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# Influence of land use/land cover on the water chemistry of Wular Lake in Kashmir Himalaya (India)

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## Abstract

**Introduction:** The impacts of land use/land cover (LULC) pattern on surface components of water are less well recognized, particularly in the Kashmir Himalaya. The paper highlights the relationship between LULC and water chemistry for Wular Lake in Kashmir Himalaya.

**Methods:** We used Indian Remote Sensing satellite (IRS) P6 using LISS III sensor with a spatial resolution of 23.5 m for various LULC categories. ERDAS IMAGINE 9.0 and ArcGIS 9.3 were used to generate the LULC map. Water parameters like pH and temperature were measured in the field, while parameters like dissolved oxygen, free carbon dioxide, chloride, alkalinity nitrogen and phosphorus values were determined by APHA (*Standard Methods for Examination of Water and Wastewater*, 1998).

**Results:** The present study provides us the information about the proportion of different land cover categories and their correlation with some limnological parameters of Wular Lake. Among the various physicochemical parameters, low dissolved oxygen (DO) was observed in the LULC class which has the highest percentage of agricultural land (47.04%;  $r = 0.688$   $P < 0.05$ ) followed by horticultural land (19.10%;  $r = 0.554$ ;  $P < 0.01$ ) in its catchment. The catchment area with greater percentage of agricultural fields drains maximum fertilizers in the lake, resulting in growth of microorganisms that deplete the dissolved oxygen content in the water body.

**Conclusions:** Pearson matrix predicts that agricultural land, built up, horticultural land and wasteland seem to be the foremost factors responsible for the deterioration of the water quality of the lake. Careful planning of land use is needed to bring significant reductions in nutrient exports from agriculture through various tributaries, in order to restore and maintain water quality of the lake. If this trend of agriculturization manifestation continues unabated, it will be difficult to restore the lake water quality and to subsequently correct ecological manifestation of eutrophication through which the lake is undergoing at present.

**Keywords:** Limnology; Catchment; Agricultural land; Dense forest; Wular Lake; Kashmir Himalaya

## Introduction

Population explosion has a tremendous effect on land use/land cover (LULC) with profound impacts on the functioning of natural ecosystems (Steffen et al. 2004). LULC analysis has become a fundamental tool in assessing the environmental consequences of human activity (Hunt and Ditzer 2001; Veldkamp and Lambin 2001; Brown 2003; Dunn 2004; Wang et al. 2007; Liu et al. 2011,

2012). LULC have consequences for level of biodiversity (Tallmon et al. 2003), geochemical cycles (Powers 2004) and water quality (Shippers et al. 2004; Nouri et al. 2009; 2011). Dynamics of LULC are in turn influenced by types of land cover involved, ecological mechanisms of succession and regeneration, physical components of the environment, socioeconomic activities together with their cultural context, and meteorological phenomena or other natural disasters (Dale et al. 1994; Kareiva and Wennergren 1995).

The chemical composition of surface water and its properties in a particular region are basically governed

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by natural processes such as precipitation rate, weathering processes, soil erosion and anthropogenic effects in the catchment of a water body which determine the magnitude of point or non-point sources of pollution (Jarvie et al. 1998; Giridharan et al. 2009; Nouri et al. 2009; 2011). Globally, numerous studies are focused on the impact of LULC on the physicochemical parameters of water (Luo et al. 2003; Louisa et al. 2006; Liu et al. 2012; Bateni et al. 2013 etc.). But here in Kashmir Himalaya, though there is a lot of information available on various limnological aspects of freshwater bodies (Pandit 1999, 2002), yet the influences of changing catchment characteristics on the water chemistry of surface waters are not well recognized excepting a preliminary report on Nilnag Lake and its catchment land use (Qazi and Pandit 2008). The present study, therefore, emphasizes that the watershed (drainage basin) and scale factors influence the water chemistry of Wular Lake which in turn impacts the biotic setup of the aquatic ecosystems.

#### Study area

The Wular catchment lies between 34°12'24.67" and 34°36'26.26" N latitude, and its longitudinal extent is between 74°26'41.42" and 74°56'02.90" E. The altitudinal range of the study area is from 1,570 m (a.m.s.l) near Wular Lake to 5,148 m (a.m.s.l) in the Harmukh range. It has an area of 1,200.36 km<sup>2</sup> and accounts for 7.6% of the total area of Kashmir valley. The location of the study area is such that on the northern side, it is delineated by the Kishenganga watershed, and on the eastern side, it is separated by the drainage system of Sind River. The Pohru catchment forms its western boundary. The River Jhelum enters into the study area from its southern side and passes through the Wular Lake. The riparian zone of the Wular Lake having the same morphological characteristics, basal level and a gentle slope towards Wular Lake was included in the catchment and named as Wular periphery. The study area has been divided into four catchments (Figure 1). These are Madhmatti, Erin, Wular I and Wular II which are further divided into eight sub-catchments and nineteen watersheds. The four catchment areas differ significantly with respect to soil characteristics and hydrology. Madhmatti catchment is characterized by skeletal soils on steep slopes with severe erosion and strong stoniness. Soil pattern located in the catchment areas of Erin are mesic, fine loamy soils on steep slopes with loamy surface moderately well drained. The soil types of Wular I and II are 40% similar to that of Erin catchment. However, the soils of Wular periphery are calcareous fine silty, coarse-loamy soils on nearly level slopes with loamy surface and slight flooding. The landscape is mountainous and rugged on the northeastern side, while it is mostly plain on the south and southwestern side of the study area. The study area is divided into various physiographic zones characterized by

varying altitude, slope, vegetation, etc. The low-lying alluvial plains, the karewas, foot hills and high-altitude mountains form the main physiographic divisions of Wular catchment (Figure 2). As far as Wular Lake is concerned, it is situated at an altitude of 1,580 m (a.m.s.l), between 34°16'-34°20' N latitudes and 74°33'-74°44' E longitudes. Wular Lake, an oxbow-type lake, is of fluvial origin located in the northwest of Kashmir about 55 km from Srinagar city, being formed by the meandering of River Jhelum, which is the main feeding channel besides other tributaries (Shah and Pandit 2013).

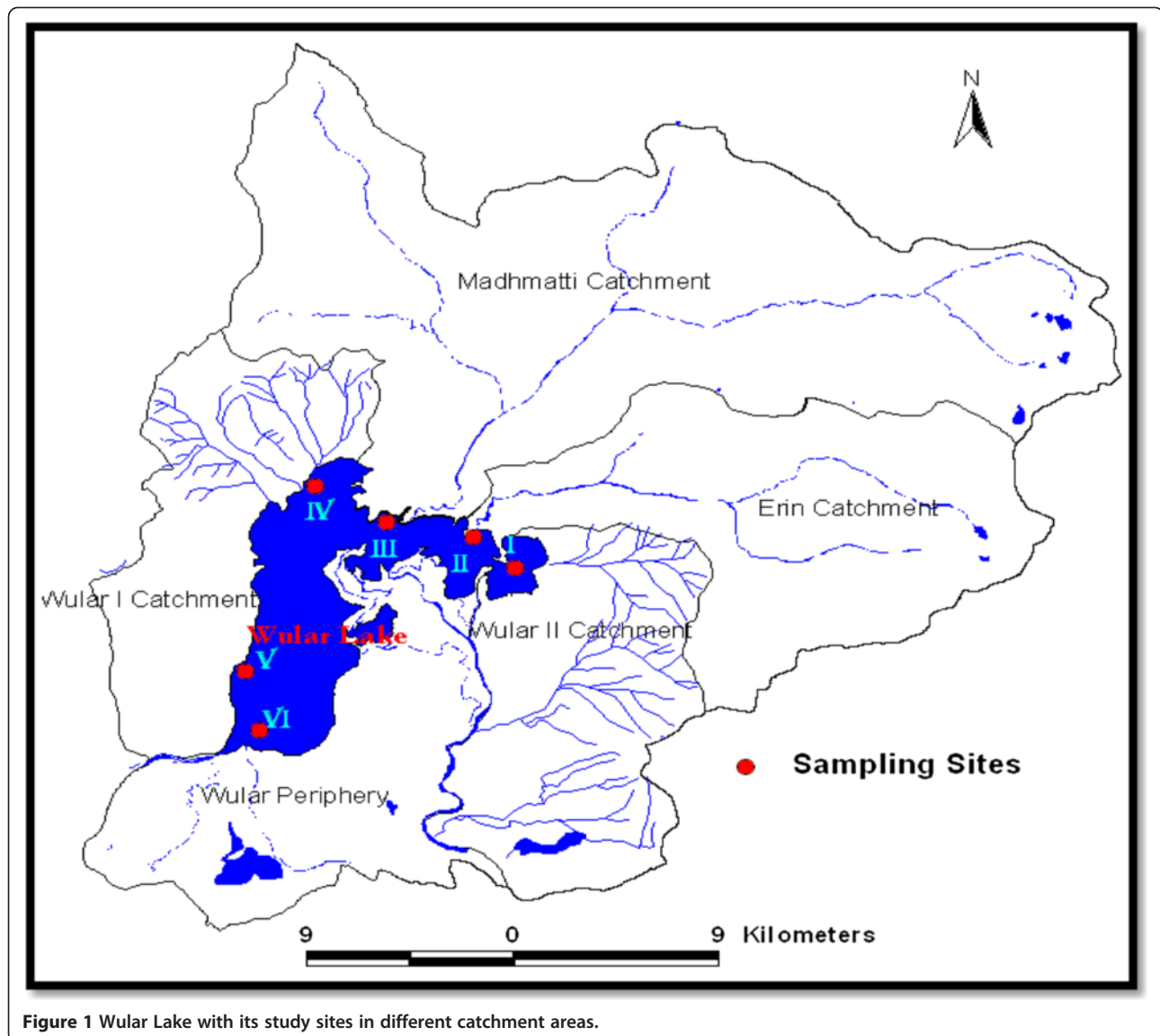
#### Hydrology of the catchment

The Wular catchment is a complex geophysical unit with highly differentiated topography and a thorough highland-lowland interaction. The topographic wetness index has clearly indicated the dominant control of local topography on hydrological processes. The area which has a predominantly gentle slope has high soil wetness. A major proportion of the catchment falls in high drainage density and frequency, thereby indicating that Wular catchment is a young immature landscape with highly dissected mountains. The zone with the highest potential of aquifer recharge constitutes 6.24% of the catchment and is characterized by suitable surface and subsurface conditions like occurrence of lineaments, permeable rock masses, good vegetation cover, low drainage density and high rainfall.

The Wular catchment is characterized by a dendritic drainage pattern. The total number of streams is 2,708, out of which 2,158 are of first order, 427 are of second order, 94 are of third order, 25 are of fourth order, 3 are of fifth order and 1 is of sixth order (applying Strahler's scheme of ordering). The Wular catchment has a high drainage density of the order of 2.41 km/km<sup>2</sup>, while the drainage frequency is of medium level and is 2.81 segments per km<sup>2</sup>. The high value of drainage density indicates that the region is composed of impermeable subsurface materials, sparse vegetation and high mountainous relief. High stream frequency is indicative of high relief and low infiltration capacity of the bedrock pointing towards the increase in stream population with respect to increase in drainage density. The mean bifurcation ratio of the study area is 4.93, indicating a young drainage basin with lower stream orders. The length of overland flow of Wular catchment is 0.84 and its form factor is 0.23, indicating high relief elongated in shape and suggesting flatter peak flow for longer duration.

#### Methods

In the study, Indian Remote Sensing satellite (IRS) P6 (Resourcesat) using LISS III sensor with a spatial resolution of 23.5 m for various LULC categories was employed. Land cover classes were mapped through

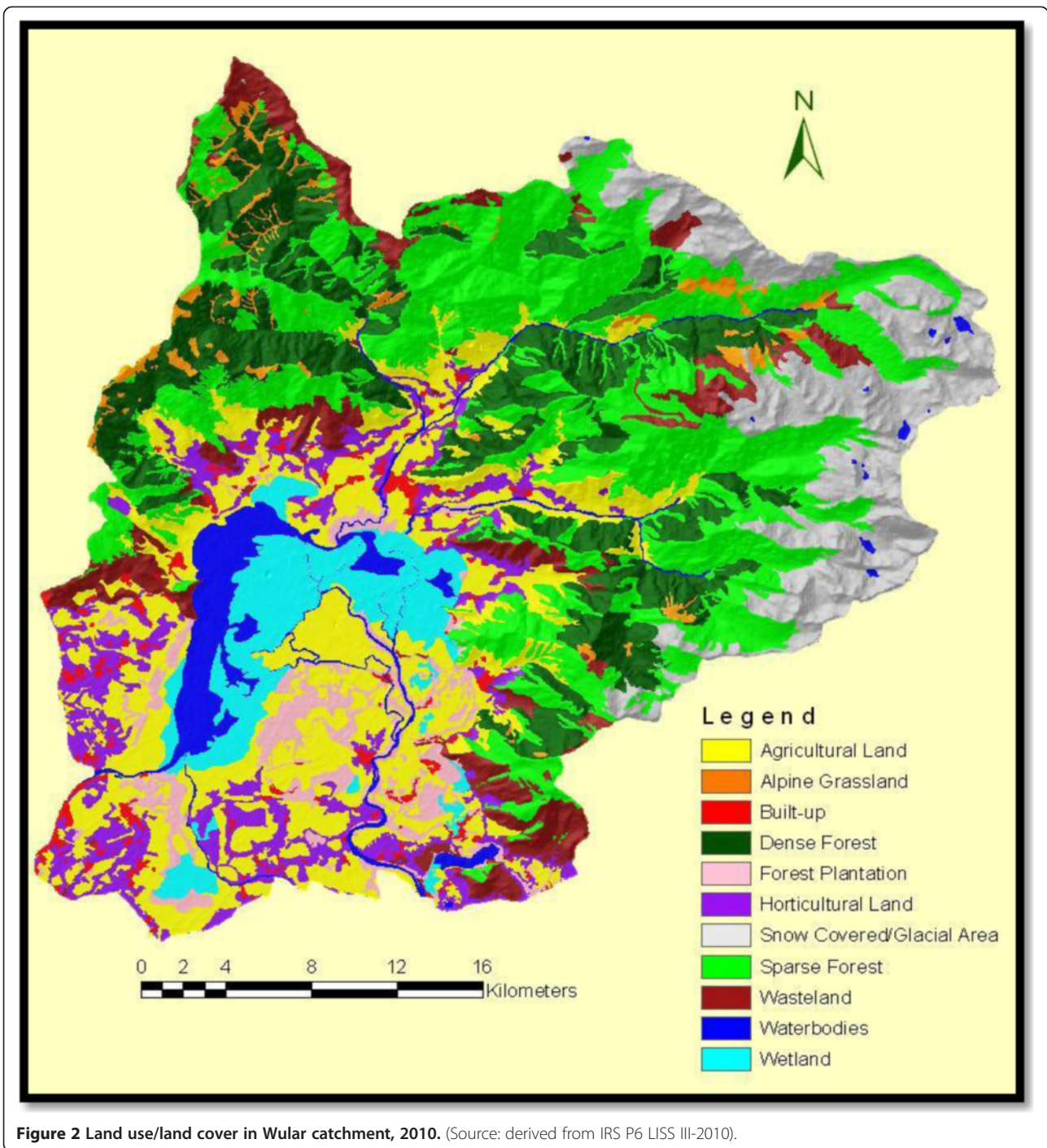


**Figure 1** Wular Lake with its study sites in different catchment areas.

the process of a supervised digital image classification (Thomas et al. 1987). Ancillary layers were generated from topographic maps and with 30 m ASTER DEM. In addition, NDVI of the IRS P6 LISS III for classification process was used so as to enhance the separability among various vegetation classes and also to reduce the shadow effect due to variations in topography. The necessary rectification to a unique geodetic system (UTM, Zone 43, Spheroid: sWGS 84 North) was carried out by measured ground control points (GCPs) using a polynomial second-order transformation with nearest neighbour resampling. During the study, signatures were collected by digitizing polygons on the satellite imagery with the help of Euclidean distance to collect the training samples. Spectral signatures served as a measure of separability for the signatures collected

for each LULC class, and the spectrally similar signatures were united. Further, the theoretical lower limit of the number of pixels is  $n + 1$ , where  $n$  is the number of spectral bands (Lillesand and Kiefer 2000). Each informational class was represented by minimum number of five to ten training areas to ensure that the spectral properties of each category were represented sufficiently (Campbell 1996). The maximum likelihood classifier (threshold level of 0.95, i.e. 95%) was also adopted, a widely used classification procedure of digital remotely sensed data (Foody et al. 1995), and it takes the variability of classes into account by using the covariance matrices of classes (Schriever and Congalton 1995).

The present study incorporated the levels I, II and III of the classification scheme of NRSA, Hyderabad and Space Application Centre, Ahmadabad, being adopted



by State Remote Sensing Centre, J&K, for generation of land use/land cover maps of J&K State in 2006. The ground verification in the present study was carried with the help of the Geographical Positioning System (GPS) and digital camera. ERDAS IMAGINE 9.0 and ArcGIS 9.3 were used to generate the land use/land cover map. Class values were matched against the reference points,

so as to get the accuracy report that finally produces the error matrix, accuracy totals and kappa coefficient.

The physicochemical parameters of water were analyzed on monthly bases for a period of 1 year. The parameters like pH (model 335, SYSTRONICS, Ahmedabad, India) and temperature were monitored on spot, while the remaining parameters were discussed below.



**Methods for collection of water parameters**

The water samples were collected from the sampling spot by dipping a 1-l polyethylene bottle just below the surface of water. Specially recommended glass bottles were used for the estimation of dissolved oxygen. For estimation of dissolved oxygen, samples were fixed at the sampling site in accordance with modified Winkler's method. Six study sites were selected in areas that varied in extent and type of catchment development. Site I was located in Wular catchment II, site II in Erin catchment, site III in Madhmatti catchment, site V in Wular catchment I and site VI in Wular periphery catchment I.

**Dissolved oxygen (Winkler's method, APHA 1998)**

The water samples were collected in airtight glass bottles of 250 ml capacity. The samples were fixed with 1 ml of manganous sulphate solution and 1 ml of alkaline iodine. The bottles were transferred to the laboratory where the precipitate of the sample was dissolved by adding 1 ml of H<sub>2</sub>SO<sub>4</sub>, and 50 ml of this solution was titrated against 0.01 N sodium thiosulphate using starch as an indicator.

Calculation

$$\text{Dissolved oxygen (mg/l)} = \text{ml of titrant used} \times 4.$$

**Free carbon dioxide (APHA 1998)**

In 50 ml of the sample in a flask, two drops of phenolphthalein indicator was added, and if a slight pink colour develops, free CO<sub>2</sub> was absent. If the solution remained colourless, the sample was titrated with standard alkali titrant to slight end point.

Calculation

$$\text{Free CO}_2 \text{ mg/l} = V_t \times 1,000/50$$

where V<sub>t</sub> = volume of titrant used.

**Total alkalinity (titration method, APHA 1998)**

One hundred millilitres of water sample was titrated against 0.02 N H<sub>2</sub>SO<sub>4</sub> using methyl orange as indicator. The results were expressed in milligrams per litre after using the following formula:

Calculation

$$\text{Total alkalinity as CaCO}_3 \text{ (mg/L)} = V_1 - V_2 \times N \times 1000 \times 50/V_3$$

V<sub>1</sub> = Volume of titrant used for the sample

V<sub>2</sub> = Volume of titrant used for the blank

V<sub>3</sub> = Volume of sample taken for titration

N = Normality of H<sub>2</sub>SO<sub>4</sub>

**Chloride (argentometric method, APHA 1998)**

To 50 ml sample in a flask, five drops of potassium chromate indicator was added. This gave a yellow colour to the sample which was titrated with standard silver nitrate solution until a brick red end point was obtained.

Calculation

$$\text{Chloride mg/l} = (A - B) \times N \times 35.466/\text{ml of sample used}$$

Where

A = millilitre of titrant used for the sample.

B = 0.20 ml of titration for the blank.

N = normality of AgNO<sub>3</sub>.

**Ammoniacal nitrogen**

To 25 ml sample in a 50-ml Erlenmeyer flask, 1 ml phenol solution, 1 ml sodium nitroprusside solution and 2.5 ml oxidizing solution were added with thorough mixing. Samples were covered with plastic wrap or paraffin wrapper film. Colour development was allowed at room temperature (22°C to 27°C) in subdued light for at least 1 h. Absorbance was measured at 640 nm on a spectrophotometer. A blank and at least two other standards by diluting stock ammonium solution were prepared into the sample concentration range. Standards were treated the same as samples and compared with the standard curve to get the exact value.

**Nitrate nitrogen**

To 50 ml of sample in a 100 ml of beaker, 1 ml of sodium salicylate solution was added. The solution was then evaporated till dryness in a water bath. To the residue, 1 ml of concentrated H<sub>2</sub>SO<sub>4</sub> was added and the beaker was tilted so that whole bottom of the beaker gets wet. The sample was allowed to stand for 10 min, and 6 ml of distilled water and 7 ml of NaOH (30%) solution was added and left for colour development. Absorbance was measured at 410 nm.

**Total phosphorus**

To 25 ml of sample, 1 ml of H<sub>2</sub>SO<sub>4</sub> and 5 ml of concentrated HNO<sub>3</sub> were added. Then, the sample was evaporated till its volume got reduced to 1 ml and became colourless. Two drops of phenolphthalein and 200 ml of distilled water were added after the sample cooled down. Then, the sample was titrated against NaOH (1 N) solution till it became pinkish. The solution was filtered and raised to 100 ml. The pink colour was discharged with one to two drops of strong acid solution. After thorough mixing, 4 ml of ammonium molybdate solution and 0.5 ml of stannous chloride were added. The blue colour developed after a pause of 10 min. The sample was subjected to absorbance test on a spectrophotometer at a wavelength of 690 nm. Total phosphorus of the sample

was calculated by comparing the absorption value with that of the calibration curve, using distilled water as blank.

**Orthophosphate-phosphorus**

To a sample (filtered) of 25 ml, 1 ml of ammonium molybdate reagent and three drops of stannous chloride reagent were added. Absorbance reading was taken on a spectrophotometer at 690 nm after 10 min. Phosphorus value was determined from the calibration curve.

**Statistical analysis**

Statistical analyses were performed using SPSS (statistical version 16 for Windows 7, SPSS, Chicago, IL, USA). Pearson correlation (*r*) was made for the statistical interpretation of the physicochemical parameters of water and its impact on catchment characteristics.

**Results and discussion**

The change in land use and the extensive agricultural activities during the past decades have led to a deterioration of the water quality of natural waters globally. Nutrients like nitrogen and phosphorus are mainly responsible for eutrophication of the water bodies. Besides, it is also affected by soil erosion and leaching of fertilizers from the near catchment area. Land use analysis (Table 1) shows that the agricultural land is the major land use category in Wular catchment I covering 30.12%, followed by sparse forest and horticultural land, respectively, contributing 16.98% and 16.28%. In Erin catchment, sparse forest contributed the highest (38.85%), being followed by snow-covered/glacial area (23.09%), while the lowest was contributed by forest plantation (0.26%). The other main land uses are built up contributing its highest percentage (9.01%) for Wular catchment I.

The most common and typical method used in the present study is to assess classification accuracy with the

help of error matrix (Congalton 1991). Accuracy tools show that wasteland in the catchment area of Wular contributes 81.48% producer accuracy while snow cover/glaciers make 88.00%. Further, user accuracy was highest for dense forests and water bodies (Table 2). The kappa coefficient has been used to address the difference between the actual and chance agreement. In general, the kappa coefficient lies typically on a scale between 0 and 1, whereas the latter indicates complete agreement and is often multiplied by 100 to give a percentage measure of classification accuracy. In the study, kappa values fall into three groupings: (i) a value greater than 0.80 (80%) represents strong agreement, (ii) a value between 0.40 and 0.80 (40% to 80%) represents moderate agreement, and (iii) a value below 0.40 (40%) represents poor agreement (Congalton 1991). A widely used, acceptable accuracy of 85% was also striven for the land use classification adopted by the United States Geological Survey (USGS). Kappa coefficient was highest for water bodies (0.9562), followed by dense forests (0.9559) and snow-covered/glacial area (0.8257) in decreasing order (Table 3).

The physicochemical limnological features of Wular Lake are depicted in Table 4. One of the most outstanding and biologically significant phenomena of the aquatic bodies is the thermal regime. As is usual for temperate climate, air and water temperature depend on geographical location and meteorological conditions such as rainfall, humidity, cloud cover, wind velocity, etc. The water temperature, during the present investigation, depicted a definite seasonal trend, with a minimum of 5.24°C in winter and a maximum of 20.74°C during summer as is common for shallow bodies of water (Wetzel 1975). pH was on the neutral to alkaline side throughout the study period and varied from a minimum of 7.43 in winter to a maximum of 8.16 in autumn. The seasonal pH concentration was not significant as the waters were well buffered. This is in conformity with Zutshi et al. (1980).

**Table 1 Proportion of different land use/land cover categories around Wular Lake**

LULC class parameters	Catchment				
	Wular I	Madhmatti	Erin	Wular II	Wular periphery
Agricultural land	30.1	28.4	14.3	28.2	47.0
Alpine grassland	1.8	0.4	0.6	0.4	0
Built up	9.0	4.9	2.1	4.9	6.7
Dense forest	10.8	8.4	15.7	8.4	0
Forest plantation	2.4	6.6	0.2	6.6	14.0
Horticultural land	16.2	10.8	3.1	10.8	19.1
Snow-covered/glacial area	0	0.2	23.0	0.2	0
Sparse forest	16.9	17.5	38.8	17.5	0
Wasteland	11.0	16.9	0.5	16.9	0.1
Water bodies	0.2	1.1	0.8	1.1	2.2
Wetland	1.1	4.2	0.4	4.2	10.6

**Table 2 Accuracy totals for different land use/land cover categories in the Wular catchment**

Class name	Reference totals	Classified totals	Number correct	Producer accuracy (%)	User accuracy (%)
Dense forest	51	50	48	94.12	96.00
Sparse	51	50	46	90.20	92.00
Alpine grassland	49	50	47	95.92	94.00
Snow-covered/glacier area	45	50	42	93.33	84.00
Wasteland	54	50	44	81.48	88.00
Water bodies	48	50	48	100.00	96.00
Wetland	51	50	46	90.20	92.00
Agricultural land	56	50	47	83.93	94.00
Horticultural land	49	50	45	91.84	90.00
Forest plantation	47	50	43	91.49	86.00
Built up	49	50	47	95.92	94.00

Over all classification accuracy = 91.45%

Dissolved oxygen is one of the most important abiotic factors influencing an aquatic environment. Oxygen plays a significant role in the regulation of metabolic processes of communities and organisms and also as an indicator of the lake condition (Reid 1961). Dissolved oxygen in the lake depicted a definite seasonal trend with maximum values being recorded in winter at site II (9.11 mg/l) and minimum values in summer (6.33 mg/l) at site VI. On annual average basis, low DO was observed at site VI (with negative correlation) which has the highest percentage of agricultural land (47.04%;  $r = 0.688$   $P < 0.05$ ) and horticultural land (19.10%;  $r = 0.554$ ;  $P < 0.01$ ), inferring high pollution load at this site (Yeole and Patil 2005). The catchment area under greater agricultural activities is subjected to huge quantities of fertilizers which after their partial utilization get leached into the lake waters, thus leading to the nutrient enrichment and eutrophication which further aggravates the growth of microorganisms. These microorganisms utilize oxygen for their growth and development, thus depleting oxygen

**Table 3 Conditional kappa for each category land/use land cover in the Wular catchment**

Class name	Kappa coefficient
Dense forest	0.9559
Sparse forest	0.9118
Alpine grassland	0.9341
Snow-covered/glacial area	0.8257
Wasteland	0.8669
Water bodies	0.9562
Wetland	0.9118
Agricultural land	0.9332
Horticultural land	0.8902
Forest plantation	0.8469
Built up	0.9341

in the water column. Furthermore, significant spatial variations in the dissolved oxygen were noticed, registering its highest for site II, which falls in the Erin catchment, having the highest percentage of dense forests (15.73%) and comparatively lower percentage of agricultural land contributing only 14.32%.

Chloride content in water is regarded as an indication of organic load of animal origin and has a significant effect of built up from the catchment area (Reddy et al. 2001; Kumar et al. 2006). During the present study, no significant temporal variation was observed. Still, higher concentrations of the ion were recorded in spring (29.7 mg/l) at site III as against winter (9 mg/l) at site IV. Higher levels in spring were possibly due to increased discharge and organic matter (Adams 2003). However, there were significant spatial variations between built up (9.01%) and horticultural land (16.28%), and the maximum was for site V lying in the Wular catchment I reflecting higher chloride content, followed by site IV in the same catchment. The concentration of free CO<sub>2</sub> varied from place to place as it depends on several factors, i.e. temperature, rainfall, photosynthesis and respiration of the biota (Shah and Pandit 2013). The gas maintained its high values during the colder months of the year (24 mg/l in winter). Our results are in general agreement with those of Salve and Hiware (2006), Kadam et al. (2007) and Shah and Pandit (2012, 2013) who observed low level or absence of free carbon dioxide in summer, thus signifying negative correlation with temperature (Table 5). The data obtained at the majority of the sites with respect to total alkalinity (>90 mg/l) indicate that Wular Lake is falling under eutrophic category of trophic evolution and is highly productive as per the observations of Alikunhi (1957).

Nitrogen is one of the major constituents of the cellular protoplasm of organisms, and its concentration in freshwaters controls the productivity of an ecosystem. Inorganic nitrogen in freshwaters occurs in three different forms,

**Table 4 Spatial and temporal variations in the physicochemical parameters of water in Wular Lake**

Parameters	Seasons	Site I	Site II	Site III	Site IV	Site V	Site VI
Water temperature (°C)	Spring	11.3	14	15.7	13.7	12	10.7
	Summer	19.8	21.5	22.3	21	20.5	19.3
	Autumn	14.3	17	14.3	13.3	12.7	11.7
	Winter	4.8	5.7	6	5.4	5	4.5
pH	Spring	7.9	7.9	7.9	8	7.9	8
	Summer	7.4	7.5	7.4	7.5	7.4	7.3
	Autumn	8.1	8.1	7.9	8.2	8.1	8
	Winter	7.1	7.1	7.2	7.1	7.2	7.1
Dissolved oxygen (mg/l)	Spring	8.1	8.5	8.6	7.8	8.5	7.5
	Summer	6.3	6.3	5.9	6.9	6.6	5.8
	Autumn	9.1	7.3	7.4	8.3	7.5	7.6
	Winter	9.4	8.3	8	7.6	7.5	7.8
Chloride (mg/l)	Spring	25.7	18.3	29.7	17.7	16.3	21.3
	Summer	23.7	21	25	17	14.7	16.3
	Autumn	13	14.3	16.3	13	16	15.7
	Winter	11	13.7	13	9	13.7	14.7
Free carbon dioxide (mg/l)	Spring	11.3	9	9.3	10.7	8.7	7
	Summer	11.7	8.7	8	8	12.7	7
	Autumn	15	14	18.3	17	13	11
	Winter	11.7	21	22.7	24	22.3	19.7
Total alkalinity (mg/l)	Spring	120.7	141.3	140.7	110.3	118.7	135
	Summer	30	60.7	65.3	50	34.3	41.3
	Autumn	107.3	101.3	140	149	136.7	150.7
	Winter	154.3	167	155	166	151.3	151
Ammoniacal nitrogen (µg/l)	Spring	126.7	142.7	133.3	123	162.7	164
	Summer	109	94	128.3	119	86.7	71.3
	Autumn	127	131	163.3	165	155	150
	Winter	144.3	154.3	170.3	176	163.3	135
Nitrate nitrogen (µg/l)	Spring	216.7	228.3	236.7	222.7	203.3	203.3
	Summer	180.7	184.7	197.3	193.3	194.3	176.7
	Autumn	223.3	221.7	225.7	237.7	238.3	215
	Winter	263.3	270.3	284.7	287.3	304	290.7
Orthophosphate (µg/l)	Spring	28	31.3	33	34.3	30.3	31.03
	Summer	19.3	21.3	26.3	25.7	21.7	23
	Autumn	34.3	36	39.3	37	29.3	28
	Winter	45	50.3	52.7	50.3	43.7	42.3
Total phosphate (µg/l)	Spring	160	190	203	180	157.7	148
	Summer	130	148.3	165	136.7	133.3	128.3
	Autumn	153.3	178.3	198.3	165	183.3	165
	Winter	216.7	223.3	220	208.3	193.3	181.7

namely ammonia, nitrates and nitrites. Agricultural as well as horticultural land practices in the immediate catchment has a direct effect on the nitrogen and phosphorus content in the water body whose loading may lead to nutrient

enrichment and the deterioration of the water quality (Harding et al. 1999; Cuffney et al. 2000). Higher concentration of these nitrogenous forms is attributed to the use of fertilizers in and around the lakes and the addition of



**Table 5 Pearson correlation between various limnological parameters and land use/land cover parameters**

Parameters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1																			
2	0.00	1																		
3	-0.63**	0.33	1																	
4	0.15	-0.02	0.07	1																
5	-0.45*	-0.65**	-0.08	-0.16	1															
6	-0.86**	0.19	0.72**	0.01	0.28	1														
7	0.11	-0.31	0.05	0.60**	0.11	-0.03	1													
8	0.59**	-0.17	-0.28	0.64**	-0.17	-0.38	0.64**	1												
9	-0.51*	-0.19	0.52**	0.48*	0.25	0.46*	0.68**	0.19	1											
10	0.67	-0.88*	-0.00	0.66**	0.51*	0.46	0.88**	0.93**	0.97**	1										
11	-0.12	0.41	0.68*	-0.13	0.77**	0.50**	0.58	0.46*	0.18	0.15	1									
12	0.86*	-0.58*	0.22	-0.36	-0.21	0.42	0.67**	0.51*	0.35	0.52**	-0.01	1								
13	0.044	0.44**	-0.31	-0.69**	0.67**	0.50*	0.64	0.54**	0.58*	0.28	0.96**	0.21	1							
14	0.89*	0.09	0.20	-0.44	-0.32	0.60**	0.26	0.32	0.29	0.47*	-0.19	0.97**	0.01	1						
15	-0.45	0.61*	-0.87**	0.78**	0.77**	0.26	0.39	-0.67**	0.65*	-0.04	0.92**	-0.38	0.82*	-0.54	1					
16	-0.26	0.38	0.55**	-0.01	0.77	0.39	0.51**	0.79**	0.14	0.68**	0.98**	-0.65**	0.93**	-0.73**	0.97**	1				
17	0.55	0.57**	0.06	-0.51	-0.53**	0.62**	-0.28	-0.17	-0.79**	0.42	-0.73	0.38	-0.70	0.58	-0.86*	-0.82*	1			
18	0.89*	0.04	0.18	0.58**	-0.37	0.37	0.79**	0.66**	0.84**	0.51**	-0.59*	0.93**	-0.69**	0.99**	-0.63	-0.43	0.68**	1		
19	0.43	0.59*	0.42*	0.02	0.20	0.32	0.60**	0.55	0.42	0.64*	0.55	0.70**	0.75**	0.52	0.28	0.48	-0.39	0.60**	1	
20	-0.21	0.55**	-0.653**	-0.221	0.81*	0.53	0.49	0.58**	0.59*	-0.54**	0.96**	-0.18	0.87*	-0.52*	0.94**	0.96**	-0.66**	-0.79**	0.63**	1
21	-0.54	0.54**	-0.548	0.064	0.76	0.22	0.49*	0.17	-0.03	0.58**	0.85*	-0.53	0.70	-0.67	0.98**	0.91*	-0.81	-0.73	0.09	.91*

Parameters: 1 = water temperature; 2 = pH; 3 = dissolved oxygen; 4 = chloride; 5 = free carbon dioxide; 6 = total alkalinity; 7 = ammoniacal nitrogen; 8 = nitrate nitrogen; 9 = orthophosphate; 10 = total phosphate; 11 = agricultural land; 12 = alpine grassland; 13 = built up; 14 = dense forest; 15 = forest plantation; 16 = horticultural land; 17 = snow-covered/glacial area; 18 = sparse forest; 19 = wasteland; 20 = water bodies and 21 = wetland. \*\*Correlation at 0.01 (two-tailed). \*Correlation at 0.05 (two-tailed).

faecal matters and other effluents from human habitation. Higher quantities of ammoniacal nitrogen were recorded during the winter which is an outcome of ammonification and slow rate of nitrification process. These findings are in conformity with those observed by Wetzel (1983) and Finlay et al. (2007). On the basis of annual mean levels of ammoniacal nitrogen, site VI ranked the highest, followed by sites III, I, V, IV and II in decreasing order. Site VI lying on the Wular periphery catchment has the maximum agricultural ( $r = 0.580$ ) as well as horticultural land ( $r = 0.919$ ), depicting collinear relationship of ammoniacal nitrogen with the aforesaid parameters (Harding et al. 1999; Cuffney et al. 2000). The concentration and rate of supply of nitrate nitrogen are intimately connected with the land use practices of the surrounding watershed (Horne and Goldman 1994). Higher values of the plant nutrient may be attributed to the agricultural run-off bringing with it  $\text{NO}_3$ -rich fertilizers. Phosphorous, like nitrogen, is an important factor which plays a pivotal role in determining the productivity of water bodies. As far as the catchment characteristics of the study sites are concerned, it seems that agricultural land and horticultural land besides built up are the major contributors for the increasing values of nitrogen and phosphorus, thereby signalling positive correlation among the study sites in Wular Lake. Vollenweider (1972) has pointed that phosphorus, being a limiting factor, plays a key role in the eutrophication of the water bodies. The low orthophosphate-phosphorous content in waters is due to the formation of an insoluble calcium-phosphate complex. Such a phenomenon functions as scavenger of some inorganic nutrients and also acts as a removal agent of dissolved organic matter by absorption (Wetzel and Otsuki 1974). Phosphorous enters freshwater from atmospheric precipitation, groundwater and surface run-off from a highly fertilized catchment area. The seasonal dynamics showed that the concentration of phosphorous in Wular Lake was less in summer which is attributed to uptake by the plants during the main growing season. This is in agreement with the previous findings of Cole (1975), Kaul et al. (1978) and Pandit (1980, 1999, 2002).

## Conclusions

There are a number of factors in the catchment of the lake that are associated with the quality of water, and among these, the stresses (agricultural, horticultural and wasteland) are impacting largely on water quality. If this trend of agriculturization manifestation continues unabated, it will be difficult to restore the lake water quality and to subsequently correct ecological manifestation of eutrophication through which the lake is undergoing at present. Careful planning of land use is needed to bring significant reductions in nutrient exports from agriculture in particular through various tributaries, in order to restore the lake environment.

## Competing interests

The authors declare that they have no competing interests.

## Authors' contributions

TAK & AKP authors are the research guides of the ZH and JAS authors respectively. They have also drafted the sampling design and critically evaluated the manuscript. Without their support it is impossible to perform the research. All authors read and approved the final manuscript.

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