduous forests with a water spread area of 1.8 km<sup>2</sup> and a maximum depth of 8.5 m.

Both selected lakes, Lake Badi and Lake Baghdara, are less influenced by human disturbances. They don't have any stream input or outlet for water and are rainfed directly and indirectly. Lake Badi is selected as the controlled/reference lake with no cases of fire incidents within the catchment for several years, while Lake Baghdara has been selected as the fire-affected lake. A severe wildfire in the catchment of Lake Baghdara took place on 13th March 2017, engulfing several hectares and damaging trees and wild animals significantly. The region received a fair amount of rainfall, i.e., 752 mm in the monsoon season, in the year 2017. Due to

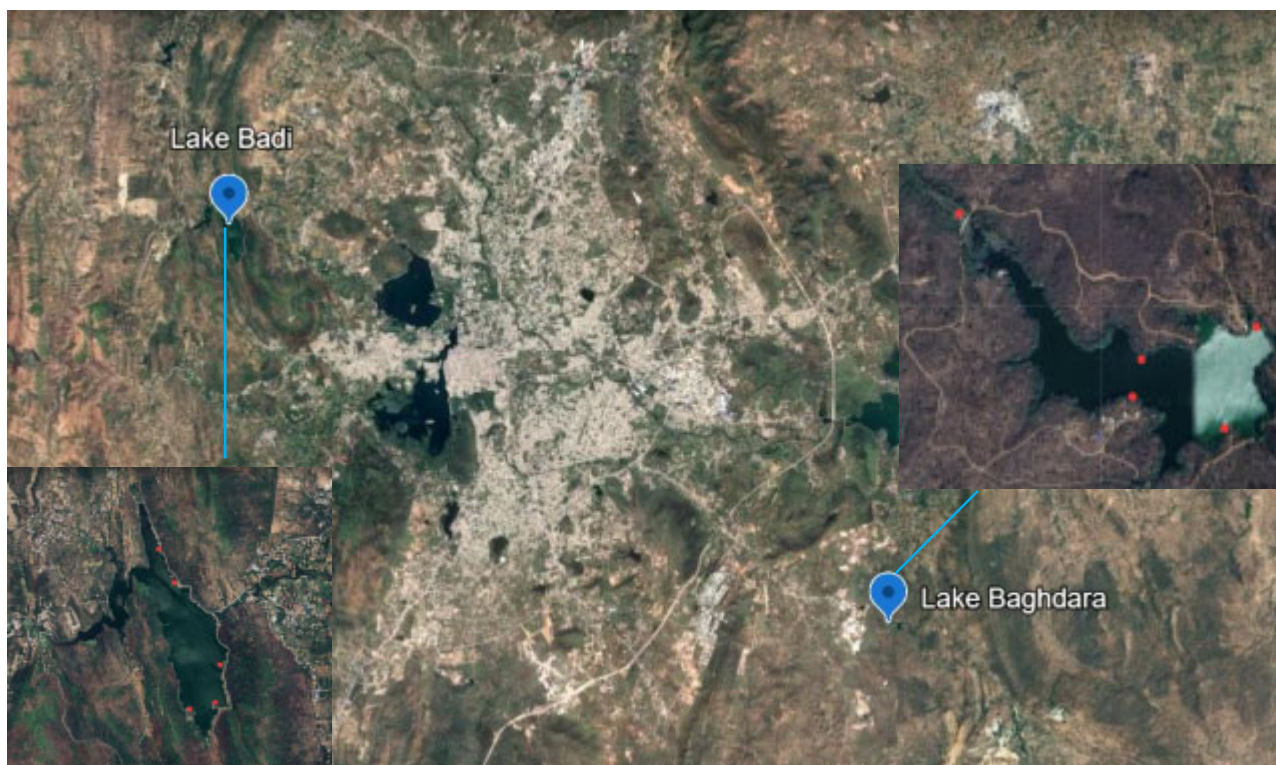


Figure 1. Study area - Lake Badi (control lake) and Lake Baghdara (wildfire affected lake)

anthropogenic activities in the catchment, including atmospheric deposition, Lake Baghdara receives a greater amount of nutrients, and once oligotrophic, this lake has been slowly turning towards a mesotrophic condition over the last two decades.

### Sampling and analysis

Sampling was done during the pre-monsoon and post-monsoon seasons for Lake Baghdara and Lake Badi, respectively. Water samples in triplicate were collected from each lake in pre-sterilized BOD bottles directly from below the water surface between 8.00 and 10.00 AM. Samples were labelled properly. A few parameters, like temperature and pH, were measured on the site. Water quality parameters (WQP) were further analysed following standard methods (Baird et al. 2017).

## RESULTS AND DISCUSSION

Fluctuations in the level and area of closed lake systems are influenced consequently due to changes in climate and drainage basins (Atwood 1994). Such systems present in arid and semi-arid regions respond quickly to geologic and climatic changes (Yilmaz et

al. 2021). In the present study, selected lakes are closed freshwater bodies and have forested catchments. Rainfall is the only source of water in these lakes, with no outlet. Such a state of a freshwater body makes it more prone to contamination and stagnation. As the rainy season starts, the concentration of contaminants increases due to flushing from the catchment, but as the season progresses, these contaminants are diluted. However, due to their enclosed nature and prevalence of high evaporation rates owing to dry tropical conditions, these lakes have a high concentration of contaminants.

The input of elements in lakes after fire depends on fire size, its intensity, ambient weather conditions, and physical, chemical & biological characteristics of the watershed (Greswell 1999). Studies suggest the role of post-fire weather, along with precipitation, in altering the water quality of lakes (Oliver 2012). The more severe the fire, the greater will be the amount of fuel consumed and nutrients released. Due to reduced interception from the forest canopy, the site becomes more susceptible to soil erosion, and nutrients enter the freshwater system (Williams et al. 2019). In the present study, significant variations

between pre-monsoon and post-monsoon values of water quality parameters have been observed for both lakes. These deviations are caused by runoff moving and picking up nutrients, minerals, and pollutants from all over the catchment of the lake and then adding to that lake. At the same time, dilution through the addition of rainwater is another important factor leading to lake water quality changes (Table 1).

The rate of change of these values is different in both lakes. The changes are large in Baghdara Lake, revealing the impact of catchment fire in freshwater lakes, as also observed in earlier studies (Greswell 1999, Carignan et al. 2000, Meneses 2019, Uzun et al. 2020). A high catchment-to-lake area ratio is also a reason for the combined impact of fire and precipitation on lake water quality (Lydersen et al. 2014), as recorded for Lake Baghdara in the present study.

Except for temperature, pH, and DO, all the values of WQP are elevated in the post-monsoon season in Lake Baghdara, whereas in Lake Badi, temperature, pH, total hardness, TDS, nitrates, BOD, and DOC are decreased (Table 1). Such variable changes may be attributed to the severe fire in the catchment of Lake Baghdara before the study.

In our study, only seasonal temperature values in both lakes are found to decrease from summer to the post-monsoon season. Greswell (1999) thinks that

in burned areas, prolonged water temperature may exist due to reduced vegetation and increased insolation. Such an increase in temperature can lead to and accelerate eutrophication of the lake. As for pH, considering the burnt catchment, lake water pH may increase (Ranalli 2004) or decrease (Appleyard 2004) depending on the presence of cations and anions in the catchment soil. The observed post-monsoon pH levels are slightly lower than pre-monsoon levels in both the lakes, which may be due to mixing of runoff and alkaline surface water with acidic bottom water (Araoye 2009, Verma and Pandey 2017). The pH value of Lake Baghdara is higher compared to Lake Badi, possibly due to the difference in watershed properties of both lakes.

Due to long dry periods resulting in high evaporation rates and the absence of a water outlet, ion concentration remains high in closed inland water bodies. A substantial rise in the value of alkalinity in both lakes in post-monsoon observations may be attributed to chemical weathering of rocks with rainwater. However, the higher rate of increase in Lake Baghdara also indicates high amounts of fire-caused DOM in the burned catchment entering the lake with runoff, resulting in an increase of carbon dioxide, carbonates, and bicarbonates owing to its decomposition. Electrical conductivity increase after rainfall is attributable to increased dissolved

Table 1. WQP of Lake Badi (control) and Lake Badgdara (fire affected) for pre- and post- monsoon seasons (mean  $\pm$  SD)

Parameter	Lake Badi		Lake Baghdara	
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Temperature	28.1 $\pm$ 0.2	26.16 $\pm$ 0.19	26.87 $\pm$ 0.16	25.6 $\pm$ 0.2
pH	7.4 $\pm$ 0.1	7.13 $\pm$ 0.15	8.3 $\pm$ 0.1	8.07 $\pm$ 0.06
Turbidity	0.37 $\pm$ 0.38	0.5 $\pm$ 0.36	0.43 $\pm$ 0.32	0.5 $\pm$ 0.1
Conductivity	345 $\pm$ 15	363.33 $\pm$ 15.28	1526.33 $\pm$ 63.72	1889.67 $\pm$ 26.08
Total hardness	168.67 $\pm$ 7.77	153 $\pm$ 2.65	953.33 $\pm$ 102.63	1260 $\pm$ 163.71
TDS	53.33 $\pm$ 2.08	46.33 $\pm$ 3.22	888.67 $\pm$ 56.08	1130 $\pm$ 50
Alkalinity	151 $\pm$ 3.61	176.68 $\pm$ 15.28	86.67 $\pm$ 24.19	180 $\pm$ 10
Nitrate	2.6 $\pm$ 0.53	1.7 $\pm$ 0.27	4.33 $\pm$ 2.08	9 $\pm$ 1
Phosphate	0.06 $\pm$ 0.02	0.21 $\pm$ 0.12	16.28 $\pm$ 2.53	27.2 $\pm$ 2.51
DO	6.95 $\pm$ 0.13	7.5 $\pm$ 0.46	7.24 $\pm$ 1.02	4.85 $\pm$ 0.74
BOD	2.52 $\pm$ 0.41	1.27 $\pm$ 0.32	5.62 $\pm$ 0.99	11.3 $\pm$ 2.23
DOC	0.87 $\pm$ 0.06	0.7 $\pm$ 0.1	2.85 $\pm$ 1	4.57 $\pm$ 1.42

constituents with runoff in both study lakes. Electrical conductivity (EC) is an excellent indicator of dissolved salts, and these values are much higher for Lake Baghdara than for Lake Badi. The rate of change in EC values is also very high for Lake Baghdara, possibly due to increased dissolved solids concentration entering through the burnt catchment. Lamontagne et al. (2000) have reported an increase in all the anions and cations after a forest fire. In the post-post-monsoon season, TDS increase is a natural process and is correlated to conductivity, which is apparent in the TDS values of both the lakes. The higher values of TDS might be due to added debris and coarse and fine particulate matter from dense vegetation in its catchment (Verma 2015). This input was then amplified after the removal of vegetation cover and the enhanced addition of burned residues after fire in the present study. The hardness of water in Lake Baghdara is very high comparatively. During post monsoon, a decrease in hardness of Lake Badi may be due to dilution with rain water, whereas increased hardness in Lake Baghdara may be a result of increased run off of salts from catchment soil after removal of vegetation by fire (Lamontagne 2000, Mast and Clow 2008).

Nutrient levels are altered or increased manifold in freshwater bodies after the burning of catchment forests (Betts and Jones 2009, Diemer et al. 2015). According to Ranalli (2004), nitrates compose most of the total N, whereas soluble reactive P composes most of the total P measured in surface water following the fire. Being enclosed systems, the study lakes have nitrate and phosphate levels high enough to support phytoplankton growth. The nitrate and phosphate levels have been increased manifold over the last two decades in Lake Baghdara, as found in previous studies (Pandey and Verma 2004, Pandey 2008), and eutrophication is noticeable in this lake at present. Phosphate levels are elevated in both lakes during the post-post-monsoon season. An increase in Lake Baghdara may be due to the leaching of P by ash deposited in lakes. Nitrate is found to be elevated more than double in Lake Baghdara from pre-monsoon to post-monsoon but reduced in Lake Badi. Many factors are responsible for such an increase, including atmospheric deposition and surface runoff, increased mineralization and nitrification after fire, and reduced nutrient uptake

due to the destruction of vegetation. In addition, the low post-fire recovery of vegetation also causes persistent higher nutrient levels in waterbodies (Rhoades et al. 2019, Rust et al. 2019). Several studies suggest an increase in nitrate levels in lakes due to burnt areas (Murphy et al. 2015, Hohner et al. 2016, Mast and Clow 2008), and this increase is directly related to burn intensity (Brass et al. 1996).

Dissolved organic carbon content is both of allochthonous (dependent on availability of water and leachable organic carbon in soils) and autochthonous origin in lakes. Dissolved organic carbon increases by forest-generated organic matter that is added through runoff to the lakes (Verma and Pandey 2017). DOC increases in lakes after precipitation following fire (Uzun et al. 2020). In our study, precipitation run off in combination with fire-induced generation of DOC is likely to enhance its concentration in Lake Baghdara. Similarly, the observed decrease in dissolved oxygen and increase in BOD in Lake Baghdara may be directly related to increased DOC due to burnt catchment runoff and its decomposition. In Lake Badi the situation is found to be reversed, i.e., lower DOC, higher DO, and lower BOD. It indicates the role of catchment fire in enhancing the DOC and related outcomes in freshwater lakes.

A t-test was conducted between the water quality parameter values of both lakes to compare significant differences between pre- and post-monsoon seasonal variations in the control lake as well as the study lake. The t-test result indicates the P values at  $<0.05$  are significant for all the parameters between pre- and post-monsoon values of Lake Baghdara, except pH, turbidity, DO, and DOC (Table 2). Whereas significant P values are obtained between pre- and post-monsoon observations of temperature, conductivity, nitrate, BOD, and DOC at Lake Badi. A comparatively larger number of significant P values for different parameters gives strong evidence of the impact of catchment wildfire on the lake water quality of Baghdara Lake. Similarly, a t-test was conducted between post-monsoon values of both the lakes (Table 2), which shows a significant p-value for all of the parameters except turbidity and alkalinity, indicating the amplified impact of catchment fire on Baghdara Lake in the post-monsoon season.

Table 2. Paired t-test between observations for pre- and post-monsoon WQP of the study lakes

Parameters	Badi (Control lake)	Baghdara (Fire affected lake)	P value < 0.05
Temperature	0.001	0.001	0.014
pH	0.094	0.073	0.001
Turbidity	0.686	0.754	1
Conductivity	0.008	0.006	0
Total hardness	0.104	0.013	0
TDS	0.145	0.001	0
Alkalinity	0.087	0.02	0.768
Nitrate	0.05	0.02	0
Phosphate	0.12	0.011	0
DO	0.183	0.131	0.006
BOD	0.002	0.027	0.002
DOC	0.038	0.099	0.009

## CONCLUSIONS

Fire in the forested catchments of closed lakes is one of the prominent factors that affect lake water quality. The current study of the enclosed inland waterbodies illustrates a comparison of differences in seasonal values of lake quality parameters in the two isolated closed lake ecosystems, coupled with amplified changes in water quality due to wildfire in Lake Baghdara. Lake Baghdara, which was once an oligotrophic lake, has now been gradually turning towards a mesotrophic lake in recent years. The major reasons are runoff from the forest floor and indirect human activities. However, frequent fires in the area, including the major and severe fire of 2017, seem to have changed the water quality of the lake substantially. The observed rate at which the WQP values are changed in the post-monsoon season in Lake Baghdara, which is highly varied from that of Lake Badi, indicates the impact of fire on water quality, where rains have washed away the increased surface minerals with runoff. Incidentally, the forest around the lake recovers rapidly after fire and thus possibly minimizes the impact of fire on lake water quality. The study helps in exploring the impact of fire on lakes. These fires are generally human-induced and need to be controlled comprehensively.

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