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Linking human-biophysical interactions with the trophic status of Dal Lake, Kashmir Himalaya, India

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ABSTRACT

The study analyses the long-term biophysical and demographic changes in Dal lake, located in the heart of Srinagar city, Kashmir India, using a repository of historical, remote sensing, socio-economic and water quality data supported by the extensive field observations. The lake faces multiple pressures from the unplanned urbanization, high population growth, nutrient load from intensive agriculture and tourism. The data showed that the lake has shrunk from 31 km^2 in 1859–24 km^2 in 2013. Significant changes were observed in the land use and land cover (LULC) within the lake (1859–2013) and in the vicinity of the lake (1962–2013). Analysis of the demographic data indicates that the human population within the lake has shown more than double the national growth rate. Additionally, 7 important water quality parameters from 82 well distributed sites across the lake were analyzed and compared with the past data to determine the historical changes in the water quality from 1971 to 2014. The changes in the LULC and demography have adversely affected the pollution status of this pristine lake. Ortho-phosphate phosphorous concentration has increased from 16.75 $\mu g L^{-1}$ in 1977–45.78 $\mu g L^{-1}$ in 2014 and that of the nitrate-nitrogen from 365 $\mu g L^{-1}$ to 557 $\mu g L^{-1}$, indicating nutrient enrichment of the lake over the years. Built-up area within the lake has increased 40 times since 1859, which, together with the changes in the population and settlements, have led to the high discharge of untreated nutrient-rich sewage into the lake. Similarly the expansion of floating gardens within the lake and agriculture lands in the catchment has contributed to the increased nutrient load into the lake due to the increasing use of fertilizers. The information about the existing land cover, demography and water quality was integrated and analyzed in GIS environment to identify the trophic status of the lake. The analysis indicated that 32% of the lake falls under sever degradation, 48% under medium degradation while as 20% of the lake waters are relatively clean. It is believed that the results provide improved knowledge and insights about the lake health and causal factors of its degradation necessary for effectively restoring its ecological and hydrological functionality.

1. Introduction

Lakes are sensitive ecosystems that contribute to regional hydrology (Kebede et al., 2006; Thiery et al., 2015) and pristine biodiversity (Jeppesen et al., 2000; Zutshi and Gopal, 2000) and play an important role in sustaining the socio-economy of the dependent populations (Carpenter and Cottingham, 1997; Eshenroder, 1987). Past 50 years of limnological research reveals that the anthropogenic activities, within the lakes and their catchments, are deteriorating the health of these pristine ecosystems at an alarming pace by altering the bio-physical setup (Du et al., 2011; Jones and Orr, 1994; León-Muñoz et al., 2013; Samecka-Cymerman and Kempers, 2001) and lake biogeochemistry (Kundangar and Abubakr, 2004; Kiage et al., 2007; Søndergaard and Jeppesen, 2007). The land system changes impair the water quality, degrade biodiversity and irreversibly alter biogeochemical cycles of a lake ecosystem (Carpenter et al., 1999; Gao et al., 2015; Huang et al., 2014; Romshoo, 2003; Scavia et al., 2014; Schindler, 2006; Smith et al., 1999; Vadeboncoeur et al., 2003). Most of the lakes in Kashmir Himalaya, India have been subjected to anthropogenic pressures which include unplanned urbanization and deforestation of catchments, extensive use of fertilizers and pesticides for agriculture and horticulture respectively and tourism infrastructure development (Hassan et al., 2015; Masoodi et al., 2013; Pandit, 1988; Rashid et al.,

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2013a; Romshoo and Muslim, 2011; Zutshi et al., 1980). Although eutrophication in Kashmir lakes is a recent phenomenon (Khan and Ansari, 2005; Vass, 1980; Zargar et al., 2012a), yet in the short span of time, it has adversely impacted the functionality of lake ecosystems in the region. Additionally, the depleting cryosphere in the Kashmir Himalayan region, under the changing climate, has significantly reduced the stream flows that sufficiently contribute to the lake inflows in the Kashmir valley (Romshoo et al., 2015).

Many lake studies have focused on assessing the state of health of Kashmir lakes, yet the knowledge about the factors responsible for their deterioration remains inadequate. Studies conducted so far are unifocal taking into consideration just a single aspect such as water quality assessment (Bhat et al., 2013; Khan, 2010; Sarwar, 1999; Wani et al., 1996), and aquatic vegetation (Shah et al., 2014; Zargar et al., 2012b). A few studies, based on the use of remotely sensed data, have determined the spatio-temporal changes of a single or a couple of factors within the lakes and their catchments in the Indian Himalaya and linked it to the lake ecosystems (Chopra et al., 2001; Mushtaq and Pandey, 2014; Romshoo et al., 2011; Sharma et al., 2015). In order to holistically comprehend and quantify the influence of causal factors on lake degradation, it is important to integrate all the available data from archives, remotely sensed platforms, in-situ measurements and field surveys in a geospatial modelling environment (Hereher, 2015; Liu et al., 2007; Nielsen et al., 2012; Wasige et al., 2013; Yan et al., 2015).

The study is an effort in this direction and aims to integrate long-term information pertaining to the observed changes in the land system within the lake (1859–2013) and its immediate catchment (1962–2013), water quality (1981–2011) and socio-economy (1977–2013) in a GIS modelling environment. Integration of the long-term multi-source spatial and non-spatial information would help to better comprehend the influence of various factors on the Lake ecosystem and the approach could be replicated for other Himalayan lakes that are showing widespread deterioration due to the multiple pressures.

2. Materials and methods

2.1. The Dal Lake

Dal lake, situated in Kashmir Himalaya, is a multi-basin drainage lake (Fig. 1) covering an area of 24 km^2 with the open water spread of about 10.5 km^2 and a water holding capacity of 15.45×10^6 m^3 (Solim and Wanganeo, 2007). The lake lies between 34°5′–34°9′ N to 74°49′–74°53′E at a mean altitude of 1585 m asl. The lake has tremendous ecological, socio-economic and cultural importance in the region and its deteriorating health is a cause of concern for the people of Kashmir. Being a major tourist attraction in Kashmir, the lake is socio-economically important as the livelihood of a large section of the population of Srinagar city is dependent on the services and products provided by the lake. The lake is an important source of vegetables, fisheries, recreation and drinking water to the people of Srinagar city. The catchment area, spread over 337 km^2, is geologically composed of Panjal Traps, Aglomeratic slates, Alluvium and Karewa deposits (Wadia, 1971; Varadan, 1977; Data, 1983; Bhat, 1989). As per Bagnolus and Meher-Homji (1959), climate of the area is sub-Mediterranean with four seasons. The total annual precipitation and average temperature recorded at the nearest meteorological station is 870 mm and 11 °C respectively.

2.2. Datasets

In order to accomplish the research, data from multiple sources was used to assess the long-term changes in the Dal lake and its immediate vicinity. The data included satellite images, survey maps, demographic data, water quality data and GPS measurements. For the land system change detection, satellite data of the same period/season has been used to eliminate the errors in the land cover information due to the changing season or time gaps in the acquisition of the data. The details of the multi-source datasets used in this study are provided in Table 1.

2.3. Methodology

The methods employed to generate the long term information about the changes in the land system, demography and water quality within and in the vicinity of the lake made use of the data from various sources including remote sensing, laboratory analysis, census, fieldwork, and archived maps are discussed hereunder:

2.3.1. Long-Term land system changes within the lake

Quantifying the long-term changes of environmental variables is important for getting deeper insights into the environmental changes occurring within an ecosystem (Lindenmayer et al., 2012; Magnuson, 1990). At the same time, it becomes essential to link the changes within an ecosystem with the causal factors like socio-economy (Redman et al., 2004). In the present study, land system changes within the Dal lake were assessed over a period of 155 years from 1859 to 2013 using the available data. For generating the reference data, an old survey map dating back to 1859 (Stein, 1859) was used. The map was digitized in GIS for delineating the lake boundaries and the land cover information as it existed in 1859. In addition to the survey maps, multi-date satellite data of the period from 1972 to 2013 was used to assess the land system changes within the lake ecosystem. Data analysis involved the processing of satellite images using standard algorithms (Lillesand and Kiefer, 1987). Using the standard geometric correction algorithm (Jensen, 1996), satellite data was corrected for geometrical distortions using map-to-image and image-to-image geo-referencing algorithms. The tie-points were taken all across the satellite image to ensure better geometric correction of the data, achieving a root mean square (RMS) error of less than 1.00. All the satellite and survey data were co-registered with respect to each other in order to ensure the precise delineation of the lake boundary. Image enhancement techniques like histogram equalization (Yang and Lo, 2000) and contrast stretch (Gillespie et al., 1986) were applied to the satellite data to highlight the land features. On-screen visual interpretation (manual digitization) of the satellite data was employed to map the land cover types (Romshoo et al., 2011) at 1:40000 scale. On-screen digitization, with cognitive inputs from the image analyst, was chosen instead of digital classification algorithms as it is advantageous for delineating land cover in mountainous areas (Rashid et al., 2016a; Rashid et al., 2016b; Rashid and Abdullah, 2016). Only four major land use and land cover (LULC) types were mapped using the multi-source data; Aquatic vegetation, Floating Gardens, Built-up and Open Waters. In absence of any ground truth data, we used high-resolution Google Earth images for checking and validating 2010 satellite data.

We quantified the uncertainties associated with the use of different resolution data for mapping physical features (Murtaza and Romshoo, 2016; Bhambri et al., 2012) advocated by Williams et al. (1997) and Hall et al. (2003) using the following formula while assuming image registration error as zero:

$$U = \sqrt{a^2 + b^2} \tag{1}$$

where 'a' and 'b' are the spatial resolutions of two images and σ is the error in the image registration.

The uncertainty with respect to area (Uarea) was estimated using the following formula:

$$U_{area} = 2UV \tag{2}$$