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Bio-physical-chemical studies of swamps in the Nilgiris, Tamil Nadu

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Abstract: Wetland ecosystems play a key role in maintaining water quality. Twelve swamps of Nilgiris district were selected based on altitude and land use to study the physico-chemical properties of swamp soil, water and the adjoining stream water which fed the swamps. The *Scirpus* spp. was the dominant species in all swamps followed by *Cyperus* spp. and *Kyllinga* spp. Soils were strongly acidic, free from salinity, rich in organic carbon (1.5 - 2.8 %), low to medium in available nitrogen (224 - 476 kg ha^{-1}), high in available phosphorous (39 - 67 kg ha^{-1}) and low in available potassium (11 - 197 kg ha^{-1}). Both the swamp and adjoining stream water quality was determined as being of adequate quality for drinking and irrigation as evidenced from the hydrochemical parameters. Agriculture and habitation land uses contribute higher nutrient load to the stream as well as swamp water as compared to the tea plantation, mixed forest and shola forest. Swamp water was more than three times higher in nutrient load than the streams which fed them because of temporal stagnation of water in the swamps which favors slow accumulation of nutrients. The effect of land use to govern the swamp water quality outperformed the altitude effect. A blend of policy, social and institutional mechanisms is needed for their conservation and making management priorities for ecological protection of Nilgiris Biosphere Reserve.

Key words: India, Nilgiris, permeability index, soil nutrients, swamps, vegetation, water quality.

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Introduction

Over exploitation and improper management of natural resources are of great concern as they lead to environmental degradation and reduce the carrying capacity of any ecosystem. Wetland ecosystem is now-a-days a threatened ecosystem in India. India has a rich variety of wetland habitats accounting about 18.4 % of the total geographical area of the country (Gupta *et al.* 2008). Wetlands are one of the most productive resources in the ecosystem and play an important role in the freshwater system. Swamps and marshes are physio-geographic features of low-lying areas resulting from hydrologic and geomorphic peculiarities (Taylor *et al.* 1990). They support characteristic vegetation because of specialized edaphic conditions, as influenced by free water accumulation and greatly contribute to the quality of both surface and ground water supplies (Miller 1990).

The Western Ghats-Sri Lanka area has been noted as a biodiversity hotspot (Myers *et al.* 2000) because it contains unique ecosystems, and rare and endemic species. The Nilgiris (Blue Mountains), situated in the Western Ghats in South

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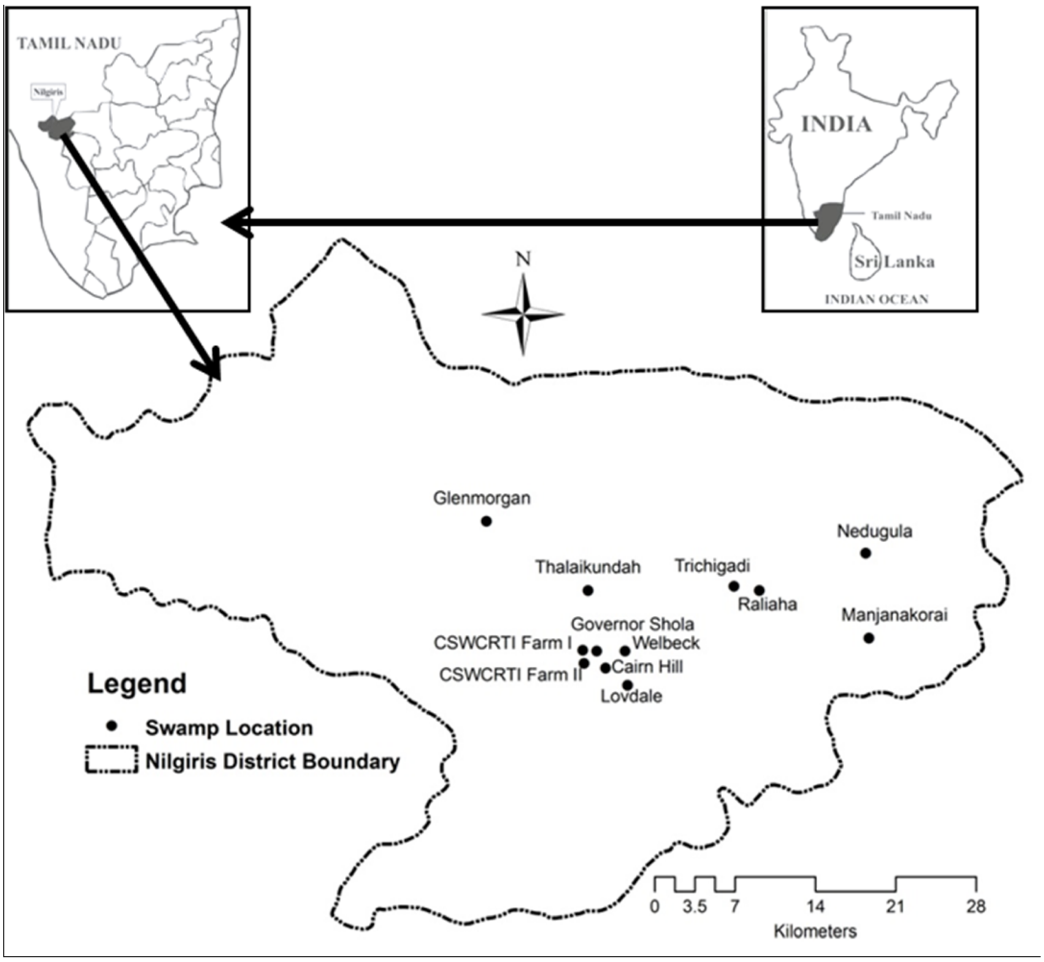

Fig 1. Map of the study area showing the location of the swamps.

India, have unique climatic-climax vegetation called "shola" forest and vast stretches of grasslands with swampy dots here and there. The shola forest, grassland and swamps are considered as associated ecosystems in the Nilgiris. Large-scale plantations of *Eucalyptus globulus* (bluegum), the native shola forest, grasslands and swamps of the Nilgiris have been extensively destroyed and converted to other land uses because they were considered to be of secondary origin and not as important as the forests (Champion & Seth 1968). A large proportion of the shola vegetation loss is due to expansion of agriculture and plantations coupled with the domestic requirement of fuel wood and fodder by the local communities (Sekar 2008). The hydrological implication of grassland conversion into plantations of fast growing *Eucalyptus* revealed 16 and 27 % reduction in water yield for first and second rotation of *Eucalyptus* in comparison to grasslands (Sharda *et al.* 1988). This drastic change in the land use system has a greater negative impact on associated ecosystems like grasslands and swamps particularly on vegetation and water quality parameters.

Characterization of ecosystems is crucial in current strategies for managing natural resources and monitoring environmental changes (Okude 2006) and also taking appropriate policy decisions. The quality of water in any ecosystem provides significant information about the available resources for supporting life in that ecosystem. Good quality of water resources depends on a large number of physicochemical parameters, the magnitude and source of any pollution load; and to assess that, monitoring of these parameters is essential.

A body of research exists on stream water quality at global (Clausen & Biggs 2000; Collier *et al.* 2000; Joshi *et al.* 2002; Walsh *et al.* 2001) and national levels (Sharma 1986); but very little information is available in relation to physico-chemical characteristics of swamp soil and water in the Nilgiris. Therefore the present study was conducted to assess the physico-chemical properties of soil and water in the swamps of the Nilgiris district, India; to assess the water quality of the streams which fed those swamps; to compare observed levels of studied parameters with the corresponding WHO guidelines values for drinking-water quality and FAO guideline for irrigation-water quality; and to identify policy implications.

Materials and Methods

Study area

The study area is the Nilgiris district, located in Tamil Nadu state of India, bounded by 11° 30′ and 11° 15′ North latitude and 76° 45′ and 77° 00′ East longitudes with elevation ranging from 400 to 2636 m amsl (Fig. 1). The Nilgiris is an ancient land mass thrust upwards at the junction of the two major mountain ranges, namely Western and Eastern Ghats near the southern end of India some 70 million years ago. The total areal extent of the district is around 2551 km^2 and is one of the smallest districts in Tamil Nadu state (Lakshumanan *et al.* 2012). The plateau is flanked by steep escarpments on all sides, dropping down to the Karnataka plain to the north (*ca.* 850 m amsl), the Malabar coast of Kerala to the west (*ca.* 250 m amsl), and the Tamil Nadu plain to the south and east (*ca.* 400 m amsl). Major part of the district is under forest cover (56 %), about 20 % of the district is under plantation crops such as tea, coffee, vegetables, arecanut, coconut, etc., out of which tea plantation dominates and is found on all slopes. Among the twelve swamps studied, four swamps are protected from any biological hindrance and anthropogenic activities. These swamps are Cairn hill, Governor shola, Glenmorgan and Raliaha swamps, the eight remaining swamps are unprotected.

Average annual rainfall of the district is 1695.7 mm. The rainfall pattern is a bimodal distribution during SW monsoon (62 %) and NE monsoon (22 %). Summer and winter rainfall contributes only 2 and 14 %, respectively, to the annual rainfall (Fig. 2). During summer the maximum temperature ranges from 21 °C to 25 °C and the minimum from 10 °C to 12 °C. During winter these are from 16 °C to 21 °C and 1 to 2 °C, respectively. The climate is of the tropical mountain type (Meher-Homji 1967).

Nilgiris district is a mountainous district of Tamil Nadu with many hill ranges and broad valleys that slope down towards the plain. The Nilgiris hills rise abruptly from the plains (300 m amsl) to an average elevation of 1370 m amsl. Some of the prominent peaks are the Doddabetta (2634 m), the highest peak in Tamil Nadu, Kolari (2625 m), Mukurthi (2554 m), Kudikadu (2590 m), Devabetta (2552 m), the conical grass covered Bear hill (2531 m) and Nilgiris peak.

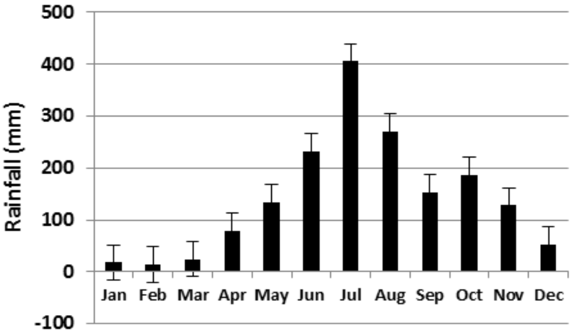

Fig. 2. Monthly average normal rainfall of the Nilgiris District.

Geomorphology and soils

The lithology of the study site is a charnockite group of bedrocks, covered by the ubiquitous red laterite or lateritic soil. The bedrock is composed of charnockites and granitoid gneisses and the soils are classified as andisols (Caner *et al.* 2000). The soil of Nilgiris district can be broadly classified into five major soil types *viz.,* lateritic soil, red sandy soil, red loam, black soil, alluvial and colluvial soil. Major part of the district was covered by lateritic soil, red sandy soil; and red loams are occurring as small patches. Black soil is developed in the valleys; where water logging is also common during the monsoon period. Based on the erodible nature, the soil was classified as highly eroded clay, very deep eroded clay, moderately eroded clay, gravelly clay, moderately eroded gravelly clay, gravelly loam with escarpment, calcareous loam and calcareous cracking clay. The alluvial and colluvial soils are seen along the valleys and major river courses, respectively. The Doddabetta landform has many high peaks having steep slope and escarpments with or without soil cover around which a radial drainage pattern occurs (Parthasarathy & Vaidyanathan 1974). The Nilgiris falls in the tropical zone of weathering. Most of the Nilgiris is deeply weathered and at some places thick soil cover of up to 40 m is found. The exposed area reveals a humus zone of 0.50 to 1.0 m

Table 1. Details of selected swamps and their status in the study area.

Location	Associated land use	Disturbance	Altitude (m)	Ownership
Cairn Hill	Mixed forest	Human & Wild life	1807	Protected area, Forest department
CSWCRTI Farm-1	Mixed forest	Human & Wild life	2193	Land leased by forest department to ICAR
CSWCRTI Farm-2	Mixed forest	Human & Wild life	2130	Land leased by forest department to ICAR
Glenmorgan	Shola forest	Human, Fire & Wild life	2200	Protected area by Forest department
Governor shola	Mixed forest	Human, Fire & Wild life	2168	Protected area by Forest department
Lovdale	Mixed forest	Human & Domestic animals	2182	Common property resources
Manjanakorai	Tea plantation	Human & Domestic animals	2189	Common property resources
Nedugula	Agriculture	Human & Wild life	2283	Rural- Common property resources
Raliaha	Shola forest	Human & Wild life	1800	Protected area, Forest department/ Coonoor Municipality/ Defense
Thalakundah	Habitation	Human & Domestic animals	2150	Common property resources
Trichigadi	Agriculture	Human & Domestic animals	1962	Common property resources
Welbeck	Mixed forest	Human & Domestic animals	2168	Private land

followed by red or brown or yellow silt and clay. The weathered zone between the clay and the fresh rock is normally about a meter thick.

Vegetation

The vegetation is a mixture of stunted forest (locally called sholas), and grasslands. The swamps occur in the valleys. The sholas are upper montane rainforests (Ashton 2003) dominated by the *Lauraceae* with many species endemic to the Western Ghats, and a few restricted to the Nilgiri/Palni highlands (Mohandass & Davidar 2009). The predominant grassland types in the upper plateau belong to the *Chrysopogon zeylanicus* and *Arundinella* spp. (Blasco 1970). In spite of their low productivity, these grasslands have been used by the Toda people as a grazing ground for their buffaloes. At elevations above 2,300 m amsl the *Pollinia phaeothrix* and *Arundinella fuscata* occur on soils with a high content of organic matter (Blasco 1970).

Selection of swamps

The study was carried out during 2006 and 2007. The list of available wetlands/swamps was collected from the District Revenue Department along with the map. Out of 37 listed swamps, 12 swamps were selected for the study based on altitudes, land use of the catchment and representing different zones of the District (Table 1). Detailed transect survey of each swamp was conducted to collect information about altitude, ownership, associated land use in the catchment, present condition and influence of biotic factors including the dominant vegetations in each site.

Vegetation study

The vegetation survey was done in each swamp to identify the plant communities. After identification of the swamp vegetation species, the species abundance was estimated. Five quadrants of 1 m x 1 m size were laid, in each swamp. The plant species with < 1 m height were considered as herbs. The floristic matrix was compiled using Microsoft Office Excel, with abundance of all the species. The data was assessed for the polythetic divisive classification of communities and species using two-way indicator species analysis (TWINSPAN) (Hill *et al.* 1975).

Soil sampling and analysis

Soil samples were collected from the dry swamp bed for two depths (0 - 20 and 20 - 40 cm), air dried, sieved and used for chemical analysis in the laboratory. The soil pH and electrical conductivity (EC) were measured by pH meter and conductivity meter (Jackson 1958), respectively. The chemical constituents of soil like Walkley-Black organic carbon (OC) by wet digestion method (Nelson & Somners 1996); available nitrogen by micro-Kjeldahl method (Subbiah & Asija 1956); phosphorus by molybdate method using UV Spectrophotometer (Bray & Kurtz 1945) and potassium by flame photometer (Hanway & Heidel 1952) were analyzed.

Water sampling and analysis of water quality

Water samples were collected from the selected swamps 10 m inside from the swamp boundary. Geographical coordinates and elevation of each sampling location was recorded using a handheld global positioning system (GPS). The sampled water was stored in soda lime glass storage bottles sealed by bromo-butyl synthetic rubber stopper, further protected by triple aluminum cap using hand held crimping tool. Collected samples were analyzed in the laboratory to measure the concentration of the hydrochemical parameters such as pH, EC, CO_3, HCO_3, Cl, Ca, Mg, Na and K using standard procedures (APHA 2006) and compared with the standards. Different water quality indices are also used to describe the swamp water quality and discussed below:

Sodium Adsorption Ratio (SAR): SAR is the indication of sodicity or alkalinity hazard of irrigation water and was computed from the following formula (Richards 1954),

$$SAR = Na^{+} / [\sqrt{(Ca^{++} + Mg^{++})} / 2]$$

where concentration of cations are in me l^{-1}

Exchangeable Sodium Percentage (ESP): ESP is also a measure of the sodicity hazard of irrigation water formed due to high concentration of sodium ion in the exchange complex. ESP was calculated as follows (Richards 1954):

$$ESP = Na^{+} / (Ca^{++} + Mg^{++} + Na^{+} + K^{+})$$

where concentration of all the cations are in me l^{-1}

Residual Sodium Carbonate (RSC): It's an indicator of bicarbonate hazard and which was calculated as follow (Richards 1954):

$$RSC = (CO_3^{--} + HCO_3^{--}) - (Ca^{++} + Mg^{++})$$

where concentrations of both cations and anions are in me l^{-1}.

Permeability Index (PI): Long-term use of irrigation water affects the permeability of soil through the influence of sodium, calcium, magnesium and bicarbonate. Doneen (1964) has established a criterion to assess the suitability of water for irrigation called permeability index (PI). It is calculated by using the following formula (Doneen 1964):

$$PI = \frac{Na + \sqrt{HCO_3}}{Na + Ca + Mg} X\ 100$$

where all the ions are expressed in me l^{-1}.

Langelier Saturation Index (LSI): To understand the scaling potential of the swamp water, Langelier Saturation Index (LSI) is used and is defined as (Langelier 1936):

$$LSI = pH - pHs$$

Statistical analysis

Physico-chemical properties of swamp soils were compared with their standard ratings as low, medium and high. Similarly, water quality parameters were compared and interpreted based on water quality standards for drinking set by BIS (1991), USEPA (2003), WHO (1993) and irrigation water quality standards set by FAO (2003). Data was also subjected to descriptive statistics *viz*., mean, standard deviation (SD), coefficient of variation (CV) and correlation (WASP-2.0). The standard errors were also calculated and error bars were given with the graphs.

Results

Swamp biotic structure and composition

The predominant vegetation observed in the swamps is presented in Table 2. The species variation was observed between the swamps. The *Scirpus* spp. is the dominant species in all the swamps followed by *Cyperus* spp. and *Kyllinga* spp.. Many species of fodder grasses are also present in the swamps such *Pennisetum* spp., *Anthoxanthum* spp., *Tripogon* spp., etc. all of which are commonly grazed by the cattle and wildlife. Species like *Scripus* spp., *Isachne* spp., *Evolvulus* spp., *Trifolium repens, Centella asiatica, Paspalum* spp., *Fragaria* spp., *Polygonum* spp., *Panicum* spp., *Anthoxanthum* spp., *Cyperus* spp., *Kyllinga* spp., *Rotunda* spp., *Commelina* spp., *Drosera* spp. are observed at mid altitude where as *Rorippa* spp., *Rotunda* spp., *Scirpus* spp., *Polygonum* spp., *Panicum* spp., *Kyllinga*

Table 2. Dominant vegetation recorded in the selected swamps in the Nilgiris District.

Location	Number of Species	Dominant species
Cairn Hill	62	*Scripus* spp., *Centella asiatica, Paspalum* spp., *Rorippa* spp., *Fragaria* spp., *Polygonum spp.*
CSWCRTI-Farm-1	48	*Scripus* spp., *Centella asiatica, Paspalum* spp., *Fragaria* spp., *Polygonum* spp., *Panicum* spp., *Anthoxanthum* spp.,*Cyperus* spp., *Kyllinga spp., Rotunda* spp.,*Commelina* spp., *Drosera* spp., *Evolvulus* spp.
CSWCRTI-Farm-2	49	*Scripus* spp., *Centella asiatica, Paspalum* spp., *Fragaria* spp., *Polygonum* spp., *Panicum* spp., *Anthoxanthum* spp., *Cyperus* spp., *Kyllinga* spp., *Rotunda* spp., *Commelina* spp., *Drosera* spp., *Evolvulus* spp.
Glenmorgan	68	*Scripus* spp., *Centella asiatica, Paspalum spp., Rotunda* spp., *Anotis* spp., *Ischaemum* spp.,*Oxalis* spp., *Kyllinga* spp., *Convolvulus* spp.
Governor shola	55	*Scripus* spp., *Anthoxanthum* spp., *Tripogon* spp., *Ischaemum* spp. , *Isachne* spp., *Centella* spp., *Eulex* spp., *Evolvulus* spp.
Lovdale	52	*Scripus* spp., *Centella asiatica, Pennisetum* spp., *Paspalum* spp.
Manjanakorai	45	*Scripus* spp., *Centella asiatica, Pennisetum* spp., *Paspalum* spp., *Rorippa* spp., *Commelina* spp., *Trifolium repens, Cyperus* spp.
Nedugula	44	*Scripus* spp., *Rotunda* spp., *Rorippa* spp., *Panicum* spp., *Polygonum* spp.
Raliaha	63	*Pennisetum clandestinum*
Thalaikundah	43	*Pennisetum clandestinum*
Trichigadi	48	*Scripus* spp., *Centella asiatica, Paspalum* spp., *Polygonum* spp., *Panicum* spp., *Oxalis* spp., *Kyllinga* spp., *Cyperus* spp.
Welbeck	50	*Scripus* spp., *Pennisetum* spp. *Rorippa* spp., *Fragaria* spp.

spp. are observed at relatively higher altitude i.e., 2000-2300 m. The commonly observed wild animal and birds in the swampy area are the Black eagle (*Ictinaetus malayensis*), Grey jungle fowl (*Gallus sonneratii*), Pond heron (*Ardeola grayii*), Jungle crow (*Corvus macrorhynchos*), Nilgiri laughing thrush (*Trochalopteron cachinnans*), Hill Myna (*Gracula religiosa*), Black bird (*Turdus merula*), Spotted dove (*Spilopelia chinensis*), Indian Bison (*Bos gaurus*), Deer (*Cervidae*), Malabar squirrel (*Ratufa indica*), Porcupine (*Hystricomorph hystricidae*), Wild boar (*Sus scrofa*) and Rabbit (*Lepus curpaeums*).

Chemical properties and fertility status of the swamp soils

Soil pH and EC: The pH values in the study area ranged from 4.4 to 6.1 in the surface soils and 4.6 to 6.0 in the sub-surface soils with mean and SD values of 5.25 and 0.45; and 5.28 and 0.40, respectively with very low variability (CV) between the swamps (Table 3). The soils at all the swamp sites were strongly acidic to very strongly acidic in reaction. The EC values in the study area ranged from 0.01 to 0.36 dS m^{-1} in the surface soils and 0.02 to 0.96 dS m^{-1}, in the sub-surface soils with mean and SD values of 0.15 and 0.12 dS m^{-1}, and 0.15 and 0.26 dS m^{-1}, respectively.

Organic carbon (OC): The organic carbon content in the study swamps ranged from 1.80 to 2.90 % in the surface soils and 1.50 to 2.80 % in the sub-surface soils with mean and SD values of 2.50 and 0.36 %; and 2.43 and 0.48 %, respectively with very low variation (CV) between the soils of different swamp sites (Table 3). Therefore the soils of the study area can be categorized as high in terms of OC. The organic carbon content of surface soil was greater than sub-surface soil in all the study sites with only minor exception.

Available nutrients: Available nitrogen status varied from 224 to 476 kg ha^{-1} with an average value of 331 and 350 kg ha^{-1} at 0 - 20 cm and 20 - 40 cm depth, respectively (Table 3). At both the sampling depths, soils were low to medium in available nitrogen in terms of soil fertility rating (Nelson & Somners 1996). About 33.3 % of swamp sites with low and 63.6 % were medium in available nitrogen at both the sampling depths.

The available phosphorous content in the swamp soils varied between 39 and 67 kg ha^{-1} at

Table 3. Soil properties at different swamps under study in the Nilgiris District.

Site	pH		EC (dS m^{-1})		OC (%)		Available Nutrients (kg ha^{-1})					
							N		P		K	
	I	II	I	II	I	II	I	II	I	II	I	II
Cairn Hill	5.3	6.0	0.01	0.06	2.7	2.6	280	280	39	45	24	11
CSWCRTI-Farm-1	4.4	4.8	0.15	0.06	2.9	2.7	420	364	48	51	29	61
CSWCRTI-Farm-2	5.2	5.2	0.13	0.03	2.8	2.8	364	364	53	48	87	32
Glenmorgan	5.2	4.9	0.15	0.05	2.4	2.4	476	476	45	66	139	102
Governor shola	4.7	5.3	0.1	0.02	1.8	1.5	336	224	62	41	16	17
Lovdale	6.1	5.3	0.35	0.11	1.9	1.7	224	252	58	57	112	43
Manjanakorai	5.9	4.6	0.05	0.16	2.9	2.9	364	420	42	59	37	27
Nedugula	5.4	5.5	0.36	0.02	2.3	2.8	308	448	67	47	105	197
Raliaha	5.1	5.5	0.03	0.13	2.4	2.6	308	364	56	51	10	14
Thalakundah	5.2	5.5	0.14	0.96	2.5	2.8	280	448	46	55	108	172
Trichigadi	5.1	5.7	0.27	0.16	2.6	1.8	280	252	51	67	55	17
Welbeck	5.4	5.1	0.04	0.05	2.8	2.6	336	308	41	45	70	21
Mean	5.3	5.3	0.14	0.15	2.5	2.4	331	350	51	53	66	60
SD	0.5	0.4	0.12	0.26	0.4	0.5	68	87	9	5	44	64
CV (%)	8.5	7	80.7	172	13.9	20.0	21	25	17	16	66	108

I=0-20 cm & II=20-40 cm

both the soil sampling depths which is considered to be very high in terms of soil fertility rating (Nelson & Somners 1996). Soils of all the swamp sites are high in phosphorous content with the mean and SD of available phosphorus content was 50.67 and 8.78 kg ha^{-1} and 52.67 and 8.32 kg ha^{-1}, respectively.

The status of available potassium content in the swamp soils ranged from 16 to 112 kg ha^{-1} at both the sampling depths which is rated as low in terms of soil fertility (Nelson & Somners 1996). No clear trend was observed between the sampling depths with respect of available potassium, but variation between the swamps was very high as indicated in CV (66 & 108 at 1st and 2nd soil depths).

Hydrochemistry of swamp water and indices for irrigation use

Swamp water quality was generally good as evidenced from the hydrochemical parameters (Table 4). The pH value did not vary too much between different swamps in the study area where some of the sites were protected and some were unprotected. The pH of swamp water varied from 8.3 - 8.7 indicating slightly alkaline to alkaline in nature, which was also supported by the presence of large amounts of Ca^{++} (2.8-4.8 me l^{-1}) and Mg^{++} (1.2 - 2.8 me l^{-1}).

Conductivity is a good and rapid method to measure the total dissolved ions and is directly related to total solids. Swamp water of the entire study area was non saline as evidenced from electrical conductivity (EC) values, which ranged from 0.02 - 0.25 dS m^{-1}.

The bicarbonate concentration of swamp water ranged between 2.0 and 4.4 me l^{-1} and mainly precipitated as calcium and magnesium bicarbonate. No carbonate content was detected from the selected swamps under study.

Chloride concentration varied from low to medium (2.8 - 4.4 me l^{-1}) and mainly concentrated in the areas surrounded by forests, especially shola forest.

The hardness is the parameter of water quality used to describe the effect of dissolved minerals (mostly Ca and Mg). The Calcium concentration in the water is in the range of 2.8 - 4.8 me l^{-1} with the mean value of 3.7 me l^{-1} where the Mg concentration varied between 1.2 and 2.8 me l^{-1}.

The sodium concentration in the swamp water varies from 0.2 - 1.7 me l^{-1} with an average value of

Table 4. Quality parameters of water collected from selected swamps in the study area.

Location	pH	EC	HCO_3	Cl	Ca	Mg	Na	K	SAR	ESP	RSC	PI	LSI
Cairn Hill	8.7	0.25	3.2	3.6	4.4	2.8	1.4	0.27	0.74	16.3	-4.00	37.08	1.30
CSWCRTI Farm-1	8.7	0.02	2.8	3.2	3.6	2.4	0.3	0.02	0.17	4.8	-3.20	31.32	1.20
CSWCRTI Farm-2	8.6	0.05	2.4	3.6	3.2	1.2	0.3	0.05	0.20	6.4	-2.00	39.34	1.00
Glenmorgan	8.5	0.10	2.0	4.4	3.6	2.0	0.4	0.14	0.24	6.7	-3.60	30.24	0.85
Governor shola	8.6	0.02	2.0	3.6	4.8	1.6	0.2	0.02	0.11	3.0	-4.40	24.46	1.10
Lovdale	8.8	0.17	3.6	3.6	3.2	1.6	1.0	0.13	0.65	17.2	-1.20	49.95	1.30
Manjanakorai	8.4	0.03	2.4	4.0	3.2	2.4	0.3	0.06	0.18	5.1	-3.20	31.34	0.82
Nedugula	8.6	0.12	4.0	2.8	2.8	1.6	0.6	0.08	0.40	12.0	-0.40	52.00	1.10
Raliaha	8.3	0.01	2.8	2.8	3.6	1.2	0.2	0.02	0.13	4.0	-2.00	37.47	0.86
Thalakundah	8.4	0.32	2.8	3.2	4.4	2.8	1.7	0.31	0.90	19.1	-4.40	37.90	0.91
Trichigadi	8.3	0.15	4.4	3.2	3.6	1.6	0.7	0.02	0.43	11.9	-0.80	47.42	0.97
Welbeck	8.8	0.06	2.4	2.8	3.6	1.2	0.4	0.06	0.26	7.7	-2.40	37.48	1.20
Mean Value	8.5	0.1	2.8	3.4	3.7	1.9	0.6	0.1	0.34	8.8	-2.8	38	1.05
SD	0.2	0.1	0.7	0.4	0.6	0.6	0.5	0.1	0.26	5.5	1.32	8.33	0.17
CV (%)	2	96	25	11	16	32	83	102	76	63	-48	21.9	16.2

Unit of all the ion concentration is me l^{-1}; unit of EC is dS m^{-1}

EC = Electrical Conductivity, SAR = Sodium Adsorption Ratio, ESP = Exchangeable Sodium Percentage, RSC = Residual Sodium Carbonate, PI = Permeability Index, LSI = Langelier Saturation Index

0.6 me l^{-1}. On the other hand, potassium concentration is very low (0.02 - 0.27 me l^{-1}).

The water quality indices indicated the suitability of swamp water for irrigation as there was no sodicity hazard (Table 4). The SAR and ESP were all very low and possessed no threat of sodicity. SAR and ESP ranged between 0.11 - 0.90 and 3.0 - 19.1, respectively, with average values of 0.34 and 8.8, respectively.

Permeability index (PI) is an important factor to judge the quality of irrigation water in relation to soil for agricultural development. According to this index water can be classified into three classes. Class I and class II water with 75 % or more of maximum permeability is suitable for irrigation purpose, while class III water having 25 % of maximum permeability is not suitable. In the present study the PI ranged from 24.4 - 52.0 meq l^{-1} (Table 4).

Problems of scaling in industrial large boilers as well as domestic utensils can be judged by Langelier Saturation Index (LSI) but it provides no indication of how much scale or calcium carbonate will actually precipitate to bring water to equilibrium. It simply indicates the driving force for scale formation and growth in terms of pH as a master variable. Calculated LSI values, given in Table 4 showed that 100 % of the samples have positive LSI values.

Water quality of protected and unprotected swamps

The water quality was compared between the protected and unprotected swamps. The results (Fig. 3) showed that both the swamp water is suitable for drinking (WHO 1993) and irrigation (FAO 2003) purposes. Except Ca, Cl and HCO_3 ions, all the other ions in the swamp water showed statistically insignificant difference with respect to protection. The protected swamp water is higher in Ca and Cl whereas the unprotected swamp water is rich in Na and HCO_3.

Swamp and adjoining stream water quality under various land uses

In the study area, there are five main land uses associated with swamps and streams. They are pure shola forest, mixed forest, agriculture, tea plantation and habitation. Although the stream water is suitable for drinking and irrigation, the nutrient load from agriculture and habitation is considerably higher than for the three other land uses (Fig. 4). The land use wise contribution of the

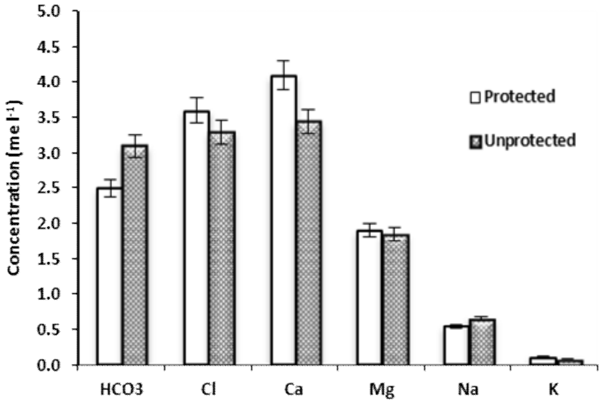

Fig. 3. Water quality of protected and unprotected swamps.

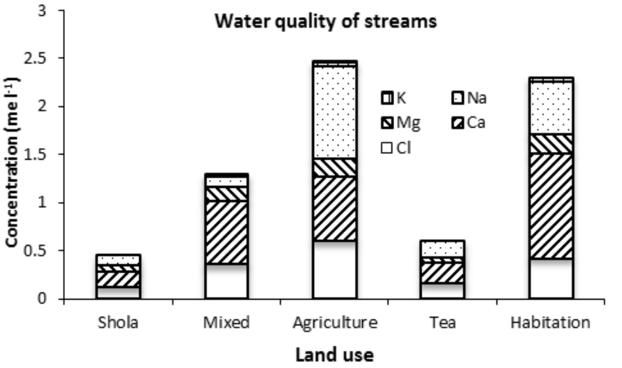

Fig. 4. Water quality of the swamp feeding streams associated with different land uses.

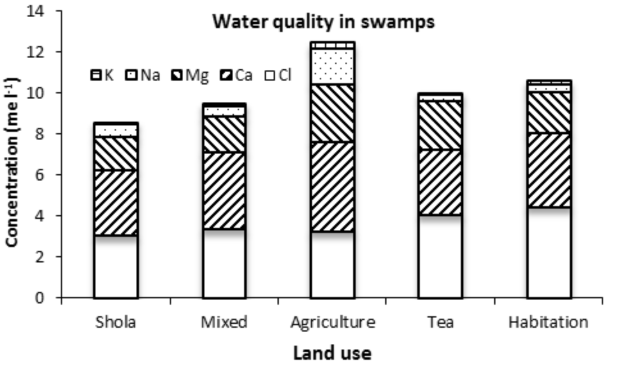

Fig. 5. Water quality of the swamps associated with different land uses.

measured ions to the stream follows the order of Agriculture > Habitation > Mixed forest > Tea plantation > Shola forest. Among the cations, Ca and Na and among the anions, Cl is the main contributor. The contribution of different land use to measured ion concentrations in the swamps follows the order of Agriculture > Habitation > Tea plantation > Shola forest (Fig. 5).

In the study area the swamps are distributed into two types based on the altitude viz., higher altitude swamps (swamps situated at an altitude > 2000 m) and lower altitude swamps (swamps situated at an altitude < 2000 m). The data revealed that with the exception of bicarbonate, the other water quality parameters were either higher in the higher altitude swamps (Fig. 6).

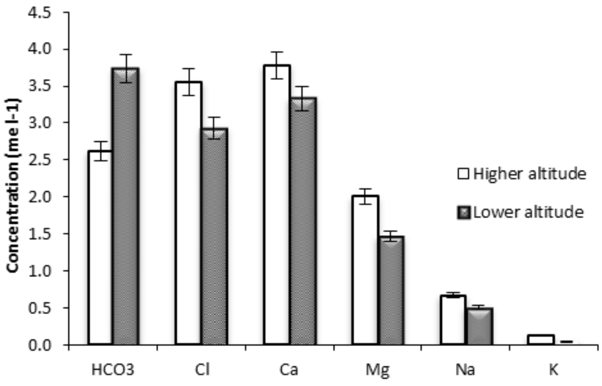

Fig. 6. Water quality of the swamps associated with altitude.

Discussion

Swamp biotic structure and composition

The species variation was observed between the swamps and observed that the *Scirpus* spp. is the dominant species in all swamps followed by *Cyperus* spp. and *Kyllinga* spp. *Rorippa* spp. has been found to be the indicator species for the wetness in the swamps (Mohandass *et al.* 2009). This variation in species composition might be attributed to variation in altitude and associated climatic factors. In the protected swamps the number of species was more in comparison to those swamps which were disturbed by human and domestic animals. A vegetation survey of swamps in the Nilgiris was studied by Puyravaud *et al.* (2012) and reported that a total of 78 species belonging to 61 genera and 31 families were recorded from the five swamps. The families with the largest number of species were *Poaceae, Cyperaceae* and *Asteraceae*. The average species richness excluding trees was found to be 53 species per swamp.

The relationship between swamp vegetation diversity and water quality parameters was not clear from this study. However, *Scirpus* spp., *Centella asiatica* and *Paspalum* spp. are the most versatile species found in all the study sites irrespective of water quality of swamps. The species like *Pennisetum clandestinum, Scirpus* spp., *Centella asiatica, Paspalum* spp., *Rorippa* spp., *Fragaria* spp. *and Polygonum* spp. are associated with the study sites where water had high in EC, Cl, Ca, Mg, Na, K, SAR and ESP. *Rorippa* spp., and *Fragaria* spp. are not found in sites with high HCO_3 and low in Cl contents. *Anthoxanthum* spp., *Cyperus* spp., *Kyllinga* spp., *Rotunda* spp., *Commelina* spp., *Drosera* spp. and *Evolvulus* spp. *Tripogon* spp., *Ischaemum* spp., *Isachne* spp., *Ulex* spp. and *Evolvulus* spp. are observed only in a few study sites where Cl and Ca concentrations were elevated. Indeed, high concentrations of chloride in freshwaters are an index of pollution (Sawant *et al.* 2010). Plant distribution is closely related to wetland water chemistry (Golet and Lowry 1987). In all the swamps investigated here, water quality parameters were less than the critical limits to restrict the growth and development of the plant species identified. Moreover, Ibekwe *et al.* (2007) reported that wetlands with 50 % plant cover may promote the growth of diverse microbial communities that facilitate decomposition of chemical pollutants in surface water, and improve water quality. Nevertheless, we found no noticeable relationship between species diversity and the measured water quality parameters. It is, therefore, possible that other factors are controlling plant diversity in these systems.

Chemical properties of swamp soils

The soils of the swamp sites were strongly acidic to very strongly acidic in reaction but the pH of the sub-surface soil was higher than the surface soil. The lower pH value in surface horizons is mainly due to leaching of bases during high rainfall (Sivashankaran *et al.* 1993). In the earlier studies on fresh water swamps of Kerala, Varghese & Kumar (1997) reported moderate acidic to neutral pH as well as lower nutrient contents was due to continuous water logging effect. A similar observation was also made by Ponnamperuma (1984). All of the swamp soils were free from salinity and the relatively higher SD value indicate that salt deposition in soil is not uniform probably as a consequence of the uneven anthropogenic activities coupled with diversified land use systems in the catchment area. However, the soil organic carbon content of all the soils of the study area falls under high category. The organic carbon content of surface soil was greater than sub-surface soil in all the study sites with only minor exception. This was attributed to the addition of litters and plant residues to surface horizons which resulted in higher organic carbon content in surface horizons than that of lower horizon. Deposition of organic carbon rich silt from a catchment area due to soil erosion and diversified vegetation in the swamps coupled with low oxidation due to low temperature are the major attributing factors for high OC content in the soils. The anaerobic conditions created under these inundated or flooded conditions often limit decomposition rates, thereby promoting organic matter accumulation in soils, and can alter reduction-oxidation reactions controlling nutrient transformations in wetland soils (Cherry 2011).

Available nutrients

The available soil nitrogen was varied between low and medium. In general, the swamps associated catchment with the land use of shola (natural forest) and man-made forest had low available nitrogen. The majority of the swamp sites were medium in available nitrogen due to high organic carbon content in the soils. There was significantly high correlation between available nitrogen and organic carbon content in the soils ($r = 0.59$, $P < 0.05$). The high organic matter content in this area due to slow degradation and consequent accumulation of organic matter coupled with a high litter fall leading to nitrogen adequacy. The important biogeochemical cycle in wetlands is the nitrogen cycle, and while the potential transformations are not unique to wetlands, the dominance of anaerobic transformations does set wetlands apart from other ecosystems. One such anaerobic transformation is denitrification, in which nitrate is lost to the atmosphere via conversion to nitrogen gas or nitrous oxide by bacteria (Mitsch & Gosselink 2007). In many wetlands, nutrient availability is dramatically altered by agriculture or other practices that increase nutrient loading, contributing to changes in ecosystem structure and function. The significance of nitrogen removal by plants is probably limited unless plants are grazed or harvested. On the other hand, the available phosphorous content in swamp soils is considered to be very high. Studies have indicated that the anaerobic conditions present in wetland systems may lead to high phosphorus bioavailability (Pant & Reddy 2001) and phosphorus is not removed from wetland environments via a gaseous stage (Richardson & Vepraskas 2001). The effectiveness of wetlands to remove phosphorus is dependent upon the amount of P already in the wetland, the volume of water moving into and through the wetland, the size of the wetland, and the retention time of water in the wetland. The available potassium in the study area was low in status due to less predominance of K rich micaceous and feldspar minerals in parent materials. The total nitrogen, phosphorus, potassium and organic carbon contents are lower in the soil than those of other forest ecosystems in the Western Ghats, which was supported by earlier reports (Varghese & Kumar 1997). High rainfall, the fluctuating water table and the characteristics of swamp may be responsible for the low nutrient levels, especially N and K (mobile elements, susceptible to leaching).

Swamp water quality

The pH of swamp water was slightly alkaline to alkaline in nature, which was also supported by the presence of large amounts of Ca^{++} and Mg^{++}. Most of the natural waters are generally alkaline due to the presence of sufficient quantities of carbonate (Trivedy & Goel 1987). The high pH may be due to the influence of fresh water influx, low temperature and organic matter decomposition as suggested by Ganesan (1992). The pH did not reveal any significant information about the expected contamination that may be induced by a point source of pollution. In general, pH was within the limit of standard values (APHA 2006) although for drinking water a pH range of 6 - 8.5 is recommended (USEPA 2003). However the quality of swamp water for irrigation appears to be good with respect to pH. The pH value significantly correlated with ESP ($r = 0.61$, $P < 0.05$) and LSI ($r = 0.86$, $P < 0.05$). The pH values observed at swamps of Niigiri is slightly closer to the pH value of Mothronwala swamp, Dehradun (Gupta *et al.* 2008). Gupta & Gupta (2006) stated that intense photosynthetic activities of phytoplankton will reduce the free carbon dioxide content resulting in increased pH values.

Swamp water of the entire study area was non saline as evidenced from electrical conductivity (EC) values and exhibited a clear sign of dilution of salts due to oozing out of fresh water from the subsurface and settlement of salts within the soil pores during travel of water from the surrounding highlands. Higher the value of dissolved solids, greater the amount of ions in water (Bhatt *et al.* 1999). The EC values were significantly correlated with Na ($r = 0.99$, $P < 0.05$), K ($r = 0.90$, $P < 0.05$) and SAR ($r = 0.98$, $P < 0.05$) and the EC of all the swamp sites was within the desirable limit for drinking water (USEPA 2003). This indicates that no adverse effect on human health and for crop production as associated with the EC of the swamp water was expected. In fresh water ecosystem, dissolved solids originate from natural sources and depend upon location, geological basins of water body, drainage, rainfall bottom deposits and inflowing water. Dissolved salts and minerals are necessary components of good quality water as they help maintain the health and vitality of the organisms that rely on this ecosystem service (Stark *et al.* 2000). Sharma & Kumar (2002) reported the presence of total dissolved solids ranged between 35.00 and 77.5 mg l^{-1} in the lakes of Garhwal Himalayas.

No carbonate content was detected from the selected swamps under study. The bicarbonate (HCO_3^-) values were significantly correlated with RSC ($r = 0.72$, $P < 0.05$) and PI ($r = 0.86$, $P < 0.05$). The level of bicarbonate is moderately suitable for irrigation (FAO 2003). Total alkalinity of water is due to the presence of the mineral salt present in it and primarily caused by the carbonate and bicarbonate ions (Adhikary *et al.* 2014). However, the concentration of chloride in the swamp water is such that no adverse health (BIS 1991; USEPA 2003; WHO 1993) and crop production (FAO 2003) effects are probable. Chloride occurs naturally in all types of water bodies. The most important source of chlorides in freshwater is the discharge of domestic sewage (Trivedy & Goel 1987). The higher concentration of chloride in water is an index of pollution and there is a direct correlation between chloride concen-tration and pollution levels (Sawant *et al.* 2010). The slightly moderate range of chloride concen-tration in these swamps was also probably due to accumulation of domestic sewages from neigh-boring human habitation and cattle sheds.

The suitability of water for domestic, industrial and drinking purpose can be determined from the concentration of bicarbonates, sulphates, chlorides and nitrates of calcium and magnesium (Rai 1974). Calcium values were significantly correlated with RSC ($r = -0.78$, $P < 0.05$) whereas magnesium was significantly correlated with Na ($r = 0.62$, $P < 0.05$), K ($r = 0.70$, $P < 0.05$) and RSC ($r = 0.63$, $P < 0.05$). The Ca and Mg values at all the sites were within the potable limit of both BIS and USEPA. Moreover, swamp water is also good for irrigation with respect to the concentration of Mg (FAO 2003). The concentration of sodium was significantly correlated with K (r = 0.90, $P < 0.05$) and SAR (r = 0.99, $P < 0.05$) on the other hand potassium concentration was significantly correlated with SAR (r = 0.88, $P < 0.05$). This indicates that the swamp water is very well suited for drinking and irrigation (FAO 2003). Total cation concentration in the swamp water of the study area followed the order of $Ca^{++} > Mg^{++} > Na^{+} > K^{+}$ and anion concentration $Cl^{-} > HCO_3^{-} > CO_3^{--}$. At all the study sites a very low sodicity hazard was found in the water indicating that the suitability of swamp water for irrigation. There was no bicarbonate hazard as all the RSC values were negative. However, RSC values significantly correlated with PI values (r = 0.84, $P < 0.05$).

Long-term use of irrigation water affects the permeability of soil through the influence of sodium, calcium, magnesium and bicarbonate. PI is an important factor to judge the quality of irrigation water in relation to soil for agricultural development. According to this index water can be classified into three classes. Class I and class II water with 75 % or more of maximum permeability is suitable for irrigation purpose, while class III water having 25 % of maximum permeability is not suitable. According to PI values, all the swamp water samples were coming under class I category indicating its suitability for irrigation purposes.

Water quality of protected and unprotected swamps

The water quality comparison also made between the protected and unprotected swamps. The results showed that both the swamp water is suitable for drinking (WHO 1993) and irrigation (FAO 2003) purposes. Except Ca^{++}, Cl^{-} and HCO_3^{-} ions, all the other ions in the swamp water showed statistically insignificant difference with respect to protection. The protected swamp water is higher in Ca^{++} and Cl^{-} whereas the unprotected swamp water is rich in Na^{+} and HCO_3^{-}. This indicates that the swamps are almost free from anthropogenic activities.

Swamp and adjoining stream water quality under various land uses

Land use can significantly affect surface water systems such as streams and swamps. Streams are lotic systems and water flow can reduce nutrient load, whereas in the lentic swamps, the partial stagnation of water can increases the concentration of ions. Although the stream water is suitable for drinking and irrigation, the nutrient load from agriculture and habitation land uses is considerably higher than other three land uses (Fig. 4). The land use wise contribution of total nutrients to the stream follows the order of Agriculture > Habitation > Mixed forest > Tea plantation > Shola forest. The relationship between land use dynamics and variations in the water quality parameters of wetlands has been studied widely and it is known that the loss of forest induces soil erosion and leads to deteriorations in water quality (Houlahan & Findley 2004). Moreover, forested areas within the catchment of a wetland can act as nutrient sink. Accordingly, Haidary & Nakane (2008) found that those wetlands, whose catchments were covered by a high percentage of forest area, played a sink function for nitrogen in outflow water from the wetlands. This is in contrast to the role that agriculture and habitation play as a source of nutrients to the wetlands (Chandra *et al.* 2010).

Land use showed the skewed distribution of ion loads to the stream water but this distribution became normal towards the contribution to the swamps. Although agricultural land use was highest, the magnitude of the contribution was similar to that of other land uses. The contribution of different land uses towards nutrient load in the swamps follows the order of Agriculture > Habitation > Tea plantation > Shola forest (Fig. 5). The partial stagnation of water in the swamps and slow accumulation of the nutrients in the stagnant water has narrowed down the differences of nutrient load contributed by different land uses in the swamp system. The average increment of nutrient load in the swamps was more than three times the average nutrient load in the adjoining streams. Haidary *et al.* (2013) suggested that the land use and water resources planning should consider controlling the extent of agricultural and urban areas in wetlands to improve the environmental quality of the wetlands. We also suggest that this should be the case in this area for the sustainable use of these swamps.

Altitude also played a role in the variation of water quality in the wetlands. The data revealed that except for bicarbonate, all other water quality parameters were higher in the higher altitude swamps (Fig. 6). This is probably due to the different land use around the higher altitude swamps. Indeed, most of these swamps were associated with agriculture and human habitation. Therefore land use can probably be considered as the main driving force controlling the nutrient load in the associated wetlands (Haidary *et al.* 2013).

Conclusions

Higher species diversity was observed in the protected swamps, however, *Scirpus* spp. was the dominant species in all swamps followed by *Cyperus* spp. and *Kyllinga* spp. The physical-chemical parameters of swamp water come under class I and class II indicating that the water can be considered fit for irrigation and drinking, however an in-depth microbial analyses of the water needs to be conducted before use of this water for domestic use. Although the swamp water quality is good and the presence of moderate level of chloride is a matter of concern as this indicates some level of anthropogenic influence on the ionic load in the swamp. Given the importance of freshwater, it is critical that we have an understanding of how aquatic ecosystems function in order to successfully manage them through a blend of policy, social and institutional mechanisms for their conservation. This is particularly important in the Nilgiris Biosphere Reserve (NBR) which is one of the 25 biodiversity hot-spots in the world.

References

Adhikary, P. P., H. Chandrasekharan, C. J. Dash & P. Jakhar. 2014. Integrated isotopic and hydrochemical approach to identify and evaluate the source and extent of groundwater pollution in west Delhi, India. *Indian Journal of Soil Conservation* **42**: 17-28.

APHA. 2006. *Standard Methods for Estimation of Water and Wastewater*. 21st edn. American Public Health Association, American Water Works Association and Water Pollution Control Federation. Washington, DC.

Ashton, P. S. 2003. Floristic zonation of tree communities on wet tropical mountains revisited. *Perspectives in Plant Ecology, Evolution and Systematics* **6**: 87-104.

Bhatt, L. R., P. Lacoul, H. D. Lekhak & P. K. Jha. 1999. Physicochemical characteristics and phytoplankton of Taudha Lake Kathmandu. *Pollution Research* **18:** 353-358.

Blasco, F. 1970. Aspects of the flora, and ecology of savannas of the south Indian hills. *Journal of the Bombay Natural History Society* **67**: 522-542.

Bray, R. H. & L. T. Kurtz, 1945. Determination of total, organic, and available forms of phosphorus in soils. *Soil Science* **59**: 39-45.

Bureau of Indian Standard (BIS). 1991. Indian Standard Specification for Drinking Water. BIS Publication No. IS: 10501, New Delhi, India.

Caner, L., G. Bourgeon, F. Toutain & A. J. Herbillon. 2000. Characteristics of non-allophanic Andisols derived from low-activity clay regoliths in the Nilgiri Hills (Southern India). *European Journal of Soil Science* **51**: 553-563.

Champion, H. G. & S. K. Seth. 1968. *A Revised Survey of the Forest Types of India.* Government of India Press, Delhi.

Chandra, R., K. A. Nishadh, & P. A. Azeez. 2010. Monitoring water quality of Coimbatore wetlands, Tamil Nadu, India. *Environmental Monitoring and Assessment* **169**: 671-676.

Cherry, J. A. 2011. Ecology of Wetland Ecosystems: Water, Substrate, and Life. *Nature Education Knowledge* **3:** 16

Clausen, B. & B. J. F. Biggs. 2000. Flow variable for ecological temperate streams, groupings based on covariance. *Journal of Hydrology* **237**: 184-197.

Collier, K. J., J. B. Smith & J. M. Quinn. 2000. Biodiversity of stream invertebrate fauna in a walkathon hill-country catchment in relation to land use, New Zealand. *Entomologist* **23**: 9-22.

Doneen, L. D. 1964. *Notes on Water Quality in Agriculture.* Published as a water science and engineering paper 4001, Department of Water Science and Engineering, University of California.

FAO. 2003. The irrigation challenge: Increasing irrigation contribution to food security through higher water productivity from canal irrigation systems. IPTRID Issue Paper 4, IPTRID Secretariat, Food and agricultural Organization of the United Nations, Rome.

Ganesan, M. 1992. *Ecobiology of Seaweed of the Gulf of Mannar with special reference to Hydrography and Heavy Metals.* Ph.D. Thesis, Annamalai University, India.

Golet, F. C. & D. J. Lowry. 1987. Water regimes and tree growth in Rhode Island Atlantic white cedar swamps. pp. 91-110. *In*: Laderman, A. D. (ed.), *Atlantic White Cedar Wetlands*. Westview Press, Boulder, Colorado.

Gupta, N., Ramesh, C. Sharma & A. K. Tripathi. 2008. Study of bio-physico-chemical parameters of Mothronwala swamp, Dehradun (Uttarakhand). *Journal of Environmental Biology* **29:** 381-386.

Gupta, S. K. & R. C. Gupta. 2006. *General and Applied Ichthyology (Fish and Fisheries).* S. Chand and Company Ltd., Ram Nagar, New Delhi.

Haidary, A. & K. Nakane 2008. Comparative study of the nitrogen dynamics of three wetlands in Higashi-Hiroshima area, west Japan. *Poland Journal of Environmental Studies* **18**: 617-626.

Haidary, A., B. J. Amiri, J. Adamowski, N. Fohrer & K. Nakane. 2013. Assessing the Impacts of four land use types on the water quality of wetlands in Japan. *Water Resources Management* **27**: 2217-2229.

Hanway, J. J. & H. Heidel. 1952. Soil analysis methods as used in Iowa State College, Soil Testing Laboratory. *Iowa Agriculture* **54**: 1-31.

Hill, M. O., R. G. H. Bunce, & M. W. Shaw. 1975. Indicator species analysis, a divisive polythetic method of classification and its application to a survey of native pinewoods in Scotland. *Journal of Ecology* **63**: 597-613.

Houlahan, J. E. & C. S. Findley 2004. Estimating the "critical" distance at which adjacent land-use degrades wetland water and sediment quality. *Landscape Ecology* **19**: 677-690.

Ibekwe, A. M., S. R. Lyon, M. Leddy & M. Jacobson-Meyers.2007. Impact of plant density and microbial composition on water quality from a free water surface constructed wetland. *Journal of Applied Microbiology* **102:** 921-36

Jackson, M. L. 1958. *Soil Chemical Analysis*. Prentice Hall of India, New Delhi.

Joshi, P. C., K. Kumar, V. Badoni & A. Singh. 2002. An ecological study on the above ground entomofauna of Nanda Devi Biosphere reserve. pp.143-149. *In:* J. K. Sharma, Easa, C, Mohanan, N, Sasidharan and R. K. Rai (eds.) *Biosphere Reserves in India and their Management*, Ministry of Environment and Forests, Government of India, New Delhi.

Lakshumanan, C., V. Pradeep Kishore, S. Viveganandan, P. Krishnakumar & G. Muthusankar. 2012. Land use and land cover dynamics study in Nilgiris district part of Western Ghats, Tamilnadu. *International Journal of Geomatics and Geosciences* **2:** 911-923.

Langelier, W. F. 1936. The analytical control of anti-corrosion water treatment. *Journal of American Water Works Association* **28**: 1500-1521.

Meher-Homji, V. M. 1967. Phytogeography of the South Indian hill stations. *Bulletin of the Torrey Botanical Club* **94**: 230-242.

Miller, B. K. 1990. *Wetlands and Water Quality*. U. S. Department of Agriculture, Extension Service, 90-EWQI-1-9242, University of Purolve, USA.

Mitsch, W. J. & J. G. Gosselink. 2007. *Wetlands:* John Wiley & Sons, Hoboken, NJ.

Mohandass, D. & P. Davidar. 2009. Floristic structure and diversity of a tropical montane evergreen forest (shola) of the Nilgiri Mountains, southern India. *Tropical Ecology* **50**: 219-229.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca & J. Kent. 2000. Biodiversity hotspots for conservation priorities. *Nature* **403**: 853-858.

Nelson, D. W. & L. E. Somners. 1996. Total carbon, total organic carbon, and organic matter. pp. 961-1010. *In*: D. L. Sparks, (ed.). *Methods of Soil Analysis, part 3: Chemical Methods*. Soil Science Society of America. Madison, Wisc.

Okude Adeyinka Sunday & Ademiluyi Israel Ajewole. 2006. Implications of the changing pattern of land cover of the Lagos coastal area of Nigeria, *American Eurasian Journal of Scientific Research* **1:** 31-37.

Pant, H. K. & K. R. Reddy. 2001. Phosphorus sorption characteristics of estuarine sediments under different redox conditions. *Journal of Environmental Quality* **30**: 1474-1480.

Parthasarathy, Y. J & R. Vaidyanathn. 1974. Evaluation of landforms over the Nilgiri, South India, *Journal of Geological Society of India* **15:** 182-188.

Ponnamperuma, F. N. 1984. Effects of flooding on soils. pp. 10-45. *In:* T. T. Kozlowski (ed.) *Flooding and Plant Growth.* Academic Press, Orlando, San Diego.

Puyravaud, J. P., D. Mohandass & Priya Davidar. 2012. Impact of human-related disturbance on *Eriochrysis rangacharii* Fischer, a rare keystone endemic grass (Nilgiris, southern India): A preliminary assessment. *Tropical Ecology* **53:** 25-32.

Rai, H. 1974. Limnological observation on the different rivers and lakes in the Ivory Coast. *Hydrobiologia* **44:** 301-317.

Richards, L. A. 1954. *Diagnosis and Improvement of Saline-Alkali soils*. USDA Handbook 60. USDA and IBH Pub. Co. Ltd., New Delhi, India.

Richardson, J. L and M. J. Vepraskas. 2001. *Wetlands Soils Genesis, Hydrology, Landscapes, and Classification.* Lewis Publishers. Boca Raton, FLA.

Sawant, R. S., A. B. Telave, P. D. Desai & J. S. Desai. 2010. Variation in hydrobiologiccal characteristics of Atyal Pond in Gandhinglaj Tahsil, District Kolhapur, Maharastra. *Nature, Environment and Pollution Technology* **9:** 273-278.

Sekar, T. 2008. Observations on survival and growth of different shoal species under a shoal afforestation programme in Nilgiris district, Tamil Nadu. *The Indian Forester* **134:** 451-457.

Sharda, V. N., P. Samraj, S. Chinnamani & V. Lakshmanan. 1988. Hydrological behaviour of the Nilgiri sub-watersheds as affected by blue gum plantation Part II. Monthly water balance at different rainfall and runoff probabilities. *Journal of Hydrology* **103**: 347-355.

Sharma, R. C. & K. Kumar. 2002. *In:* Kumar, A. (ed.) Ecology and conservation of Lakes, Reservoirs and Rivers. Vol. II, ABD Publishers, Jaipur, India.

Sharma, R. C. 1986. Effect of physico-chemical factors on benthic fauna of Bhagirathi river, Garhwal Himalaya. *Indian Journal of Ecology* **13**: 133-137.

Sivasankaran, K., M. S., Mithyantha, S. Natesan & C. T., Subbarayappa, 1993. Physicochemical properties and nutrient management of red and lateritic soils under plantation crops in Southern India, National Beaurs of Soil Science Publication No. 37, NBSS, Nagpur.

Stark, J. R., P. E. Hanson, R. M. Goldstein, J. D. Fallon, A. L. Fong, K. E. Lee, S. E. Kroening, & W. J. Andrews. 2000 United States Geological Survey, Circular 1211. 2000, http://pubs.usgs.gov

Subbiah, B. V. & Asija, G. L. 1956. A rapid procedure for the determination of available nitrogen in soil. *Current Science* **25**: 259-260.

Taylor, J. R., M. A. Cardamone & W. J. Mitsch. 1990. Bottomland hardwood forests: their functional values. pp. 13-86. *In:* J. G. Gosselink, L. C. Lee & T. A. Muir (eds.) *Ecological Processes and Cumulative Impacts.* Lewis Publishers, Inc., Chelesia.

Trivedy, R. K. & P. K. Goel. 1987. *Chemical and Biological Methods for Water Pollution Studies.* Environmental Publications, Karad, India.

USEPA. 2003. Human health toxicity values in superfund risk assessments. OSWER Directive 9285.753. December 5, 2003.

Varghese, V. & B. M. Kumar. 1997. Ecological observations in the fresh water swamp forests of southern Kerala, India. *Journal of Tropical Forest Science* **9**: 299-314.

Walsh, C. J., A. K. Sharp, P. F. Breen & J. A. Sonneman. 2001. Effect of urbanization on streams of the Melbourn region, Victoria, Australia. I. Benthic macro invertebrate communities. *Fresh Water Biology* **46**: 535-551.

World Health Organization (WHO). 1993. *Guidelines for Drinking Water Quality* (2nd ed. Volumes. 1-3). World Health Organization, Geneva.

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