Chapter-9

SUMMARY AND CONCLUSION

Wetlands are the hydrological landscapes that are periodically or consistently submerged by water and host unique flora and fauna (Winter, 2001). They act as ecotones between terrestrial and aquatic environments. Their diverse functions, such as environmental purification, preservation of water quality, enhancement of floodwater retention, control of soil erosion, and provision of habitats for wildlife, make them one of the most critical landscapes on the earth's surface (Bullock and Acreman, 1999; Burt, 1995; Carter, 1986, Bradley,1996; Gala and Young, 2015; Hunt et al., 1996; Winter et al., 2003, Acreman and Holden, 2013). Riverine wetlands are a category of wetlands confined within floodplains and associated with rivers or streams. Among all types of wetlands, riverine wetlands hold relatively higher ecological value and are more environmentally delicate (Costanza et al. 1997). But in the present time, this crucial ecosystem is facing human-induced stress due to encroachments, increased water demands, agricultural activities, etc. About 3.4 million km2 of inland wetlands have been lost since 1700, primarily for conversion to croplands (Fluet-Chouinard, et al. 2023).

The Gangetic Plain is one of the most extensive floodplains in the world and is the home of numerous riverine wetlands. Simultaneously, it encompasses one of the world's densest populations; therefore, the riverine wetlands in the Gangetic Plain also face the problem of stress. The interfluve of the Ganga and Sai Rivers has a tract of riverine wetlands, and it appears they are interconnected. These riverine wetlands have remarkable characteristics as they offer seasonal habitat to many migratory birds for breeding and nurturing their young and provide a migratory stopover habitat. Recognising two riverine wetlands as Ramsar sites makes the whole tract ecologically and environmentally indispensable. In the adjoining area of these wetlands, a momentous deposition of salt-affected soils has been observed along with the salt deposition in the roots of some plants. These riverine wetlands are the hydrogeomorphic environmental unit of the Gangetic floodplain, but no work has been done with aspects of its geomorphological study, its spatio-temporal analysis or the impact of wetland's degradation on the soil's quality. It is necessary to keep a holistic approach and understanding of their hydro-geomorphological distribution and geological origins for any management plan for their conservation and restoration. In the present thesis, the riverine wetlands in the interfluvial zone of the Ganga and Sai Rivers have been taken for detailed investigation of hydrogeomorphic distribution, analysis of their spatial-temporal changes, the effect of their degradation on the soil's quality and plan for their revival.

The remote sensing data, i.e., Landsat 8 OLI (Operational Land Imager) satellite image, Shuttle Radar Topography Mission- Digital Elevation Model (SRTM- DEM) data and Sentinel image were used as primary data for the delineation and extraction of riverine wetlands in the form of hydro-geomorphological features. All the on-screen work in the GIS environment was performed using ERDAS Imagine-2014 and ArcGIS-10.6 software. The sinusoidal pattern of the hydro-geomorphological features, their well-defined connectivity with each other, vegetation along these patterns, and high reflectance in near-infrared (NIR) due to abundant vegetation were used as characteristic signatures for identification and delineation. The Image- based indices, i.e., NDVI and MNDWI, were used for identifying water bodies and water- vegetation-associated features, which helped in the delineation of riverine wetlands. The electrical resistivity surveys and sedimentological studies, such as grain size analysis across the channel belts, were carried out at the places where the identification and delineation of the hydro-geomorphological features were not confirmed in remote sensing images. Furthermore, the geomorphology of the hydro-geomorphological features was understood by the geomorphological parameters such as wavelength, amplitude, angle of curvature, radius of curvature, sinuosity index, bend tightness index, etc.

Applying the above methodology, we reveal that a series of continuous and properly interconnected riverine wetlands in the form of hydro-geomorphological features (such as traces of channel, underfit rivers, and associated ox-bow lakes and meander scars) in the upper reaches of the currently flowing Bakulahi River in the interfluvial zone of the Ganga and Sai Rivers are an integral part of the Bakulahi River. This reveals that the Bakulahi River originated from Gouria Kalan village near Bangarmau in the Unnao district. Flowing through 3 districts (Unnao. Raibareli, and Pratapgarh), it meets the Sai River at Khajurni village in the Pratapgarh district. The total length of the channel course of the Bakulahi, with several disconnected channels/streams of Bakulahi, is 558 km, and its average width is 150 m. The geomorphology and sedimentological analysis of Bakulahi River presents a specific stage of the river in flood plains, which has lost the continuity of its channel course and its continuous flow. It shows two important signatures: firstly, the self-burying of its course by its own sediment loads and, secondly, the obliteration of parts of its course and complete looping of courses with angular turnings. These characteristics are associated on both sides with abnormal bending and turning. Owing to the effect of neo-tectonism, the river underwent a decrease in its mass, and therefore, energy could not survive its course, and became extinct. Later on, a system of ox-bow lakes, meanders, relict fluvial features, and complex scrolls eventually converted into riverine wetlands. Presently, there are two Ramsar sites associated with the riverine wetland system. Presently, the whole tract is ecologically and environmentally indispensable and valuable, and two riverine wetlands have been considered as Ramsar sites. Thus, the study provides an understanding of the entire course of the Bakulahi River, which immensely helps in the conservation and management of riverine wetlands in the interfluvial zone of the Ganga and Sai Rivers.

After identifying and delineating these riverine wetlands, which evolved from relics of the extinct Bakulahi River, we analyse the spatio-temporal changes in the areal extent of these riverine wetlands in the last twenty years (from 2000 to 2019). Satellite images of 2000, 2008, 2014 and 2019 were used for post-monsoon, while satellite images of 2001, 2009, 2015 and 2020 were used for the pre-monsoon season. The spatio-temporal changes were further affirmed by variations in the hydrological condition of the Riverine wetlands based on spectral index value changes. Further, the Hydrologic drought analysis was done using 50 years (1970 to 2020) of rainfall data on the scale of 12 months (SPI-12) to know the effect of drought on the spatio-temporal changes in the areal extent of riverine wetlands.

The results of this study show that these riverine wetlands in the interfluvial zone of the Ganga and Sai Rivers have been declining continuously. Over the last twenty years, 25.13% of the area of riverine wetlands has been degraded, which warns for the timely commencement of area-specific planning and management of these wetlands and other similar cases of floodplain wetlands. There is a lack of social awareness amongst political, administrative, social workers, and even agriculturists and the general public about the fact that the entire interfluvial tract has been a vibrant wetlands ecosystem. Therefore, there is an urgent need to conserve these wetlands and revive their ecological role. For effective conservation, the entire area must receive recognition as a tract of interconnected wetlands. If proper planning over the stretch of the wetlands is undertaken and social awareness and involvement are encouraged, many more such sites can be considered for development as Ramsar sites in future.

Further, we assess the impact of riverine wetlands degradation on soil quality in the adjoining areas in the interfluvial zone of the Ganga and Sai Rivers. To study the entire interfluve of the Ganga and Sai, we selected the Samaspur Bird Sanctuary (Ramsar wetland sites) and the adjoining areas as sample sites. The soil samples from the three types of soil (i.e., the white- coloured barren soils in the form of white patches adjacent to the Samaspur Bird Sanctuary, dark-coloured soil from Samaspur Riverine wetland soils, and brown-coloured soil from agricultural soils) were collected. In the laboratory, the grain size analysis, chemical constituent of soil such as pH, electrical conductivity (EC), soil organic matter (SOM), extractable phosphorous (P), extractable potassium (K) and extractable sodium (Na), exchangeable sodium percentage, cation exchange capacity (CEC) and clay mineralogy (FTIR and XRD) have been determined for the analytical study of the soil. Most parameters were derived using Indian Standard Codes (used in civil engineering). X-ray photoelectron spectroscopy (XPS) (Model: K-Alpha) of the salt sample was conducted to identify the chemical constituents in the salt deposited in the roots of plants (Yuan et al., 1998).

The analysis of soil in the adjoining area of Samaspur riverine wetlands shows that, the quality of soils is deteriorating with the degradation of these riverine wetlands. The deteriorated soil at degraded wetlands sites in the adjoining area of Samaspur Bird Sanctuary appears as white patches. These white-patches soils are salt-affected soils. They are dispersive in nature and have unfertile characteristics. The excess saline content in the top surface soil reduces the growth of most crops and plants. The sodicity of the soil is due to the high sodium content in the soil, which is responsible for the fragile nature of the soil. This affects the physical properties of soil adversely, which has created unfavourable conditions that do not support plant growth in white-patches soil, the zone which once had a luxuriant wetland forest. The high concentration of sodium content in white-patches soils is due to the reason that the water table in the white-patches soils is very shallow and, therefore, encourages heavy capillary action and deposition of salt. Due to the long-term effect of this type of process, sodium content accumulates in sufficient amounts on the top of the surface soil. There is an urgent need for plant vegetation which is friendly to the wetland ecosystem, and thereby, the protection of this vibrant and functional wetland, a Ramsar site, would be possible.

The revival of the Bakulahi River can facilitate the reconstruction of the riverine wetlands in the interfluves of the Ganga and Sai Rivers. A model has been prepared, in which the elevation along the delineated traces of channels of the Bakulahi River in SRTM DEM (original DEM map) was lowered by 3 meters using Arc GIS 10.6 software, and a modified DEM map was prepared. The concept behind lowering the elevation along the river is to increase its longitudinal connectivity, which is a very important aspect of a river network as it reduces sedimentation and helps maintain the riverine system. Further, the Soil & Water Assessment Tool (SWAT) were applied on both the original DEM map and the modified DEM map. In addition, all the required data, such as land use land cover (LULC) data, soil data, and meteorological data for SWAT, were used to find out the catchment area, watershed, number of sub-basins, length, discharge and other hydrological components after the revival of current Bakulahi River and Revived Bakulahi River. Later, the catchment area, watershed and all hydrological components of the current Bakulahi River and the revived Bakulahi River were compared.

The results show that, by lowering the elevation by 3 meters in the DEM map along the delineated traces of channels, the Bakulahi River could be revived. The SWAT estimated that, after the revival, the Bakulahi River became a 4th-order river. The watershed has increased by 267%, with its mouth located at the confluence point with the Sai River. The length of the Bakulahi River also increased by 419% compared to the current Bakulahi River. The topography surrounding the river exhibits little elevation differences, suggesting low runoff and a greater ability to absorb water into the ground. Therefore, it may be inferred that the river's flow has a certain degree of impact on the groundwater. The whole tract of the Bakulahi River in the interfluvial zone is the house of riverine wetlands, which are the relics of the Bakulahi River. All these wetlands are somehow connected with each other, and if we revive the Bakulahi River according to the given model, the whole Bakulahi River will be regained, and with time, the runoff of the Bakulahi River may increase and become converted into the actual Bakulahi River existing in the past and in this way, all the riverine wetlands may be reconstructed.

This study can set as an example for the revival of all the Quaternary Riverine wetlands in the Gangetic Plain as well as other riverine wetlands in any part of the world where floodplains are facing danger of extinction.

Future Work

For better effectiveness of the revival of riverine system the following study can be done in future:

(i) Control of Tectonism on the River courses.

(ii) Groundwater modelling, Ecological modelling, Water quality and nutrient modelling.

(iii) A comparative study of hydro-geomorphological behaviour of both the riverine wetlands systems of Bakulahi River and Sai River may provide interesting information about the relict systems and long-term process of sedimentation.

(iv) A model can be developed to established the hydrological connectivity between the riverine wetlands systems of Bakulahi River