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Surface water quality in sacred groves of Garhwal Himalayan region, India

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We have studied the quality of surface water in three sacred groves of Garhwal (Uttarakhand, India). The water samples were collected in March–April 2013. Results showed that all water samples conformed to WHO standards for potability. Water of Hariyali Devi recorded the lowest dissolved oxygen and water of Tarkeshwar had the highest hardness. The quality water of Ravigaon was found to be the best among the waters of the three groves. Water from deodar-dominant forests recorded higher dissolved oxygen, total hardness, calcium and magnesium hardness. The overall drinking water quality of oak-dominated forests was found to be better.

Keywords: Deodar and oak forest types, sacred grove, water quality.

SINCE long, popular media and academic circles have given widespread recognition to the idea that indigenous people and some other small societies are exemplary conservationists[1,2]. Indigenous conservationism has often been attributed to spiritual respect and practical understanding of the natural world[2–5] and has given rise to sacred groves at some sites. A sacred grove is a grove or forest with a group of trees or patch of vegetation, which has been protected by local people through religious and cultural practices[6,7]. Sacred groves which have cultural or spiritual significance for the people living around them, have been protected by communities around the world for

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several reasons, including religious practices, burial grounds, watershed value, etc.[4,8–12]. The sacredness, religious beliefs and/or taboos play a significant role in promoting sustainable utilization and conservation of flora and fauna of the sacred groves. Sustainable use as well as management of natural resources and habitats by small scale societies are widespread. They may indirectly result in the preservation of biodiversity or even enhancement of habitat mosaics[13].

Sacred groves are well preserved forest patches, have high hydrological value and fulfill water needs of nearby communities. They are intact forests. Their floors which are covered with litter and humus have better water infiltration capacity than grass lands, scrubs and rocky areas[14]. The dense and deep root network, various types of burrowing soil organisms and incorporation of decomposing organic matter induce more porosity and sponginess to the top soil, promoting greater water infiltration. Therefore, the intact forests of sacred groves always have greater watershed value in terms of water yield and quality than other types of landscapes[14]. Very few studies have quantified the water yield and water quality of sacred groves[15].

The present study was carried out in the Hariyali Devi, Tarkeshwar and Ravigaon sacred groves of Garhwal region (Uttarakhand, India) (Table 1). The objectives of the study were: (a) to determine physico-chemical parameters of water in the sacred groves and assess the quality of water and compare the water quality of adjacent sites outside the groves and (b) to assess and compare the physico-chemical quality of water in oak and deodar dominated forests.

Surface water from the sacred groves and springs from adjacent areas is used for drinking, irrigation and other domestic purposes. Sacred groves of all the three study areas are part of reserve forests. Though anthropogenic disturbances were expected to be almost nil in these we observed forest stands, socio-cultural activities (marriage ceremonies, festivals, etc.) of surrounding villages and several construction activities (in Tarkeshwar sacred grove).

Sampling was carried out during March–April 2013. The water samples were collected at three sites in each of the sacred groves. At each station three samples were collected using random sampling method. In the case of Tarkeshwar, in the down-stream of the 2nd point, water moved underground. Therefore, from that source, three water samples were collected from only two points. The average of analytical values of replicates was reported as the final value of physico-chemical parameter of each site. GPS co-ordinates of each sampling point on the stream water were obtained and reported.

All samples were collected from the mid-channel of the stream water source, thereby avoiding local in-homogeneities along the bank. Samples were stored in 500 ml plastic bottles; for dissolved oxygen (DO) a 300 ml biochemical oxygen demand (BOD) bottle – a glass bottle with a ‘turtleneck’ and round glass stopper – was used. The samples were analysed for pH, oxidation reduction potential (ORP), total dissolved solids (TDS), calcium hardness (Ca–H), magnesium hardness (Mg–H), total hardness (TH) and DO as per standard methods[1].

Data on the physico-chemical quality of water within the sacred grove and areas adjacent to the sacred grove of three study areas are presented in Tables 2–4 and areawise observed values (mean ± SD) compared with the WHO standards are given in Table 5.

Mean and standard deviation (SD) of the physico-chemical parameters show that water from Hariyali Devi SG and adjacent areas is slightly alkaline and characterized by high ORP. However, water samples from the sacred grove have higher DO than water from adjacent sites. TH and TDS are higher in adjacent site samples relative to sacred grove water samples (Table 2).

Mean and SD values classify the water of Ravigaon as slightly alkaline. The water is characterized by high ORP and DO in both the areas. TH, Mg–H and TDS are higher in waters of adjacent sites than of sacred grove sites (Table 3).

Mean and SD values of water samples from the Tarkeshwar sacred grove fall in the slightly alkaline range. They have high ORP and DO in both the areas. TH and TDS solids are higher in sacred grove water samples than in adjacent water samples (Table 4).

pH values of water samples are within the permissible range of 6.5–8.5 (Table 5). The ORP values of all the three sacred sites and their adjacent sites are positive, which indicate that water in these areas is more oxidized and aerobic.

DO values of water samples from Hariyali Devi sacred grove led and its adjacent area are below the WHO standard values, while those from Ravigaon and Tarkeshwar areas are higher (Table 5). Tarkeshwar water is characterized by the highest DO and that of Hariyali Devi has the lowest DO.

TH values in all samples fall within the permissible limit of 500 mg/l (Table 5). Tarkeshwar site samples have the highest TH and those of Hariyali Devi have the lowest TH. The waters of Hariyali are the best in terms of hardness.

The Ca–H and Mg–H levels in water samples of the three sites also fall within the permissible range of 200 mg/l (for Ca–H) and 150 mg/l (for Mg–H) (Table 5). Hariyali Devi sacred grove samples have the lowest Ca–H and Mg–H, while Tarkeshwar samples have the highest Ca–H and Mg–H values. TDS of all water samples are well within the limits given by the WHO standard.

pH values of water samples from the oak dominated forests, i.e. Hariyali Devi and Ravigaon are 7.78 ± 0.61 and 7.8 ± 0.266 respectively; pH of water samples from deodar dominated forests, i.e. Tarkeshwar is 7.66 ± 0.78.

Table 1. Details of sampling sites (three groves and their adjacent sites)

Information	Hariyali Devi	HAD	Ravigaon	RAD	Tarkeshwar	TAD
Location	30°14′51.3″N 79°02′12.1″E to 30°17′59.4″N 79°03′ 14.8″E	30°15′7.6″N 79°04′57″E to 30°15′36.9″N 79°04′51.6″E	30°34′17.8″N 79°02′45.9″E to 30°34′33.3″N 79°02′49″E	30°33′22.3″N 79°02′47″E to 30°33′12.3″N 79°02′0.3″E	29°50′16.3″N 78° 47′20.5″E to 29°50′38.6″N 78°47′57.5″E	29°49′46.6″N 78°47′18″E to 29°49′39″N 78°47′18″E
Elevation	703.7 m to 2798 m above msl	1541 m to 1329 m above msl	1601 m to 1718 m above msl	1745 m to 1459 m above msl	1523 m to 1829 m above msl	1728 m to 1525 m above msl
Area (hectare)	205.5		3.5		20	
Village deity	Hariyali Mata		Triyug Narayan		Lord Tarkeshwar Mahadeva	
No. of villages	19		20		22	
Comments	110 km away from university campus	10 km downstream away from sacred grove	100 km away from university campus	4–5 km downstream away from sacred grove	100 km away from university campus	10–15 km downstream away from sacred grove

HAD, Hariyali Devi adjacent site; RAD, Ravigaon adjacent site; TAD, Tarkeshwar adjacent site; msl, Mean sea level.

Table 2. Physico-chemical quality of water within and outside the sacred grove adjacent of Hariyali Devi

Place	Physico-chemical parameters						
	pH	ORP (mV)	DO (mg/l)	TH (mg/l)	Ca–H (mg/l)	Mg–H (mg/l)	TDS (mg/l)
Sacred grove (site 1)	7.35 ± 0.02	18.33 ± 2.51	5.72 ± 0.07	22.64 ± 0.01	11.32 ± 0.006	11.21 ± 0.18	30 ± 0
Sacred grove (site 2)	7.85 ± 0.03	68.33 ± 4.51	4.42 ± 0.33	17.325 ± 0.005	11.317 ± 0.005	6 ± 0.006	15 ± 7.071
Sacred grove (site 3)	8.22 ± 0.01	163.33 ± 1.15	3.77 ± 0.25	57.32 ± 0.01	31.328 ± 0.007	25.99 ± 0.003	152.5 ± 3.53
Adjacent (site 1)	7 ± 0.01	67.33 ± 3.51	3.39 ± 0.025	18.64 ± 0.01	10 ± 1	8.64 ± 1	167.5 ± 67.17
Adjacent (site 2)	7.88 ± 0.045	167.66 ± 2.3	3.51 ± 0.01	45.32 ± 0.01	20.66 ± 0.01	24.66 ± 0.02	145.5 ± 0.7
Adjacent (site 3)	7.9 ± 0	164.33 ± 10.11	3.88 ± 0.025	84 ± 1	39.32 ± 0.01	44.68 ± 1.01	85 ± 35.35
SG overall	7.78 ± 0.61	90.83 ± 102.53	4.64 ± 0.99	32.43 ± 21.72	17.99 ± 11.55	14.40 ± 10.37	65.83 ± 75.42
AD overall	7.59 ± 0.514	133.1 ± 56.9	3.59 ± 0.25	49.32 ± 32.86	23.28 ± 14.84	25.990 ± 18.06	132.66 ± 42.72

This difference is insignificant. ORP values of water samples from oak dominated forests are 90.83 ± 12.53 mV (Hariyali Devi SG) and 105.55 ± 38.64 mV (Ravigaon SG) while that of deodar forests is 89.22 ± 18.5 mV (Tarkeshwar SG). With respect to ORP, the oak forests showed higher ORP than the deodar forests.

Deodar forest waters have higher DO (9.76 ± 0.288 mg/l in Tarkeshwar SG) when compared to oak forest waters (4.64 ± 0.99 mg/l in Hariyali Devi SG and 8.51 ± 0.204 mg/l in Ravigaon SG). Water samples from deodar forest groves have higher TH, Ca–H and Mg–H than samples from oak forests.

In many parts of rural India, untreated groundwater or water from rivers and lakes is used for drinking. Water consumed without treatment should be monitored for variables which may pose a potential risk to human health. Guidelines for maximum concentration of such variables in drinking water have been set by the WHO[16]. Water, whose parameters meet the standards for a given use, is considered suitable for that use. If the water fails to meet these standards, it must be treated before use[5].

The pH of a water body is important in determining water quality, because it affects other chemical reactions such as solubility and metal toxicity[15]. The pH plays an important role in maintaining conducive conditions for biochemical and metabolic reactions that take place[2]. The average pH of the sacred grove water samples from Hariyali Devi, Ravigaon and Tarkeshwar and the sites adjacent to them is found to be moderately alkaline. It has been reported that rivers in Uttarakhand exhibit alkaline pH (ref. 17) but within the permissible range of 6.5–8.5 prescribed for potable water[18,19].

The DO content of water is influenced by the source, raw water temperature, treatment and chemical or biological processes taking place in the distribution system. Depletion of DO in water can encourage microbial reduction of nitrate to nitrite and sulphate to sulphide[20]. The average DO content of waters of sacred groves of Ravigaon and Tarkeshwar and their adjacent sites is well above the WHO standard while that of Hariyali Devi and its adjacent area is lower than the standard. Actually, the source point of the stream in Hariyali Devi is the only point that is situated within the area of sacred grove; here

Table 3. Physico-chemical quality of water within and outside the sacred grove adjacent of Ravigaon

	Physico-chemical parameters						
Place	pH	ORP (mV)	DO (mg/l)	TH (mg/l)	Ca–H (mg/l)	Mg–H (mg/l)	TDS (mg/l)
Sacred grove (site 1)	7.53 ± 0.023	69 ± 2	8.72 ± 0.01	38 ± 2.82	21 ± 1.41	17 ± 1.41	115 ± 91.92
Sacred grove (site 2)	7.82 ± 0.06	101.66 ± 1.15	8.31 ± 0.003	28 ± 5.65	22 ± 0	6 ± 5.65	134.17 ± 38.89
Sacred grove (site 3)	8.066 ± 0.015	146 ± 0	8.51 ± 0.005	40 ± 0	21 ± 1.41	19 ± 1.41	101.67 ± 0
Adjacent (site 1)	7.63 ± 0.01	106 ± 1	8.12 ± 0.25	26 ± 2.82	16 ± 0	10 ± 2.82	30.015 ± 30.66
Adjacent (site 2)	7.77 ± 0.005	126.66 ± 0.57	8.07 ± 0.02	36 ± 5.65	19 ± 4.24	17 ± 9.89	153.35 ± 87.18
Adjacent (site 3)	7.71 ± 0.02	141.66 ± 0.57	8.03 ± 0.26	52 ± 4.5	17 ± 1.41	34 ± 3.2	253.33 ± 0
SG overall	7.8 ± 0.266	105.55 ± 38.64	8.51 ± 0.204	35.33 ± 6.42	21.33 ± 0.57	14 ± 7	116.94 ± 16.33
Adjacent overall	7.7 ± 0.07	124.77 ± 17.9	8.072 ± 0.04	38 ± 13.11	17.33 ± 1.52	20.33 ± 12.34	145.564 ± 111.86

Table 4. Physico-chemical quality of water within and outside the sacred grove adjacent of Tarkeshwar

	Physico-chemical parameters						
Place	pH	ORP (mV)	DO (mg/l)	TH (mg/l)	Ca–H (mg/l)	Mg–H (mg/l)	TDS (mg/l)
Sacred grove (site 1)	6.8 ± 0.005	71 ± 5.56	9.6 ± 0.1	48 ± 4	32.66 ± 2.3	10 ± 0	80 ± 14.14
Sacred grove (site 2)	7.82 ± 0.025	88.66 ± 1.527	9.6 ± 0.1	173.33 ± 3.05	64 ± 5.3	109.33 ± 6.11	155 ± 21.21
Sacred grove (site 3)	8.32 ± 0.011	108 ± 1	10.1 ± 0.1	130.67 ± 1.15	70 ± 6	60.67 ± 6.11	135 ± 49.49
Adjacent (site 1)	7.56 ± 0.025	108 ± 1	8.43 ± 0.13	68.66 ± 3.05	41.3 ± 2.3	27.33 ± 5.03	60 ± 14.14
Adjacent (site 2)	7.26 ± 0.025	92.33 ± 2.08	9.36 ± 0.5	56.66 ± 4.16	34.66 ± 3.05	22 ± 7.21	55 ± 35.35
SG overall	7.66 ± 0.78	89.22 ± 18.5	9.76 ± 0.288	117.33 ± 63.71	55.33 ± 20	60 ± 50	123.33 ± 38.83
Adjacent overall	7.4 ± 0.21	100.165 ± 11.08	8.89 ± 0.6	62.66 ± 8.48	37.99 ± 4.7	24.66 ± 3.768	57.5 ± 3.53

the DO level of the sample is 5.67 mg/l which is within permissible limit given by WHO. The remaining sampling points selected in the middle and end point of the stream were far outside the sacred grove due to the long stretch of the stream. Also these two points are under heavy anthropogenic pressure due to contamination from domestic and agricultural wastes. DO over long distances may reduce due to respiration of biota, decomposition of organic matter, rise in temperature, increase in oxygen demanding wastes and inorganic reductants such as hydrogen sulphide, ammonia, nitrites, ferrous ion, etc.[21].

Hardness in water is caused by dissolved calcium and to a lesser extent by magnesium. It is usually expressed as an equivalent quantity of calcium carbonate and is indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning capability[20]. The average total hardness of sacred grove water samples and adjacent sites is less than 500 mg/l, which is the prescribed WHO standard for potable soft water. It is observed that the water sample of Tarkeshwar sacred grove has the highest hardness value, i.e. 117.33 ± 63.71 mg/l, which is well within the prescribed limit for hardness of potable water. No health related guideline has been proposed for hardness in drinking water[20].

The taste threshold for calcium ion is in the range of 100–300 mg/l, depending on the associated anions, and the taste threshold for magnesium is lower than that of calcium. In some instances, consumers tolerate water hardness in excess of 500 mg/l (ref. 20). Average calcium and magnesium hardness of waters from the sacred groves and their adjacent sites are well within the threshold set by WHO (refs 19, 20).

Water with TDS less than 600 mg/l is generally considered to be good and palatable; drinking water becomes significantly and increasingly unpalatable at TDS levels greater than 1000 mg/l (ref. 20). The average TDS value of the water samples in the study was within the permissible limit. It has been reported that the TDS values in the Himalayan rivers range from 35 to 151 mg/l (ref. 22) and in the Himalayan rivers of Uttarakhand the TDS values range from 90.23 to 121.33 mg/l (ref. 23). The present study is consistent with these observations.

With respect to the forest type, water samples from deodar dominated sacred groves recorded higher DO, TH, Ca–H and Mg–H than oak-dominated groves. Oak forests support good growth of ground vegetation compared to deodar forests. Therefore, due to lesser growth of ground vegetation, the soil in the deodar forests is much more vulnerable to erosion. This may result in higher TDS.

Total dissolved solids collectively indicate the existence of carbonate, bicarbonate, nitrate, sulphate, phosphate and chloride of Ca, Mg, K, Mn and organic matter, salts and other particles[15,24,25]. Therefore, Ca–H, Mg–H and TH are higher in waters of deodar-dominated sacred groves. Again, deodar forests make the soil slightly acidic in nature[26] which ultimately causes the stream water to also become slightly acidic (Table 4, pH at site 1). Streams coming out of oak forest soils are more alkaline. It is important to note that in all these three groves

Table 5. Areawise observed values (mean ± SD) and comparison with WHO standard

Parameter	WHO standard (2009, 2011)	Hariyali devi		Ravigaon		Tarkeshwar	
		Sacred grove	Adjacent	Sacred grove	Adjacent	Sacred grove	Adjacent
pH	6.5 to 8.5	7.78 ± 0.61	7.59 ± 0.514	7.8 ± 0.266	7.7 ± 0.07	7.66 ± 0.78	7.4 ± 0.21
ORP (mV)	–	90.83 ± 12.53	133.1 ± 56.9	105.55 ± 38.64	124.77 ± 17.9	89.22 ± 18.5	100.165 ± 11.08
DO (mg/l)	5	4.64 ± 0.99	3.59 ± 0.25	8.51 ± 0.204	8.072 ± 0.04	9.76 ± 0.288	8.89 ± 0.6
TH (mg/l)	500	32.43 ± 21.72	49.32 ± 32.86	35.33 ± 6.42	38 ± 13.11	117.33 ± 63.71	62.66 ± 8.48
Ca–H (mg/l)	200	17.99 ± 11.55	23.28 ± 14.84	21.33 ± 0.57	17.33 ± 1.52	55.33 ± 20	37.99 ± 4.7
Mg–H (mg/l)	150	14.40 ± 10.37	25.99 ± 18.06	14 ± 7	20.33 ± 12.34	60 ± 50	24.66 ± 3.768
TDS (mg/l)	1000	65.83 ± 75.42	132.66 ± 42.72	116.94 ± 16.33	145.564 ± 111.86	123.33 ± 38.83	57.5 ± 3.53

there is absence of any other water source except for the permanent springs.

In Tarkeshwar region, strong water scarcity exists mainly during the lean season (March–June). Local dwellers keep acquiring their daily needed water from the sacred grove source. In the absence of this source, the dwellers would have to go far-away places for their daily water requirement. The importance of sacred groves in conserving water is well recognized from both practical experience and documentary evidence[27].

Sacred groves are considered to reduce the chance of flash floods as they regulate the runoff because of the presence of comparatively rich vegetation and thick litter cover that release the water slowly during the lean season[27]. This helps to supply daily needed water to local dwellers during periods of water scarcity. Some studies in Meghalaya have shown that a well conserved sacred grove can prevent soil erosion and nutrient washout by reducing the erosive power of the runoff water[28]. Other studies in the Himalayan region have also revealed that sacred groves have a very distinct role in regulating water flow and sedimentation[29].

It has been stated that sacred groves are important in the Western Ghats region of southern India, as they are associated with perennial streams which create important water supply sources throughout the year for the communities living in their proximity[4]. Some studies have shown that in the Ratnagiri district of Maharashtra, during the summer months, the groves are major sources of water that help meet the daily needs of local dwellers[28].

Sacred groves (where the whole micro-environment remains untouched because of certain beliefs, taboos, etc.) are necessary for maintaining the good health of a stream, restoring and maintaining the natural level of water, minimizing sedimentation and woody debris in the channel and maintaining associated riparian vegetation[29].

The study showed that the water samples of the three sacred groves from the Himalayan region conform to WHO standards for potable water. Sacred grove waters are endowed with better physico-chemical properties than waters of adjacent sites. Water from the oak-dominated forests has better drinking water quality compared to deodar-dominated forests. The latter shows higher hardness and TDS.

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Kinematics and timing of brittle–ductile shearing of Mylonites along the Bok Bak fault, Peninsular Malaysia

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Study on the Bok Bak fault in Peninsular Malaysia reveals it to be a predominantly dextral brittle–ductile strike slip fault zone. This fault zone is characterized by gentle to sub-horizontal NE stretching lineation. The deformation occurred in a brittle–ductile domain. ^{40}Ar/^{39}Ar radiometric dating of biotite from the mylonite assigns an age of 136.1 ± 1.4 Ma. This age is the first reported radiometric dating of the Bok Bak fault, suggesting that the fault affected Sundaland prior to the collision between India and Asia, and therefore indicates an early faulting in the Malay Peninsula.

Keywords: ^{40}Ar–^{39}Ar dating, Bok Bak fault, Peninsular Malaysia, Sundaland, strike slip.

CONTINENTAL core of SE Asia (Sundaland) is dominated by Cenozoic tectonics, which include the genesis of large-scale faults such as the Khlong–Marui fault, Ranong fault, Three Pagoda fault, Sagaing fault and Ailao-Shan Red River fault. These Cenozoic faults have been linked to either the slab pull of the Proto-South China Sea, or escape tectonics[1]. In Peninsular Malaysia, the fault systems which encompasses the Bok Bak fault, Kuala Lumpur fault, Bukit Tinggi fault, Mersing fault, and Lebir fault show trends parallel to the large-scale faults of SE Asia such as the Three Pagoda fault, Mae Ping fault and Ailao Shan–Red–River fault. The faults of Peninsular Malaysia are considered to have pre-dated the India–Asia collision event[2–10], although information on kinematics and dating of these faults is lacking. As such, their implication to the regional tectonics is inconclusive. Here we examine the kinematics of the Bok Bak fault, and date its timing by the ^{40}Ar/^{39}Ar method.

The Bok Bak fault is classified as one of the terrane crossing faults of Peninsular Malaysia[3]. It is visible as NNW and NW trending of en echelon tectonic lineaments sets spanning of ~200 km (Figure 1). A structural study was carried out in the study area, NW of Peninsular Malaysia, near the border of Kedah-Perak state, where mylonite and sheared granite along the Bok Bak fault zone are well exposed. Several kinematic studies of mylonite of other faults in Peninsular Malaysia[11,12] and

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