

*Assessment and Monitoring Land Degradation
Dynamics using Geo-Spatial Technology in Ballia
District of Uttar Pradesh, India*



THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

Master of Science (Agriculture)

In

Soil Science and Agricultural Chemistry

Supervisor

Prof. Nirmal De

Submitted by

Plabani Roy

**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
INSTITUTE OF AGRICULTURAL SCIENCES
BANARAS HINDU UNIVERSITY
VARANASI-221005
INDIA**

ID No.– 18412SAC024

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Dear Sir,

I have great pleasure in forwarding the thesis entitled **“Assessment and Monitoring Land Degradation Dynamics using Geo-Spatial Technology in Ballia District of Uttar Pradesh, India”** submitted by **Ms. Plabani Roy (I.D No.18412SAC024, Enrolment No. 406181)**, in partial fulfillment of the requirements for the degree of **Master of Science (Agriculture) in Soil Science and Agricultural Chemistry**, from the Department of Soil Science & Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.

I certify that the entire scheme of investigation presented herein was planned and carried out solely by the candidate under my guidance and supervision. The data presented in the thesis, to the best of my knowledge and belief, are genuine and original. No part of the work has been submitted for any other degree or distinction.

Thanking you,

Forwarded by

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(Nirmal De)

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Date : October, 2020

Place : BHU, Varanasi

(Plabani Roy)

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INTRODUCTION

Natural resources like sunlight, atmosphere, water, land, soil, forest, vegetation, air and animals are the basis of life on earth that exist without actions of human kind. Human being makes use of materials that are provided by the earth to create more complex substances. Land is important one to comprise all naturally occurring resources as well as geographical lands are included. The land of the Earth interacts with and influences climate heavily since the surface of the land heats up and cools down faster than air or water. Numerous human activities are done in or/ upon land surface, uses land in habitat purpose or for agriculture, planting and other purposes therein affecting soil and its functions. Soil is an integral part of land system and it plays an important role in life supporting system.

Soil fertility is the inherent capacity of soil to contribute nutrients to the plants and its growth. Various problems of soil like salinity, alkalinity and erosion causing degradation. Soil degradation is the decrease in the quality of soil like soil air, water, nutrients etc. Soil quality can be depleted by various natural and anthropogenic processes and it changes the physical, chemical and biological properties of soil. The degradation of soil can be occurred by decline the organic matter content of soil which affects their structural integrity also. Due to various adverse changes in various soil properties the soil may not be appropriate for further cultivation and cropping reduces its scope for future use.

Natural or anthropogenic activities set out soil from its normal functioning lead to impact negatively render soil for its degradation. Degradation is the depletion of earth's natural resources. Degradation is the lowering the quality of substance or declining from its original state. The value of the bio-physical environment is affected by a combination of human-induced processes acting upon the land; the process is called as land degradation, most probably a threat to the environment. Degradation of land is deleterious and undesirable. Soil degradation causes degradation of quality and productivity of soil due to ecological and economical function of soil. Poverty,

agricultural practices, overgrazing, over population and inappropriate policies are the main reason of land degradation (**Drechsel *et al.*, 2001; Duraiappah, 1998**). There is interconnection between various factors and their impacts on land.

Human mostly depend on land and various land resources for their various use. Due to various actions by human land is degraded thus affect the human being the most in direct and indirect way. One of the physico -chemical property is land use or land cover, due to frequent change in land uses nutrient loss from soil occurs and it degrade the land quality (**Emadi *et al.*, 2008**). Deforestation cause excess carbon-dioxide emission, reduction in ground and land storage carbon, ability of ecosystem to regulate soil-water-vegetation-atmosphere system (**Cao *et al.*, 2001**). Soil Carbon is one of the important factor diminish gradually due to heavy cultivation of forest. It also decreases the level of nitrogen mineralisation (**Murty *et al.*, 2002**).

Industrialisation or urbanisation effect land quality and pollute land via discharge or dumping of hazardous waste materials. Moreover, continuous and extensive use of heavy implements and agricultural substances degrade land quality. Poor management and excessive use of various chemical fertilisers, pesticides affects land quality and degrade land in long term via destroying soil structure leads to crusting of soil, desertification, compaction, erosion. Various changes of chemical properties of soil like salinisation, alkalinity, and acidification, leaching and altered cation exchange capacity leading to soil degradation.

Population is increasing day by day and crop production should be increased to meet up their food requirements. Due to demographic pressure production load on soil is highly increases and non-ecological use of various cropping practices deteriorate soil quality day by day and it is increases gradually. Modern human population significantly degrade the land in large scale measure. Actually population is not the only responsible factor of land degradation, their activity and use the land sources is the main problem. Industries and factories which discharged large amount of polluted effluents and chemicals in water bodies and soil thereby affects quality.

Apart from all above land quality also gets affected by natural means low precipitation or drought accelerate immobilization or slow down mineralization of nutrients, heavy rainfall or runoff peel off soil's uppermost fertile layer. It is a very

crucial time to think about land degradation and its causes, management. It is necessary to aware the people about its consequences.

Ballia district of Uttar Pradesh earlier has huge forest cover; people of that area gradually transform the forest area to agricultural land and pastoral land for their own need. The greatest Ganges river and its various courses are also affected due to the same pollution.

Soil is one of the key elements of biosphere. Soil act as a geochemical sink in which contamination occurs as well as soil as a buffer system which control the chemical contamination and transportation of elements in hydrosphere, biosphere and animal community. Agricultural production is mainly depends upon the soil and its production capacity. Due to various anthropogenic activities causes soil contamination affects the ecological and agricultural production. The increasing amount of industrialisation in last century is the root cause of soil pollution increases worldwide (**Adriano, 2001**).

For agricultural production rainfall is one of the main input observed by calculating various weather model that the rainfall of Ballia is decreasing by last decade and the water requirement of crop is not fulfilled by rainfall only. The agricultural production is depended on irrigation water now. Due to use of chemical fertiliser and excess use of amendments the soil become problematic as salinization, alkalisation problem occurs. The chemical substance leaches into the ground put greater impact on ground water quality also. Thus the soil as well as ground water resources are also polluted. Improper disposal of waste water is also the main problem.

The biosphere is affected mainly by increasing industrialisation. Smelting industry, heavy metals, wastewater, sewage, agrochemicals, mining, burning of fossil fuels are the main primary source. Soil and water pollution effect the plant population by reducing their growth, structural growth, effect to their physiochemical and biochemical activity (**Carpena et al., 2003**). Soil pollution effect on the ecology as well as human health by their degrading agents is a global concern now. In agriculture and in industrial production the chemical disposal which contains mainly by hydrocarbons, pesticides, petroleum hydrocarbon, solvents ,heavy metals, lead, mercury, arsenic, poly nuclear aromatic hydrocarbon etc.

Human activities, ignorance and greed destroy the soil as well as land quality. It can be cured by better management practices and modern technologies. Soil, ecology, environment and human being are in intimate relationship and it's dependent on its management and its quality. People should be aware of the main problem of soil degradation and their remedies. Proper management should be taken to increase the soil quality in which human health could be better directly or indirectly.

In earlier age man's sole interest in soil is to cultivate crops, produce food, fibre, fuel and fodder. Increased population size creates huge demand for soil as well as land use consequently. Land is degraded due to overuse. Industrialisation and urbanisation fasten the degradation process that unstable the ecological and environmental balance. Soil becomes problematic day by day so proper management strategies and regular surveying of soil as well as land quality should be done. Effective modern technological use should be adopted to monitor land degradation and mapping such problematic soil for necessary action.

Soil degradation is a problem which is prevalent in many parts of our country, India. But its severity from local scale to country level is not be understood clearly (**Bassett and Zueli, 2000**). Imbalanced use of fertilisers, over-grazing, salinization, agricultural practices, soil erosion are the main indicator of land degradation. The assessment of these factors may help in taking proper decision making regarding management practices (**Warren, 2002**). Soil health should be assessing at regular interval. Different soil bio-physical data of different sites and mathematical models are required to assess various soil properties and soil health at spatial and temporal scale. Human change the soil system and alter the environment, so the models and equations are required to evaluate the effect of various anthropogenic effect on soil (**Grunwald et al., 2011**).

Making use of modern tools and techniques for proper decision to evaluate soil as well as lands and their problems so to predict their effects and management can be taken. Detail soil survey and up-to-date maps are the most needed for proper assessment of soil problems and management strategies should be taken based upon it.

Remote Sensing (RS) and Geographic Information System (GIS) are the important information acquiring system and are the geo-spatial techniques by which soil

degradation assessment is done. Remote Sensing (RS) and Geographic Information System (GIS) helps in acquiring information about soil including collection of raw data, data processing, analysing, interpretation of that data and presenting them in an appropriate manner.

Geo-spatial techniques evaluate the various physio-chemical properties of soil and severity of soil degradation. By evaluating the spatial variability of soil properties and chemical properties selection of soil management practices and decision making approaches should be carried out (**Cambardella *et al.*, 1994**). Physiochemical and biological factors such as soil properties, topography and climatic factors and their interactions are the main cause of land degradation (**Brevik *et al.*, 2015**). The main spatial properties of soil are pH (H⁺ activity), EC (electrical conductivity), soil organic carbon, organic matter etc which influence the soil properties and quality. But land degradation mapping is not only depends on these factors only it includes land use management factors and many other anthropological factors (**Khaledian *et al.*, 2017**; **Cerda *et al.*, 2016**).

Digital soil mapping is to evaluate the severity of land degradation and by interpretation of those values proper management strategies can be adopted. It is a modern technique of soil property evaluation and link between various factors as well as climatic factor in soil degradation. It becomes one type of spatial distribution technique of soil properties.

To assess the land degradation many other soil physiochemical properties are evaluated besides pH, EC and organic carbon including spatial variability in alkalinity(CO₃²⁻,HCO₃⁻), soil-Na⁺/K⁺, soil-Ca²⁺/Mg²⁺,soil-S,available soil-N, soil-P, soil-K, cation exchange capacity (CEC), structural properties and textural class of soil. Considering the present scenario of land degradation soil surveying, Chemical and Geo-spatial analysis are performed to evaluate the degree of land degradation. Some current quantitative data regarding various land use practices are not available. All the above facts keep in views and present the research work entitled “***Assessment and Monitoring Land Degradation Dynamics using Geo-spatial Technology in Ballia District of Uttar Pradesh, India***” with following objectives:

1. To monitor and mapping of degraded soil of Ballia district, UP.
2. To map the spatial variation in physico-chemical properties of soil.
3. To compute spectral indices and correlate land degradation with climatological and anthropological factor.



REVIEW OF LITERATURE

Review of literature will be discussed under following heads:

2.1 Soil Survey and Monitoring

2.2 Land Degradation Scenario and Sources

2.3 Correlation Matrix of Soil Physico-Chemical Properties with Soil Degradation

2.4 Geospatial Technology in Assessment of Soil Degradation

2.5 Remote Sensing Indices and Spectral Reflectance in Relation to Soil Degradation

2.6 Geographic Information System (GIS)

2.7 Techniques of Spatial Variability Mapping

2.8 Geo-Statistic and Classical Statistic in Variability Mapping

2.1 Soil Survey and Monitoring

Soil Survey is the method of describing the characteristics of soil, classified them into different groups, publishing information about the soil and mapping of that area. Soil Survey is done in a very systematic way. It includes giving a brief overview of area and its geography, description of the major soil types of area, description of their physical, chemical properties, erodibility, total area land use planning of that area and crop production information about the area. Ultimately mapping is done to describe the area and its various soil characteristics.

Soil survey data is changed gradually with time as the change of requirements and questions asked by the users in soil survey. Soil survey comes after soil genesis and classification which depend on the soil type of different topographic position (**J. Bouma, 1989**). Soil forming process, soil properties, land use cover are necessary properties to understand and to be monitored to plan management approaches to reclamation of land and increase crop productivity. In the semiarid zone of Western Siberia, data obtained by soil survey is used for modeling of land use planning. For chestnut soil properties, probability distribution is obtained for evaluating the effect of soil forming factors on various soil properties. Long term ploughing, use of irrigation water containing high sodium bicarbonates are the reasons for poor land quality (**Mikheeva I., 2013**).

Paradigm theory of science is first invented by Thomas S. Kuhn. Science related to soil dynamics is included to paradigm theory. Soil survey is based on soil-landscape based model which is an operative paradigm (**Hudson, B. D. 1992**). Soil survey is the classification of landscapes according to common soil properties and characteristics. Soil characteristics are changing day by day and we observed it in long time run. Soil survey is done to make decision and evaluate soil change. In ecological site concept the dynamic soil properties are changed as result of poor management. Soil resource management can be done by interpreting the soil properties and grouping them accordingly. Soil change can be used as a reference of soil health assessment (**Wills S. et al., 2017**). Traditional polygon-based soil maps are used by surveyor for unmapped areas. Many geo-spatial models are made by soil forming factor

covariate. Raster soil-landscape models are better soil survey program. These are the pre-mapping estimation of soil survey (Howell *et al.*, 2008).

2.2 Land Degradation Scenario and Sources

Degradation of land is most important problem in many areas in the World. Urbanisation, deforestation and mismanaged agricultural practices are the causes of degradation of arable land. Other causes may be over use of pesticides and fertilisers, salinisation, acidification, alkalinisation, use of heavy farm implements, water and wind erosion etc. (Tolba *et al.*, 1992). Land is a natural complex which comprises rocks, climate, hydrology, landforms, biology and soil included to it. In different periods of time qualitative and quantitative comparisons of land such as deserts, rocky areas, snow, gobi should be done to understand the land degradation process. Land degradation may cause decrease in crop productivity which is the resulting factor of human and climatological activity (Meng *et al.*, 2020). Land degradation can be assess by Global Assessment of Soil Degradation (GLASOD) which is the compilation of various opinions of experts. Global land degradation is assessing by global assessment of land degradation and improvement (GLADA) by using climate-adjusted GIMMS NDVI data to identify hot spot of land degradation and bright spots of land improvement. In a study it was observed that 24% of global land was degraded during 1981 to 2003 (Yengoh *et al.*, 2015). In European Mediterranean Countries from earlier period of this century agricultural system are shifted from traditional to modern agricultural system by national and common agricultural policies. Due to overexploitation of natural resources degradation of land is increased. In Sardinia cultivation of forage production is increased due to growing demand of sheep cheese. Land cover maps are obtained by using GIS technology and interpretation of aerial photographs (D'angelo *et al.*, 2001).

2.3 Correlation Matrix of Soil Physico-Chemical Properties with Soil Degradation

Various soil forming factors are soil PH, EC, soil organic carbon (SOC), soil organic matter (SOM), salinity (soil- Na^+/K^+), alkalinity (soil- $\text{Ca}^{2+}/\text{Mg}^{2+}$), Carbonate and Bicarbonate content etc are the physico-chemical factors. There are other factors like

active factor like climate and organisms and passive factors such as parent materials, topography and most importantly time. All these factors affect soil forming process and they are correlated to each other.

Topography and land use land cover are important factor effecting land degradation. In Uludere catchment, it is observed that the above mentioned factors affect the area. The effect of land use and land cover changes on soil organic carbon and other soil properties are observed in upper soil layer (0-20cm) by comparing the soil with the adjacent soil of natural forest, grassland and cultivated area. There is significant change in soil bulk density (BD), soil organic carbon (SOC), soil organic matter (SOM) and soil total nitrogen content (TN) in agricultural land the amount of SOC, SOM and TN becomes very low due to various management practices, the forest land has the lowest BD value as compared to grassland. Natural vegetation is the one of the most appropriate land cover and land use to protect the quality and decrease desertification in semi-arid region (Gol C., 2017). In Europe and Middle East Turkey has significant importance in terms of bio-diversity. Nine thousand plant species and endemic species of vertebrates occur in lakes and marshy lands. Because of agricultural potential, biodiversity, high population, economical and social structure, topographical factors desertification occurs in Turkey which is a global concern (Camsi *et al.*, 2007). Soil quality index contain many soil physico-chemical properties soil inorganic nitrogen content is the one of the most important content. In the mountain forest area in the north of Iran, in arable land and in pine forest soil, ash plantation and beech stand inorganic nitrogen content and nitrogen mineralization rate is observed. In arable land and pine forest total nitrogen content are high as compared to others. Extractable $\text{NH}_4^+\text{-N}$ content is higher in beech soil. There is no significant difference in Net Nitrogen mineralization, net nitrification and net ammonification rate among all the different land type. The conversion of forest land in agricultural land cause poor soil quality and agricultural production (Asadiyan *et al.*, 2013).

2.4 Geospatial Technology in Assessment of Soil Degradation

Remote sensing is obtaining information of an object without get contact with that. Data is obtained by a device separated from that object at a certain distance, the data should be analysed and interpretive the physical attributes of that object. Data

acquisition is done by electromagnetic radiation from aerial sensors flying in space platforms. The US National Aeronautics and Space Administration (NASA) has developed many space and aerial programmes which provided remote sensing data information worldwide (**Gupta and Ravi, 2017**).

At the end of the 20th century in western China it was observed by remote sensing data that soil erosion is a prime environmental problem there. Poor management in farmland, forestland destruction are the main cause of erosion. Slight water erosion occurs in hilly and mountain region and high water erosion occurs on loess landforms. Wind erosion also occurs in grassland (**Feng et al., 2002**). In Dibrugarh district of Assam, soil physiographic analysis was done with help of Indian topographic maps using Landsat-4 MSS data in the form of FCC (4, 5 and 7). By composite interpretation maps as base various ground data are transferred to soil data in four major physiographic areas like active flood plain, recent alluvial plain, gently undulating old alluvial plain and gently sloping to undulating piedmont plain (**Sen T. K., 1992**). A case study on erosion mapping of Mahaboobnagar area was done by space technology and remote sensing. It is done by comparing visual interpretation of imageries, I^2S and computer analysis of LANDSAT digital data with aerial photo interpretation and soil map drawn by conventional method. Spaceborne and airborne data are more accurate, effective and economical than conventional method of mapping (**Karale R. L., 1983**). Satellite Remote Sensing and GIS are valuable tools for physiographic analysis and soil resource mapping. In Solani Watershed digital image processing was done and delineated various different soil mapping units. Colluvial and denudational processes in the upper part and sedimentation processes in the lower part of that watershed are the main cause of the different physiography of that area (**Velmurugan et al., 2010**). In an arid watershed of Jodhpur district (Rajasthan) identification and mapping of various physiographic units are obtained by IRS-LISS-II (January, 1995) FCC (1:50,000 scale) of spectral bands 2, 3 and 4. Based on image characteristics and field transverses seven major physiographic characters are characterized (**Khan et al., 2000**). Salinization in soil and water is very important regarding environmental pollution. Its impact is high on crop growth and production in arid and semi-arid area. The determination of salt crusting in soil and

underground water sources are done by airborne remote sensing and proximal sensing-based geophysical tools. The salt affected areas are diagnosed by several aerial satellite system and remotely sensed data .To get accurate data ground truthing and chemical laboratory analysis are essential. Various level of salinity is detected by combining the proximal and remote sensing data. Diagnosis becomes easier by combining the methods (Sethi *et al.*, 2016).

2.5 Remote Sensing Indices and Spectral Reflectance in Relation with Soil Degradation

NDVI refers to as Normalized Difference Vegetation Index. NDVI is used in changes in global environment. It is based on time series data which is derived from AVHRR/NOAA, VEGETATION/SPOT, AQUA/ MODIS AND TERRA etc. NDVI value is decreased by poor atmospheric condition. It shows the growth of vegetation (Chen *et al.*, 2004). NDVI shows the land processes and vegetation conditions spatially, spectrally and radiometrically. NDVI is produced by Advanced Very High Resolution Radiometer (AVHRR) 4-km global area coverage data in daily daytime basis. It is done from july, 1981 to dec, 2004 for all continents except Antarctica. NDVI is used to minimize the variation of solar zenith angle effect which is caused by orbital drift observed from the data from NOAA-16 for 2000–2003 and NOAA-17 for 2003–2004 compared to the dynamic range of MODIS NDVI.10-days Africa-only database and Bi-monthly database-these two type of NDVI composite intervals are introduced (Tucker *et al.*, 2005).

2.6 Geographic Information System (GIS)

Land use and land cover change (LULC) is one of the important factor for proper management and decision making regarding land degradation. In the Koga watershed, North-western Ethiopia, for sustainable use of resources and management of land they detect the drivers of land cover changes by using MSS of 1973, TM images of 1986, 1995 and 2011 and compare with survey and demographic data. Deterioration of grass and bush lands is caused by the growing demand for food and agricultural land (Sewnet A., 2018). Land degradation may be caused by physical, chemical or any biological process. Water, wind erosion, crusting, compaction, water

logging etc are some physical cause, while chemical process are pollution, alkalization, salinization, acidification etc. Degradation of vegetation and reduction in soil organic matter content are the main biological factors of land degradation. In local scale assessing and monitoring the land degradation is done by integrating high-resolution remote sensing data and digital elevation models obtained by satellite like Cartosat-1 and Cartosat-2 and Light Detection and Ranging (LIDAR) with ground data. Remote sensing and GIS tools applications are more accurate and efficient in assessment, mapping and monitoring the degraded land (**Reddy Obi G.P., 2018**). In the eastern part of the Nile Delta, Egypt land degradation is the most threatened problem due to agricultural activities. The main problems of that area are salinization, alkalization, water logging and compaction. The monitoring of different degradation degrees are carried out by using remote sensing, GLASOD and GIS technology. Anthropological factors like over irrigation, improper time of using heavy machineries and human intervention in natural drainage are the causative factor of land degradation of that area. The data obtained by geo-spatial techniques are used in decision making for sustainable planning (**Mohamed E.S., 2013**). In mountain region land exhibit high risk of soil erosion. Increase in heavy rainfall and runoff decrease the agricultural productivity. Soil water conservation (SWC) implementation in field is not efficient in all areas. The high risk area of land degradation should be monitored by GIS approach and SWC should be implemented accordingly. The prior indication of high risk erosion that are land curvature, flow accumulation, slope steepness data are derived from 25 m digital elevation model (DEM) and classified the land degradation as low, moderate and high risk accordingly. High risk areas are land with low flow accumulation and steep slope. It is one of the most appropriate methods of provide scientific decisions for implication of SWC to the most degraded land (**Wadaey A., 2014**). In Jhagrabaria watershed Allahabad, U.P. a spatial mapping of soil erosion is developed by Revised Universal Soil Loss Equation (RUSLE) in combination with LANDSAT 7ETM⁺ remote sensing data and geographical information system (GIS). Soil erodibility factor (K) is developed by soil map and topographical data, topographic factor (LS) is determined by digital elevation model (DEM) image. Based on vegetation, shades and various soil properties crop management factor(C) is developed by analysis of a LANDSAT

Enhanced Thematic Mapper Plus (LANDSAT 7 ETM⁺) image. Practice factor (P) is determined by operation in land use land cover and slope factor. Value of K varies from 0.25-0.48. C and P value is less than 1 and value of LS is less than 1.4. Soil erosion risk map is divided into 5 classes as very low, low, medium, moderate high and high. Soil erosion risk maps are produced by GIS linked with land use land cover (LULC). Mature and vegetation zones are under low soil erosion risk and barren, fallow lands comes under moderate to high soil erosion risk areas (Rawat *et al.*, 2014).

2.7 Techniques of Spatial Variability Mapping

Spatial variability is the uncertainty of a location site or point. From location to location there is some difference in properties in various different functions. This is commonly referred to as spatial variability. Spatial variability also depends on time that is called as temporal variability (Moss R.E.S., 2020). Spatial variability is essential estimation for geo-statistical modeling. Various soil properties such as soil texture (sand, silt and clay), electrical conductivity (EC), organic matter, mineral content (CaCO₃) are analysed by both classical and geo-statistical method. Geo-statistical methods are semivariograms, cross-semivariograms, descriptive statistics, spatial kriged and co-kriged prediction maps and interpolation. In the study area moderate to strong spatial variability is observed. Parent materials and mineral compositions are the factors of spatial variability. Co-kriging is the one of the most important, accurate and efficient method for spatial interpolation and evaluation of soil properties (Saleh A.M., 2018). Every soil exhibit different characteristics and unique properties, so digital soil mapping should be done to know the characteristics (Akshay *et al.*, 2006). Structural factors like parent materials, topography, structural factors, topography and soil properties are the influential factors of spatial distribution of soil properties. Geo-spatial analysis is done to demonstrate the spatial variability of soil properties by using GIS technology and interpolation of kriging (Denton *et al.*, 2017). Parent materials, mineralogical composition and management practices influence on chemical properties of soil. For detection of mine related contamination and their pattern of occurrence are monitored by multispectral remote sensing with combination of soil geo-chemistry (Maya *et al.*, 2015).

2.8 Geo-Statistic and Classical Statistic in Variability Mapping

There is a clear need to establish precise quantitative relationships between soil properties and the factors that influence their variability in the landscape. These relationships represent the basis of the techniques of digital soil mapping (DSM) and are considered future research lines (**Lagacherie & McBratney, 2007**). Various prediction or interpolation methods have been applied in the mapping of soil properties, especially statistical methods such as multiple linear regression (**Hengl *et al.*, 2007; Mabit *et al.*, 2008; Ciampalini *et al.*, 2012**), geostatistical approaches such as ordinary kriging (**Bishop & McBratney, 2001; Grunwald *et al.*, 2008**) and co-kriging (**Ersahin, 2003; Rivero *et al.*, 2007**), and hybrid techniques such as regression-kriging (**Sun *et al.*, 2012**). The root mean square error (RMSE) was used as an index to assess the quality of prediction (**Bishop and McBratney, 2001**). Effect of agricultural activities on heavy metal (Zn, Cd, Ni, Pb, Cu, Cr, Co, As and V) concentrations and spatial correlation analyzes with soil pH, organic matter and soil texture using geostatistics (MAE and MBE functions) (**Soffianianet *et al.*, 2015**). The interpolation maps of Pb can be produce by discrete kriging and exponential model, for Cr ordinary kriging. Heavy metals concentration of As, Cd, Cu, Fe, Hg, Pb, S, Sb, and Zn was best predicted using multiple linear regression analysis (MLR) and an artificial neural network (ANN) approach (**Kemper *et al.*, 2002**). Regression with band (838 nm, 1930 nm and 2148 nm) selection has better accuracy to cross validate the reflectance spectra and soil lead (Pb) concentrations measured in the laboratory. Partial least squares regression (**Zhanget *et al.*, 2010**) is a good choice for the soil lead content retrieval by spectral remote sensing data, and genetic algorithm can improve the retrieval by band selection promisingly. Correlation analysis revealed that most wavelengths important for prediction could be attributed to absorptions features of heavy metals in soils contaminated by mining residuals using the rapid and cost-effective reflectance spectroscopy (**Kemper *et al.*, 2002**). Comparison study among multiple linear regression (MLR), BPNN and GA-BPNN to establish a relationship between the spectral data and the soil mercury content show that the GA-BPNN provided the best soil mercury prediction model modeling R^2 , the root mean square error (RMSE), and the mean absolute error (MAE) provide a scientific basis and

technical support for the spectral inversion of the soil mercury content (**Zhao et al., 2018**). Time series Landsat 8 data and linear regression models fitting analysis based on Coefficient of Determination (R^2) and Root Mean Square Error (RMSE). The EVI and GNDVI indices showed better accuracy and precision with coefficient of determination (R^2) and 0 with RMSE value (NAQVI *et al.*, 2019). Soil properties analyzed using both classical and geostatistical methods that included descriptive statistics, semivariograms, cross-semivariograms spatial kriged and cokriged prediction maps and interpolation (**Saleh et al., (2018). Odeh et al., (2007)**) used MLR and scorpan-kriging (SK) for the spatial prediction of soil properties (sand, silt, clay, pH, organic carbon, Ca^{2+} , Mg^{2+} , K^+ , Na^+ , CEC, and electrical conductivity) in different layers.



MATERIALS AND METHODS

The investigation entitled “*Assessment and Monitoring Land Degradation Dynamics using Geo-Spatial Technology in Ballia District of Uttar Pradesh, India*” was undertaken with special emphasis on soil physico-chemical properties along with certain environmental factor. Case study was carried out on the Ballia district of U.P. in order to create spatial variability map and calculation of remote sensing indices to predict extent of degradation. A management approach was then developed which could use the available soil status as the input requirement for future decision making. Thus, the present investigation was undertaken considering following: preparation of soil spatial variability map for analyzed soil parameter and derive relationship between as well as among different indices which satisfied the three objectives of study.

3.1 Study Area

Study area named Ballia district, the eastern part of the Uttar Pradesh (UP) is situated in central part of Ganges basin and lies between the Great Himalayas in the north and peninsular plateau in the south. The geographical extent of the district is 2981 sq. km. (298100 hectares) from 25°23" to 26°11" North latitude and from 83°38" to 84°39" East longitudes.

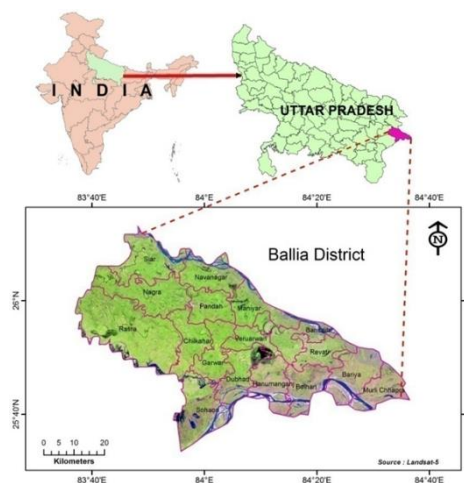


Figure 3.1: Location map of the study area

3.1.1 General Information about study area

Ballia situated in Uttar Pradesh, India. The name is given Ballia because of the abundant of sandy soil in the area. Local name is Ballua (Balu) which means sand. The district is surrounded by three rivers, Ghaghara in the north side and in south by the Chhoti Saraju and Ganga. The district comes under sub humid type of climate region. Agriculture is the major source of income of the district. Major food and commercial crops are wheat, rice, lentil, sugarcane etc. Major horticulture crops are mango, guava, tomato, potato, papaya etc. The industrial sector of Ballia is dominated by agro processing. The main sources of irrigation are canals and Tubewells.

Parent material, climate, topography, organisms, time, drainage, pH, texture and color vary a little in the Ballia district so there is very less variation in soil. The soil in the study area is loamy in nature. As discussed in previous paragraph that the district is covered with three geomorphic units i.e. flood plain, newer/younger alluvial plain and older alluvial plain. Soil quality of the district is directly related to these geomorphic units.

Four type of Land capability classification is grouped on basis of soil in the study area i.e. Good Cultivable Land, Moderately Good Cultivable Land, Fairly Good Land (Occasional Cultivation and Non-Cultivable Land (**Tripathi, 2008**)). The areas of younger and older alluvium (major parts of the district) come under good cultivable land which has color light sandy/grey and yellowish brown with 7.8 to 8.3 pH level. The areas of canal command area and around lakes and ponds come under fairly good land and the soil of this area has moderate to imperfect drainage with pH value from 7.8 to 9.2. Here pH values are increased due to deposition of salts near the surface of soil due to low water table. Non cultivable land/not suitable for cultivation is found in northern part of Chhoti Sarju River and southern part of Rasra with brown loam soil texture, occurs in patches and clayey in nature with pH ranges from 9.5 to 10.3 due to deposition of salts near surface by capillary action (**Tripathi, 2008**).

3.1.2 Administrative set-up

The administrative set up of the study area has been taken from National Information Centre (NIC), Ballia and the report of Census of India, 2011. The district has six

tehsils viz Ballia (Sadar), Bansdih, Rasra, Belthra, Bairia and Sikanderpur. These tehsils are divided into seventeen (17) blocks- Bansdih, Belhari, Bairiya, Chilkahar, Dubhad, Siar, Nagra, Rasra, Navanagr, Pandah, Maniyar, Veruarwari, Revati, Garwar, Sohaon, Hanumanganj, and Murlichapra. Each block is further divided into Gram Panchayats (total 83) and further each Gram Panchayats consists of several revenue villages. According to Census report 2011, there are 163 Nyaypanchayats, 02 Nagar Palika, 07 Assembly constituencies, 17 Panchyat Samitis, 83 Gram Panchayats, 1830 revenue villages, 6 circle office and 31 police stations in the district with a population of 34.40 lakhs.

3.1.3 Physiographic Features

Ballia lies towards north-west to south-west towards the river Ganga and Ghaghara. The district area represents alluvial level plain with sand, clay silt and gravel, intersected by numerous streams, having a gentle south easterly slope. The district covered by the central portion of Gangetic plain which can be divided into two natural subdivisions of central Gangetic plain i.e. the interior upland and the lowland tract along the river Ganga and Ghaghra. The upland has an average altitude of 65 m above MSL comprising the western part in Rasra, Ballia and Bansdih tehsils of the district. The lowland tract is highly undulating and irregular. It has deposition with its more recent alluvium than upland.

The district comes under flood affected area and the river brings flood and of course fertile soils almost every year to some extent. It brings a large amount of sediment from foothills and deposits it in the plain after local reworking. Surface elevation in the district ranges from 27m to 115m higher in eastern parts than the western part with topographic slope ranges from 0 to 12 percent.

Newer alluvial plain is refers to old flood plain cycle of deposition which is mostly consists of unconsolidated coarse to fine sand, silt and clay of varying amounts. The fluvial landforms are found in these plains like paleo-channels meander scar, back swamps etc. These plains are low lying area i.e. water-tables is high due to small distance from rivers which is directly correlated to As concentration i.e. the values of As contamination is found high in these areas.

3.1.4 Geology

Structurally Ballia district is a segment of great Indo–Gangatic plain trough. The whole Indo-Gangetic plain was formed by the process of alluviation which is continuing even at present (**Wadia, 1966**). The district is mostly covered by alluvial plains which mostly deposited by the river Ganga and its tributaries. Sub- surface geology constitutes clays, sands, silts and kankar in the district. Clay formations dominate in the western part and sand formations increases in percentage towards east in Reoti, Bairiya, Murali Chhapra blocks. Clay beds are generally thicker in western part in Rasara Chilkapar etc. blocks. The southern part of the district in Sohaon block the back- swamp deposits are found present.

3.1.5 Climate

The district comes under sub humid type of climate region. It can be best classified as monsoonal climate (Cwg) as classified by Koppen in his climatic classification scheme. It has cool and dry winter and summer season is very hot with daily maximum even touching 47°C in the months of May-June. The district often suffers from the extremes of climatic conditions such as floods. There are three distinct seasons, i.e., winter or cold season (November to February), summer or hot season (March to June) and rainy or monsoon season July to October (**Tripathi, 2008**). The temperature keeps rising and pressure keeps falling till the end of May, which is the hottest month of the year. The mean daily maximum temperature is 41.8°C (107.2° F) and the mean daily minimum at 25.4° C (77.7° F) and the maximum temperature often crosses 45°C in the month of May (**NIC, Ballia, 2017**). The maximum temperature recorded at Ballia was 47.5° C on June 9, 1966 (**NIC, Ballia 2014**).

3.1.6 Rainfall and Wind

The maximum humidity is recorded in August (82.5%) and September (80%) respectively. On the basis of Varanasi data, annual PET of Ballia district is 1608.9 mm. Normally, the annual rainfall is recorded 983 mm while monsoon rainfall is 864.8 mm. In the years 2010, 2011, 2012 , 2013,2016 and 2019 the rainfall were 511.5mm, 699.5mm, 677.3mm, 786.5mm,756.5mm and 765.5mm respectively, that is below normal annual rainfall (India Meteorological Department, New Delhi). Murli

Chhapra, Reoti, Bansdih, Maniar, Belehari and Bairia block are the major flood prone area of district. The humidity keeps decreasing as there is no rainfall and temperature soaring with high velocity winds leads to formation of hot winds in the region locally called as *loo*. This wind is sometime so devastating that it takes away several lives of humans and live stocks. By the month of June a low pressure trough is formed in the region. The wind direction changes from north or north-west to east or south-east. This wind is called monsoon and brings rainfall in the region.

3.1.7 Agriculture and Irrigation

The most dominant class in the district is the agricultural land followed by water bodies. About 80 per cent area is covered with agricultural land i.e. agriculture is the major source of income of the district. Soil of the district is very fertile with in most areas. Rabi and Kharif are broad category crops grown in winter and summer seasons respectively, with wheat, rice, lentil, sugarcane etc. Major horticulture crops are mango, guava, tomato, potato, papaya etc. The industrial sector of Ballia is dominated by agro processing industries. The sources of irrigation in the district are canals, state tube well, pucca well, shallow tube well, medium tube well and deep wells. Total cultivated area of the district is 219858 hectares. Other sources of irrigation are Reoti Tal, Surha Tal, Mundvi Shah and Sikandarpur Tal etc. As per Central Groundwater Board (CGWB), Rasra Belehari, Murlichhapra Bairia and Dubhar blocks are fully dependent on groundwater for irrigation due to not having canal network.

3.1.8 Demographic Profile

As per the Census of 2011, the district has 1,087 population density per sq. km. The population which was 2,761,620 in 2001 increased to 3,239,774 in 2011. In the year 2011 total male and female population is 1,672,902 and 1,566,872 respectively in the district. The decadal growth rate of population is recorded as 17.31 percent between the year 1991 to 2001 and 22.07 percent between the year 2001 to 2011. Rural and urban population is 24, 91,676 and 2, 69,944, respectively in 2011.

Description	2011	2001
Actual Population	3,239,774	2,761,620
Population Growth (%)	17.31	22.07
Density /km ²	1,087	926
Proportion to UP Population (%)	1.62	1.66
Sex Ratio (Per 1000)	937	953
Average Literacy	70.94	57.86

Source: Census of India, 2011

3.2 Data Acquisition Source and Methodology

3.2.1 Data Used

Data used in this study is Landsat (TM and OLI), Sentinel-2A, CHIRPS and ASTER DEM Other ancillary data used in this study are statistical map, boundary related to the study.

3.2.1.1 Landsat Data

Ortho-rectified Landsat satellite images were downloaded from USGS site (<http://www.usgs.gov.in>) and details are given in table 3.1. In addition, the Survey of India (SOI) toposheet map at the scale of 1:50,000 were used in this study.

Table 3.1: Detail of satellite images

Satellite/sensor	Year/date	Path/Row	Band used	Spatial resolution(m)
Landsat5/TM	4 th ,13 th October 1994	(141-142)42	1,2,3,4,5	30
Landsat5/TM	15 th 24 th October 2004	(141-142)42	1,2,3,4,5	30
Landsat 8/OLI	16 th 25 th October 2019	(141-142)42	2,3,4,5,6	30

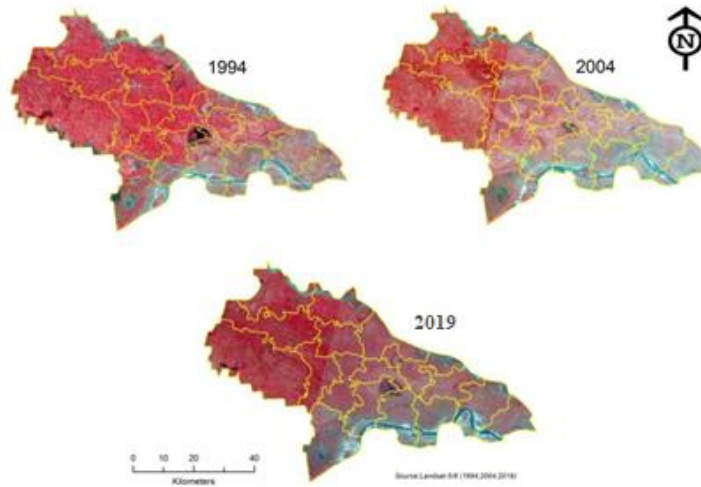


Figure 3.2: LANDSAT- TM, ETM+, OLI Satellite image

3.2.1.2 CHIRPS

Climate hazards group infrared precipitation with station data (CHIRPS) is a more than 30 year quasi-global rainfall dataset. Spanning 50⁰S-50⁰N (and all longitudes), starting in 1981 to near-present, CHIRPS incorporates 0.05⁰ resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring. CHIRPS data of the year 1994, 2004, and 2019 has been used for rainfall purpose.

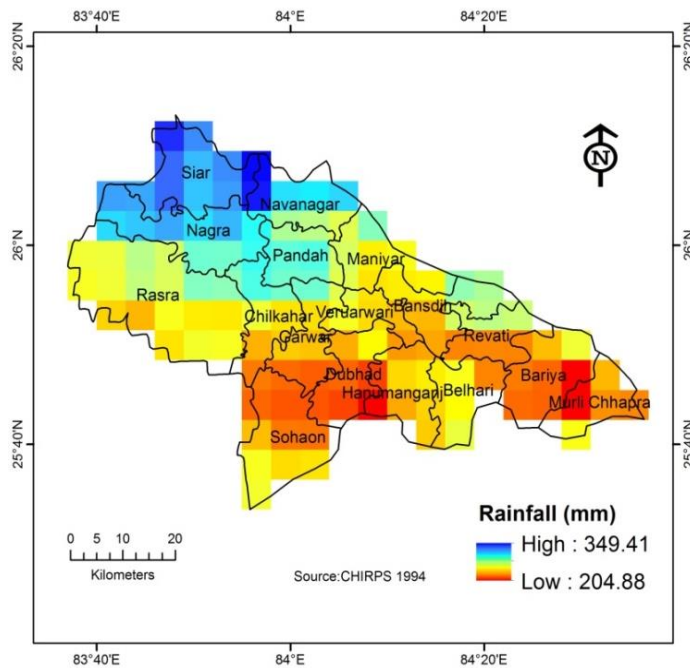


Figure 3.3: CHIRPS image of the study area

3.2.1.3 ASTER

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument onboard the National Aeronautics and Space Administration's Terra spacecraft has a long-track stereoscopic capability using a near-infrared spectral band to acquire data. ASTER is an advanced multispectral imager. ASTER covers a wide spectral region with 14 bands from visible to thermal infrared with high spatial, spectral, and radiometric resolution. The wide spectral region is covered by three separate telescopes.

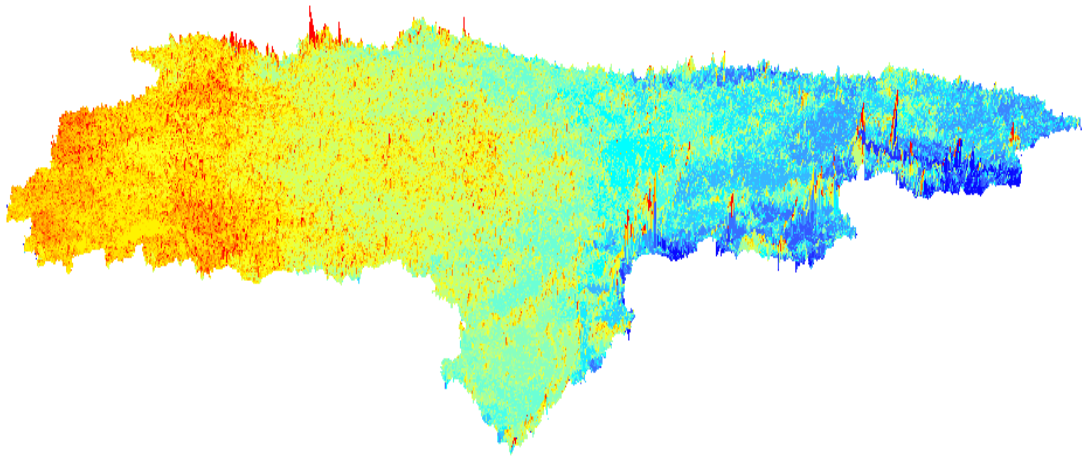


Figure 3.4: 3D view of DEM

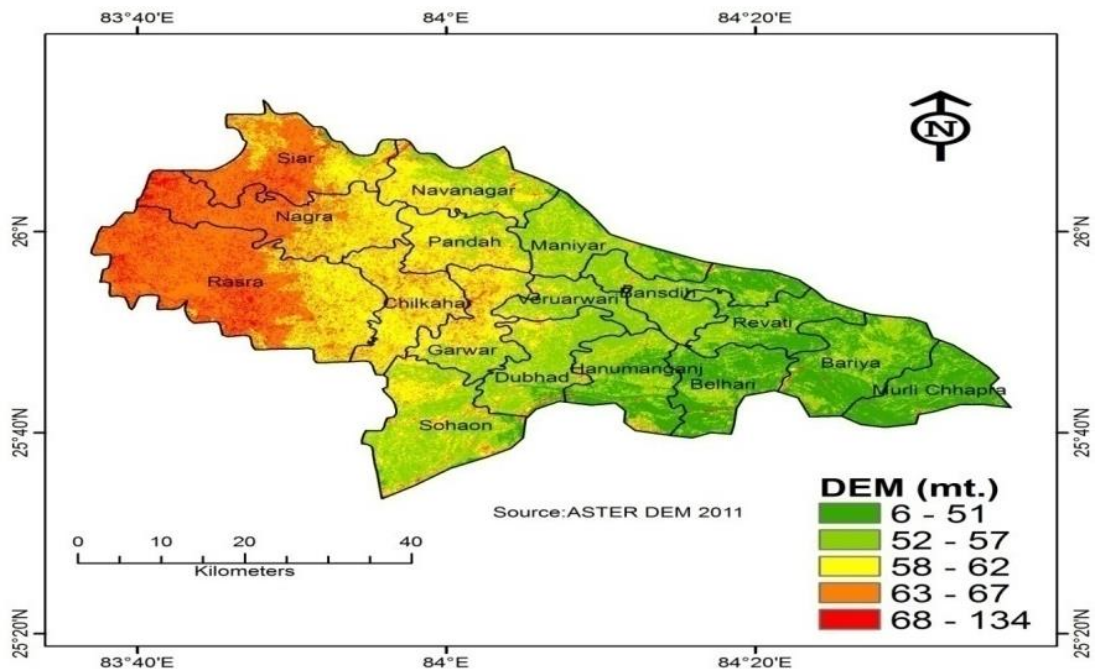


Figure 3.5: 2D view of DEM

Three visible and near-infrared (1,2,3N,3B) bands, six shortwave infrared (4,5,6,7,8,9) bands and five thermal infrared (10,11,12,13,14) bands have a spatial resolution of 15, 30 and 90 m, respectively. The current ASTER product derived using bands 3N and 3B from an ASTER Level-1A data set. All current ASTER DEM products are generated without using ground control points (GCPs). Digital Elevation Model (DEM) product was implemented using new production software at the Land Processes DAAC starting on May 24, 2006. This is the final validated version of the DEM.

Table 3.2: Location Details of Sampling Sites

Sample ID	Coordinates		Elevation	Block at site
	Lat. (DD)	Long. (DD)		
1	25.69631	83.99938	62	Sohon
2	25.68340	83.98047	43	
3	25.59573	83.96762	47	
4	25.70701	84.01588	57	
5	25.74857	84.02437	45	
6	25.90338	84.06985	48	Gorwar
7	25.90128	84.02163	46	
8	25.90790	84.01298	46	
9	25.81637	84.02611	42	
10	25.82273	84.02381	50	
11	25.97946	84.18378	42	Maniyar
12	26.00069	84.16762	40	
13	25.98019	84.16015	43	
14	25.97018	84.15021	42	
15	25.94391	84.17461	39	
16	25.97598	84.19657	38	Bashdih
17	25.94737	84.20315	41	
18	25.92852	84.16801	43	
19	25.93614	84.16956	41	
20	25.89141	84.18651	37	
21	25.86885	84.23898	38	Siar
22	26.13531	83.82290	48	
23	26.12596	83.82741	48	
24	26.13940	83.86203	47	
25	26.13253	83.88367	53	
26	26.11463	83.93370	47	Pandah
27	25.96132	84.05440	46	
28	25.94903	84.00972	47	
29	25.94348	84.02503	48	
30	25.93378	84.00171	51	

31	25.97238	83.86285	47	Nagara
32	25.98846	83.84419	49	
33	26.02189	83.81587	54	
34	26.09064	83.90682	52	
35	26.05228	84.01970	55	Nawanagar
36	26.07593	83.98422	44	
37	26.05941	84.04991	41	
38	26.02466	84.05181	34	
39	25.91716	83.93754	44	Chilkahar
40	25.83325	83.91814	46	
41	25.85103	83.99075	45	
42	25.83332	84.00975	44	
43	25.84955	83.83693	55	Rasra
44	25.88348	83.80712	55	
45	25.89528	83.87506	46	
46	25.83397	83.90486	49	
47	25.80144	84.12297	37	Hanumanganj
48	25.82038	84.14425	41	
49	25.83029	84.15858	36	
50	25.84950	84.13233	48	
51	25.87919	84.15495	43	Barivarbari
52	25.88595	84.11011	64	
53	25.89544	84.10510	46	
54	25.73019	84.54473	-2	
55	25.75530	84.38915	37	Murli Chapra
56	25.77649	84.54182	43	
57	25.75033	84.52019	41	
58	25.77313	84.49122	40	
59	25.74758	84.46219	38	Bairiya
60	25.76478	84.44744	42	
61	25.79642	84.45861	34	
62	25.80152	84.43136	36	
63	25.81000	84.44185	34	Rewati
64	25.83890	84.37765	42	
65	25.83260	84.34435	42	
66	25.82632	84.28921	40	
67	25.86554	84.35718	37	Belahari
68	25.81139	84.36427	36	
69	25.77960	84.36102	45	
70	26.77960	85.36102	46	
71	27.77960	86.36102	47	Dubahad
72	28.77960	87.36102	48	
73	25.80515	84.21923	44	
74	25.76982	84.20321	37	
75	25.75860	84.22740	39	Dubahad
76	25.72397	84.25628	40	
77	25.24595	84.18053	41	

Methodology

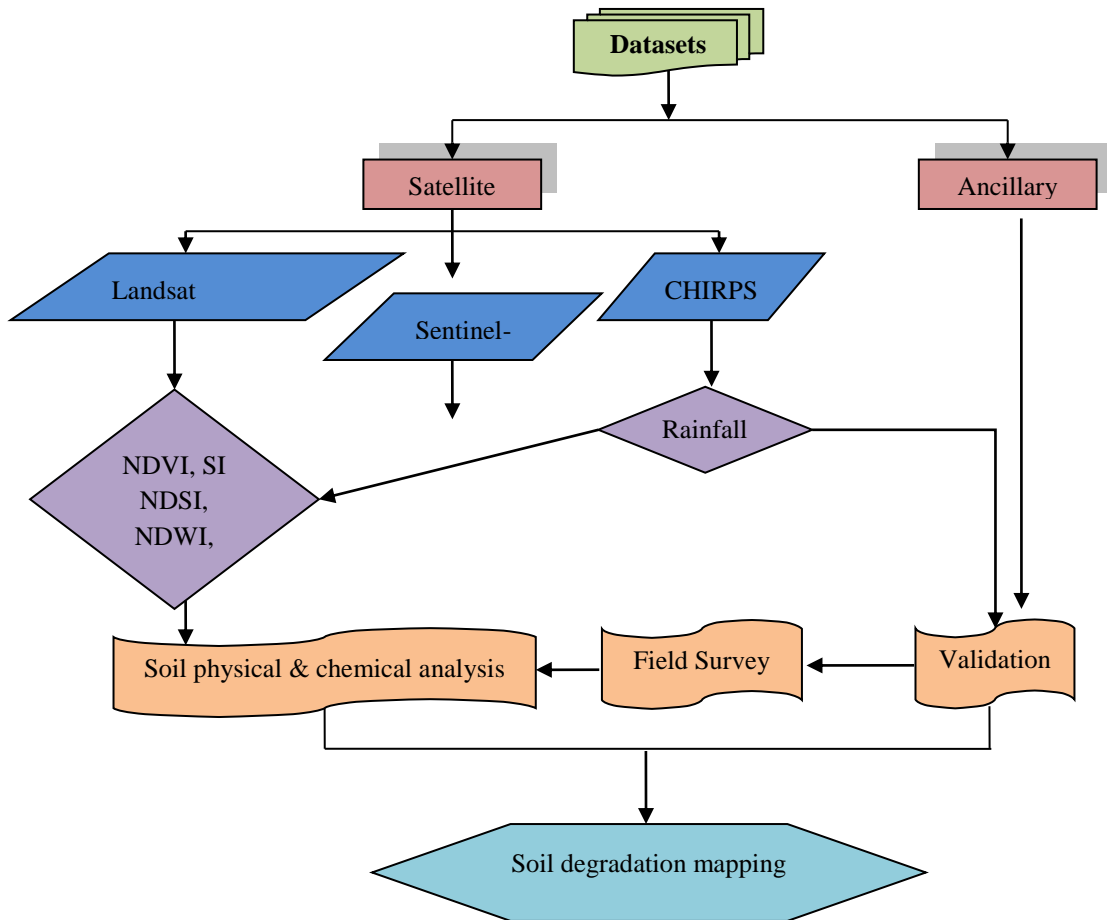


Figure 3.6: Flow chart of the methodology

3.3 Computation of Remote Sensing Indices

3.3.1 Normalized Difference Vegetation Index (NDVI)

Since the urban thermal environment is related to the reduction of evaporation from the surface vegetation cover, it is useful to recognize the relationship between surface vegetation cover and water availability. NDVI is a good indicator of surface temperature (Lo *et al.*, 1997). NDVI for the Ballia district is therefore computed from the Landsat TM/OLI image data using the following formula.

$$NDVI = \frac{RED - NIR}{RED + NIR}$$

3.3.2 Normalized Difference Water Index (NDWI)

The Normalized Difference Water Index (NDWI) has been developed to delineate open water features and enhance their presence in remotely-sensed digital imagery. It is suggested that the NDWI may also provide researchers with turbidity estimations of water bodies using remotely-sensed digital data.

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR}$$

3.3.3 Normalized Difference Soil Index (NDSI)

$$NDSI = \frac{SWIR - NIR}{SWIR + NIR}$$

3.3.4 Salinity Index (SI)

$$SI = (BLUE * RED) \frac{1}{2}$$

3.4 Rainfall (CHIRPS)

In India, the monsoon months of June to September account for more than 80% of the annual rainfall. During June and July, the number of Ballia blocks showing increasing rainfall is almost equal to those showing decreasing rainfall. In August, the number of Ballia blocks showing an increasing trend exceeds those showing a decreasing trend, whereas, in September, the situation is the opposite. The majority of Ballia blocks showed very little change in rainfall in non-monsoon months. The 17 blocks of Ballia showed no significant trend in annual and monthly rainfall in most of the months (Vijay Kumar *et al.*, 2010). According to the Intergovernmental Panel on Climate Change (IPCC, 2007), future climate change is likely to affect agriculture, increase the risk of hunger and water scarcity, and lead to more rapid melting of glaciers. Freshwater availability in many river basins in India is likely to decrease due to climate change (Gosain *et al.*, 2006).

3.5 Ground Truth data

With the help of Ground Positioning System (GPS) and a printed map of satellite data ground truth has been done. Data were collected using stratified random sampling (Table 3.2). About 77 ground control points and soil sample were collected for each

stratum which is shown in Fig 3.7 and subsequently subjected for physico-chemical analysis.

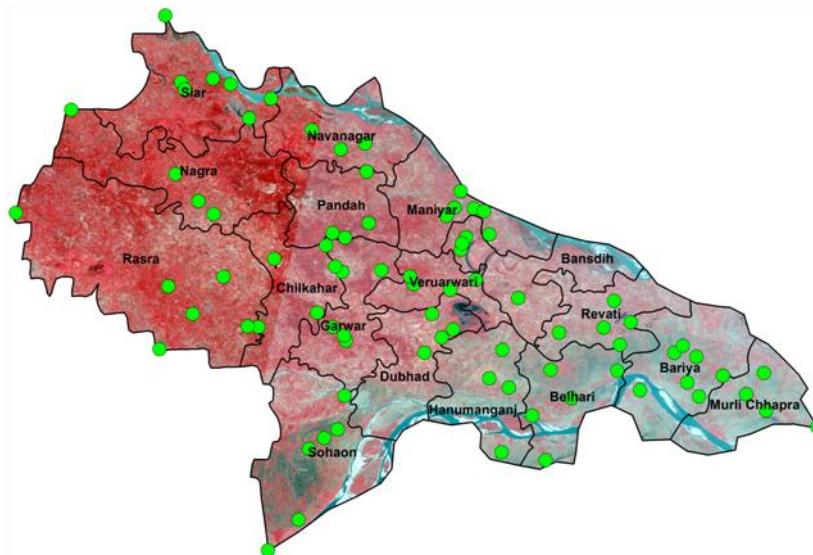


Figure 3.7: Sample point location map

3.5.1 Soil Physical Parameter Analysis

3.5.1.1 Particle Size Analysis:

Mechanical analysis of soil was determined by Bouyoucos hydrometer method (Bouyoucos, 1962). A 50 g of soil was weighted into a beaker; 60 mL of 6% H₂O₂ and 40 mL water was added and stirred for 10 minutes on water bath. Suspension was transferred into a cylinder and makeup upto 1 liter and shakes it vigorously for 5 minutes. Hydrometer was placed in suspension and reading was taken exactly after 4 minutes and 2 hours. Present sand, silt and clay were calculated and textural classes were determined with help of USDA textural triangle.

3.5.2 Soil Chemical Parameters Analysis

3.5.2.1 Soil pH

A soil-water suspension was prepared in the ratio of 1:2.5 (10 g soil with 25 mL of distilled water) and pH was measured with the help of hand pH meter (Chopra and Kanwar, 1982).

3.5.2.2 Electrical Conductivity

The soil water suspension prepared for determination of pH was used to estimate the electrical conductivity of soil. Soil suspension was allowed to settle till supernatant become clear. Electrical conductivity was measured with the help of hand EC meter and expressed as dS m^{-1} .

3.5.2.3 Organic Carbon

Organic Carbon in the soil was determined using Walkley and Black method (Walkley and Black, 1934). One gram of soil was taken in a 500 ml of conical flask. Ten ml of 1 N $\text{K}_2\text{Cr}_2\text{O}_7$ solution was added and mixed. Then 20 ml of Concentrated H_2SO_4 was added, the flask was swirled 2-3 times and allowed to stand for 30 minutes in dark. The suspension was diluted with 200 ml of distilled water. Ten ml of 85% H_3PO_4 and 1 ml of diphenyl indicator were added and titrated against the solution of 0.5 N Ferrous Ammonium Sulphate till color changed from violet to bright green. A blank titration was also carried out.

$$\text{Organic carbon in soil (\%)} = \frac{N \times (B - T) \times .003}{2 \times \text{WT. OF SOIL}} \times 100$$

Where

B = Volume of 0.5 N FAS solution used for blank titration

T = Volume of 0.5 N FAS solution used for sample titration

3.5.2.4 Organic Matter

Organic matter content of soil can be determined by simply multiply the organic carbon content by 1.72. This conversion factor assumes organic matter contains 58% organic carbon. However this can vary with the type of organic matter, soil type and soil depth.

$$\text{Organic Matter (\%)} = \text{Total organic carbon (\%)} \times 1.72$$

3.6 Available Nitrogen

Available Nitrogen content in soil was determined using Kjeltec Semi-Auto Nitrogen Analyzer by alkaline potassium permanganate method as proposed by (Subbiah and

Asija1956). The method has been widely adopted to get a reliable index of Nitrogen availability in soil due to its rapidity and reproducibility. Five gram of soil sample was weighed and transferred in a distillation tube..Twenty five ml 0.32% KMnO_4 was added to it and the distillation tube was set to the instrument. In a 250 ml conical flask, 20 ml of 2 % boric acid mixed indicator was taken and placed under the receiver tube. Twenty five ml of 2.5% NaOH was sucked and added to the distillation tube. Then it was put on distillation for 9 min. During this process the N released in the form of ammonia is trapped in the boric acid, which develops green color. The flask containing the distillate was removed. The distillate was then titrated against 0.02 N H_2SO_4 until pink color developed.

Calculation

$$\begin{aligned}\text{Mineralizable N } \left(\frac{\text{kg}}{\text{ha}} \right) &= \frac{(S - V) \times 0.005 \times 14 \times 10^6 \times 2.24}{1000 \times 5} \\ &= (S - V) \times 31.36\end{aligned}$$

S = Sample titration reading

V = Blank titration reading

3.7 Available Phosphorus

Available phosphorus content of soil was determined by Olsen's method (**Olsen, 1954**). Firstly reagent A was prepared by using ammonium molybdate, antimony potassium tartarate and H_2SO_4 . Then reagent B was prepared with the help of reagent A. Two gram of soil was taken in a 150 ml conical flask, a pinch of Darco G-60 and 40 ml of Olsen's reagent (0.5 M NaHCO_3) was added to it. It was then shaken for 30 minute on mechanical shaker and the suspension was filtered through Whatman No. 1 filter paper. Five mL of filtrate was transferred in a 25 ml volumetric flask and was acidified with 2.5 M H_2SO_4 to pH 5.0 and 20 ml distilled water was added followed by 4 ml of reagent B. After waiting for 10 min the intensity of blue colour was measured on spectrophotometer at 882 nm. Simultaneously a blank was also run. First standard reading was taken followed by sample reading

Calculation

2 g soil was extracted with 40 ml of 0.5 N NaHCO₃ solution

Hence, First dilution = (40/2) = 20 times

5 ml of aliquot was taken and final volume made up to 25 ml

Hence second dilution = (25/5) = 5 times

Therefore, total dilution factor (DF) = 20 x 5 = 100 times

From the graph,

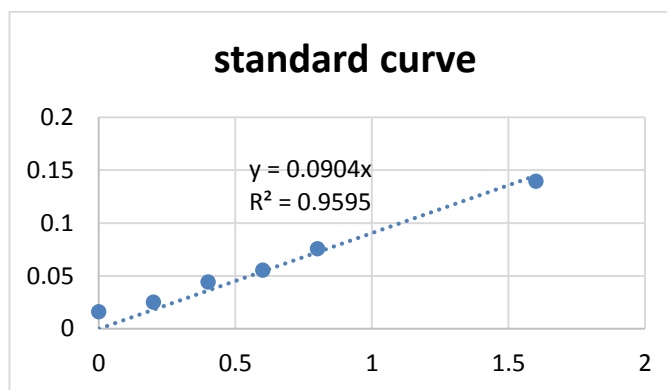
Where,

$$y = 0.0904x$$

x = concentration

y = absorbance

m = 0.0904 (slope)



Hence,

$$\text{Concentration of Phosphorus (mg kg}^{-1}\text{)} = \frac{y(\text{absorbance from standard curve})}{m(\text{slope of standard curve})} \times 100$$

$$\text{Available Phosphorus (kg ha}^{-1}\text{)} = \text{Concentration of Phosphorus (mg kg}^{-1}\text{)} \times 2.24$$

3.8 Available Potassium

Available potassium content of soil was determined by Flame Photometer (1 N ammonium acetate extract) method (**Hanway and Heidal, 1952**). Five gram soil was transferred in a 100 ml conical flask and 25 ml of 1 N ammonium acetate solution was added and it was shaken for 5 minutes. The suspension was then filtered through Whatman No. 1 filter paper and potassium concentration in the filtrate was measured using flame photometer. First standard reading was taken followed by sample reading.

Calculation

Dilution factor = $25 / 5 = 5$ times

Reading of the flame photometer for the test sample = R

Available K (kg ha^{-1}) = $R \times 5 \times 2.24$

3.9 Available Sodium

10 g air dried soil was taken into a 500 ml conical flask and add 200 ml 1N neutral ammonium acetate solution. Then allow to stand for 18 hours, stirring occasionally. Then samples were withdrawn and centrifuge the suspension. Then transfer 5 ml of the supernatant liquid to a 50 ml volumetric flask and dilute to the mark with 1N neutral ammonium acetate. Standard of 5 ppm, then 2,3,4 ppm were prepared. At first a blank solution was run in flame photometer and set as zero and 5 ppm run and set at 100. Then the samples reading was taken and construct a calibration graph. Determined the sodium concentration from the calibration curve.

3.10 Available Sulphur

Available sulphur content in soil was determined by Turbidity method (**Chesin and Yein, 1950**). Five gram of soil was taken in a 100 ml conical flask and 25 ml of 0.15% CaCl_2 solution was added to it. Then it was shaken for 30 minutes on a shaker and the suspension was filtered through Whatman No. 42 filter paper. Then 10 ml of the aliquot was transferred to a 25 ml volumetric flask and 1 g of the sieved BaCl_2 crystals were added and it was shaken for 1 minute. One ml of 0.25% gum acacia solution was added and the volume was made to the mark. It was shaken for one minute and the turbidity was measured after 25 to 30 minute on spectrophotometer, using a blue filter at a wavelength of 420 nm. Simultaneously a blank was also carried following same procedure. First standard reading was taken followed by sample reading.

Calculation

5 g of soil sample was extracted with 25 ml 0.15% CaCl_2 solution

Hence, dilution factor = $(25/5) = 5$ times

10 ml of aliquot was taken and final volume made up to 25 ml

Hence, dilution factor = (25/10) = 2.5 times

Therefore, total dilution factor (DF) = 5 x 2.5 = 12.5 times

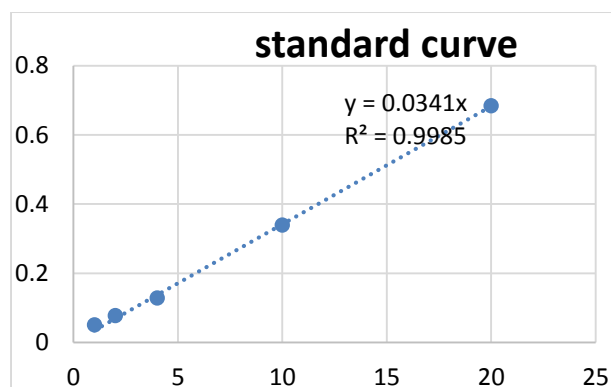
From the graph,

$$y = 0.0341x$$

Where, x = concentration

y = absorbance

m = 0.0341 (slope)



$$\text{Hence, Available S (mg kg}^{-1}\text{)} = \frac{y(\text{absorbance from standard curve})}{m(\text{slope of standard curve})} \times 12.5$$

3.11 Carbonate and Bicarbonate

Carbonate and bicarbonates in soil extract were determined by titrating against standard 0.01N H₂SO₄ using phenolphthalein and methyl orange respectively as indicators. An appearance of pink colour indicated the presence of carbonates. The carbonates were estimated by titrating with 0.01 N sulphuric acid till solution became colourless. Methyl orange indicator was then added to same flask content. Titration was continued till the colour changed from yellow to rose red.

$$\text{CO}_3^{2-} (\text{cmol(p+)}/\text{kg soil}) = \frac{2 * \text{titration reading} * \text{normality of H}_2\text{SO}_4 * 1000}{\text{ml of sample taken for titration}}$$

$$\text{HCO}_3^{1-} (\text{cmol(p+)}/\text{kg soil}) = \frac{\text{Titration reading} - 2 * (\text{titration reading for CO}_3) * \text{normality of H}_2\text{SO}_4 * 1000}{\text{ml of sample taken for titration}}$$

3.12 Cation exchange capacity

5 gram of soil was taken in a 50 ml centrifuge tube in duplicate. Then 33ml of NaOAc solution was added and shake for 5 min in a reciprocating shaker. Then the tubes are centrifuged for 10 minutes at 8000 rpm. The clear supernatant liquid should be

decanted and discarded. Then the extraction was repeated 3 more times with 33 ml of NaOAc solution and venturing each time. The samples were shaken with 33 ml of 95% ethanol for 5 minutes. Then the liquid was centrifuged and discarded. Then repeat the ethanol washing 3 times. Finally extract the soil with 33ml portion of NH₄OAc solution and collected in a 100 ml of graduated flask. Ocassionally it was necessary to filter the extract after centrifuge. The solution was diluted to volume 100 ml with NH₄OAc solution and Sodium content in the extract was determined by flame photometry.

$$\text{Dilution factor} = 5 \times 25 = 125$$

$$\text{Na concentration from flame photometer} = A \text{ ppm}$$

$$\text{Amount of Na in 100 ml of extract} = A \times 125$$

$$\text{1000 gram solution contains Na concentration} = A \times 125$$

$$\text{100 gram solution contains Na concentration} = A \times 125 / 10$$

$$= A \times 12.5$$

$$23 \text{ mg of Na/100 g soil} = 1 \text{ meq of Na/100 g soil}$$

$$\text{Then } A \times 12.5 \text{ mg solution per 100 g soil contains } = A \times 12.5 / 23 \text{ meq Na/100 g soil}$$

Interpretation

Rank CEC(cmol(p+)/kg soil)

Low <10

Medium 10-25

High 25-45

Very high >45



RESULTS AND DISCUSSION

Soil a natural resource exist as habitat of all the living and non-living organisms. It is a integral part of all natural resources and it acts as a life supporting system. Soil degradation becomes a worldwide threat now-a-days and becomes a global issue during 21st century (**Goulding *et al.*, 1995**). Soil degradation included various problems like decreased vegetation, deterioration of water quality, changes in soil properties like pH, EC, organic carbon, Cation exchange capacity, available Na, K, HCO₃⁻ and CO₃⁻²etc. Increasing degradation need to be monitor and managed with the advancement of technologies (i.e. geo-spatial techniques) viz: calculation of relative spectral indices using remote sensing imageries, mapping spatial variability via ArcGIS software. Hence, the present study entitled “**Assessment and Monitoring Land Degradation Dynamics using Geo-Spatial Technology in Ballia District of Uttar Pradesh, India**”. This study was focused to investigate the quality of the soil and its extent of degradation using scale of time and space.

4.1 Spectral indices as a measure of soil degradation using remote sensing imageries

4.1.1 Normalized Difference Vegetation Index (NDVI)

Data pertaining to the NDVI are produced using Landsat (TM/OLI) imageries at 30 m spatial resolution to measure the soil degradation from the period of 1994 to 2019 (Table 4.1 and Fig. 4.1). Spatio-temporal trend in NDVI value from 1994 to 2019 is presented in figure 4.2. Mean, minimum- maximum (range), standard deviation and coefficient of variation are the parameters which are used to analysis the data (Fig. 4.2). Variation range of NDVI based on the annual mean is calculated as 0.116-0.452, 0.056-0.397 and 0.0234-0.287 for the year 1994, 2004 and 2019 respectively. In Nagra highest NDVI values (0.449) was observed in 1994 while lowest NDVI was observed in Belhari (0.0234). Annual NDVI value was decreasing from northwest to southeast of Ballia. Low NDVI value from 0.04 to 0.18, was mainly observed in the southeast of the study area and in the western areas (Pandah, Nagra and Rasra) of the Ballia while high NDVI

above 0.3, was mainly located in the northwest region of Ballia, among all these in Nagra 0.521 highest NDVI was observed. Based on the NDVI in conjunction with other factors it can be depicted that Soil degradation occurred in most parts of Ballia from 1994 to 2004 and then slightly improved till 2019.

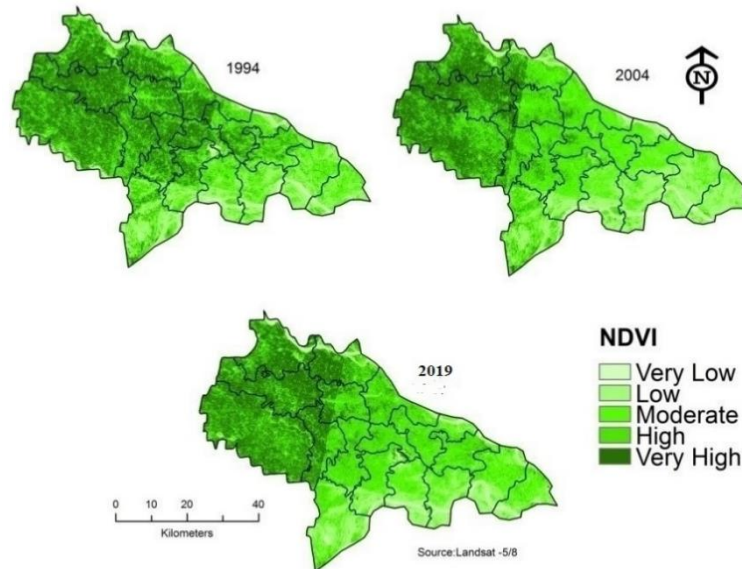


Figure 4.1: Normalize Difference Vegetation Index (NDVI) of Ballia district

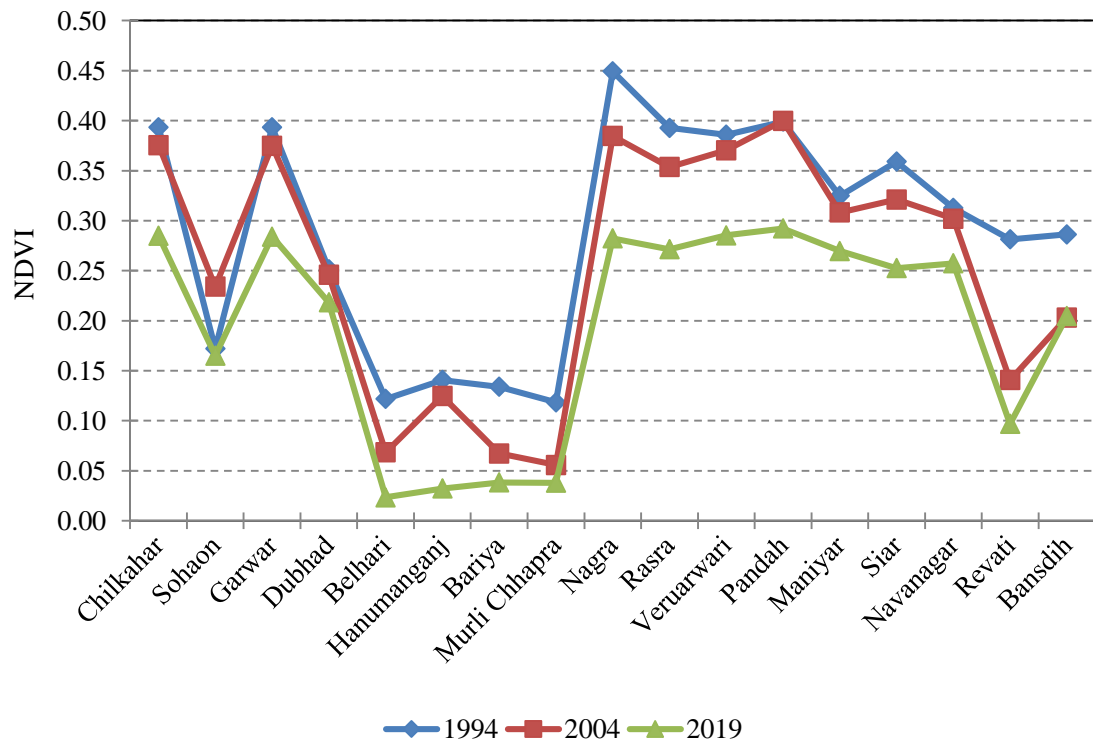


Figure 4.2: Spatio-Temporal Pattern of mean NDVI (1994-2019)

4.1.2 Normalized Difference Soil Index (NDSI)

A critical perusal of data pertaining to the Normalized Difference Soil Index (NDSI) presented in Table 4.1 and Fig. (4.4). Significant decrease was found in NDSI from 1994 to 2019 showing a just similar trend to salinity indices (NDSI and SI) while opposite trend to NDVI but much higher decrease in 2004 (Fig. 4.3). This might be due to the fact land use accelerating the agricultural activity initially but in next 10 year demographic pressure lead to limit the land use for the agriculture to facilitate the other land use. The range of NDSI value in the study area can be calculated as -0.078 to 0.141, -0.400 to -0.056 and -0.292 to -0.121 for the year 1994, 2004 and 2019 respectively. The NDSI values of most of blocks were close to their respective negative average (0.024, -0.255 and -0.223) in the respective year. It was observed to increase from northwest to southeast.

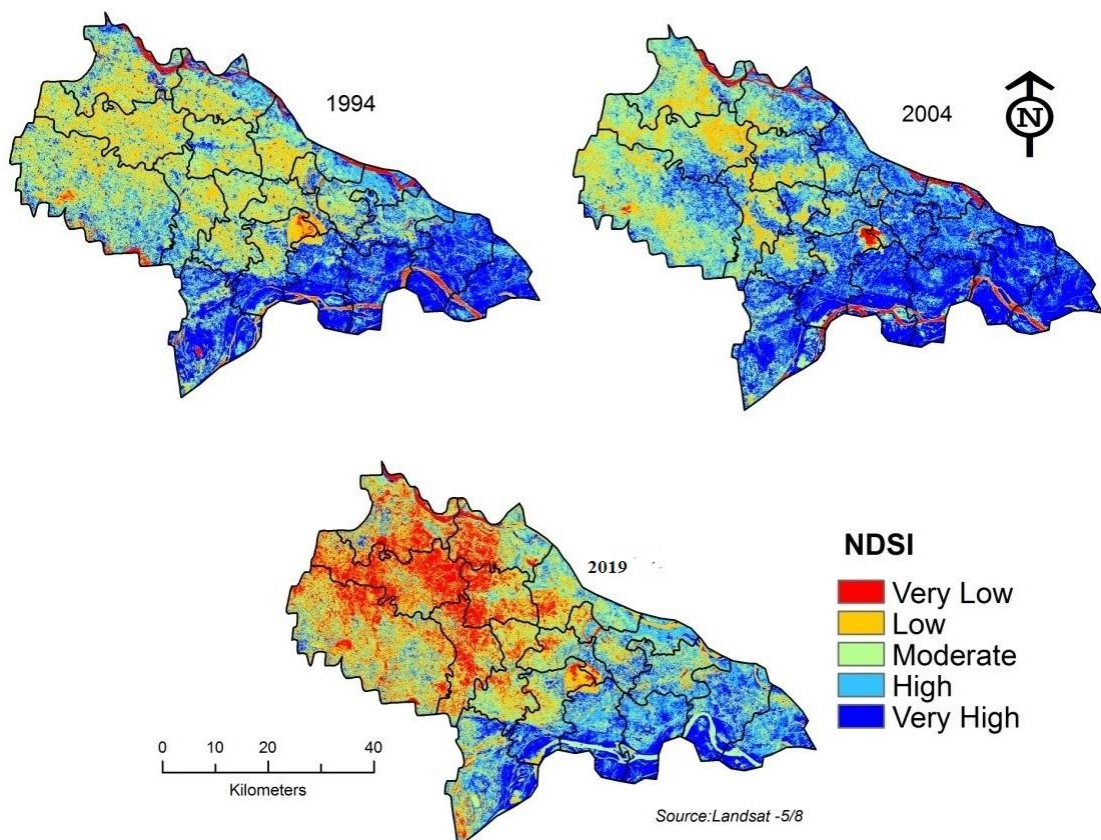


Figure 4.3: Normalized Difference Soil Index (NDSI)

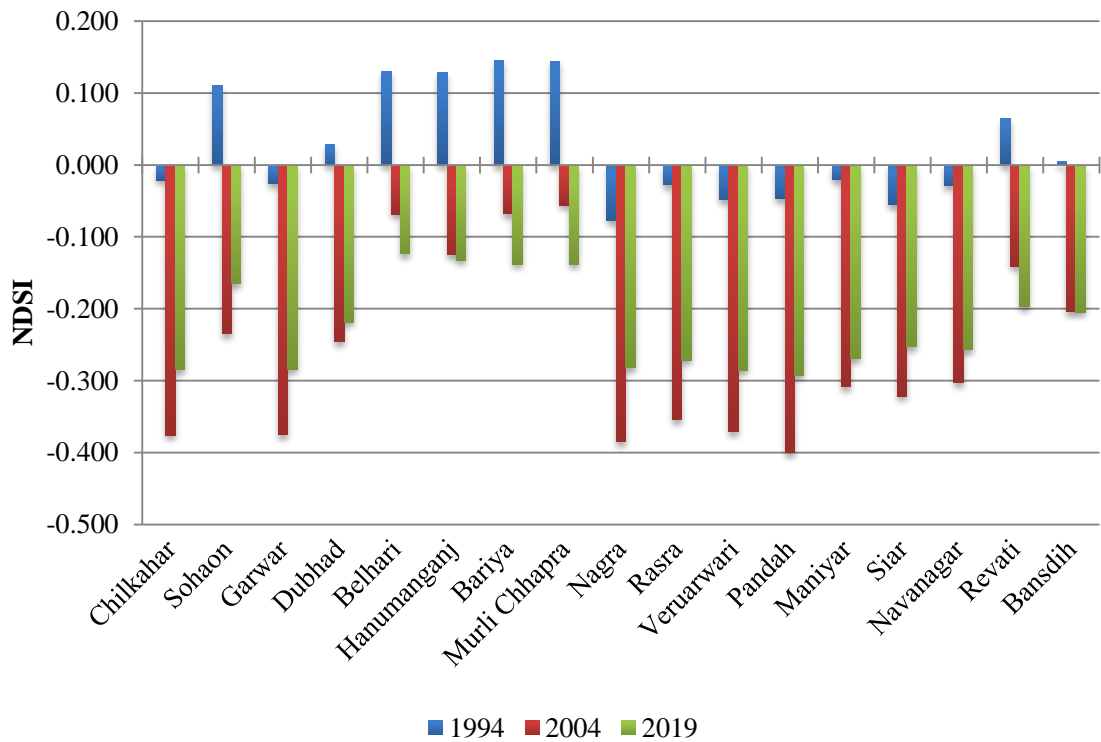


Figure 4.4: Spatio-Temporal Pattern of mean NDSI (1994-2019)

4.1.3 Salinity Index (SI)

Salinity in the study area was quantified for October in the years 1994, 2004 and 2019 presented in Table (4.1) and Fig. (4.6). The extent of salinity with annual mean SI showed an increasing trend from northwest to southeast for an overall period of 25 years from 1994 to 2019 (Fig. 4.5). Based on the annual mean SI (1275.74, 1990.73 and 3808.12) from 1994 to 2019 the variation range of SI in the study area written as 804.7 to 1739.61, 1118.16 to 2777.46 and 1741.93 to 5792.69 for the year 1994, 2004 and 2019 respectively. Nagra was found with minimum SI while the maximum SI varies between Hanumanganj, Bariya, and Garwar blocks in south-eastern region of Ballia in the years of study. Moderate to high salinity in south-eastern areas accounted for 54–60 % of the study area. It was found that the salinity index (SI) increases for all the blocks from 1994 to 2019 but Bariya (5642.17), Dubhad (5482.02), Murli chhapra (5371.78) and Hanumanganj (5349.31), were recorded with much higher SI, however, Garwar block found with maximum SI (5792.69) in 2019. Salinity had increased in the study area, with salinity increasing at a drastic rate during the past 26 years.

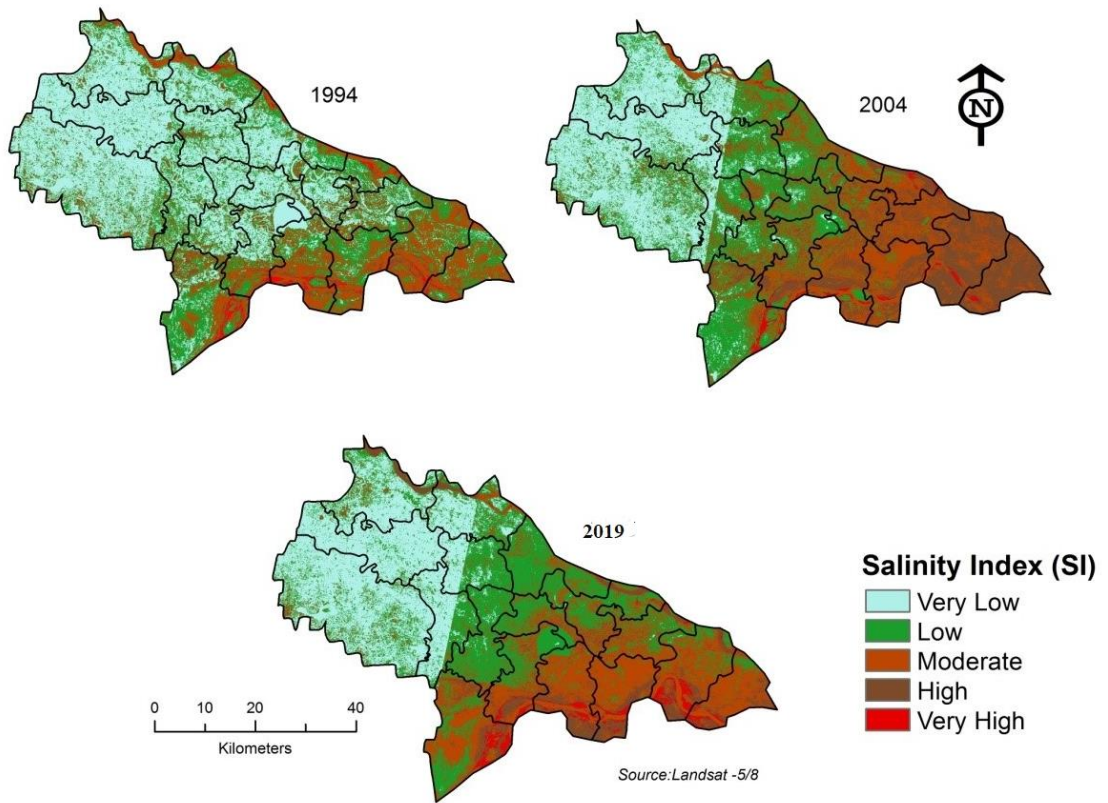


Figure 4.5: Salinity Index (SI)

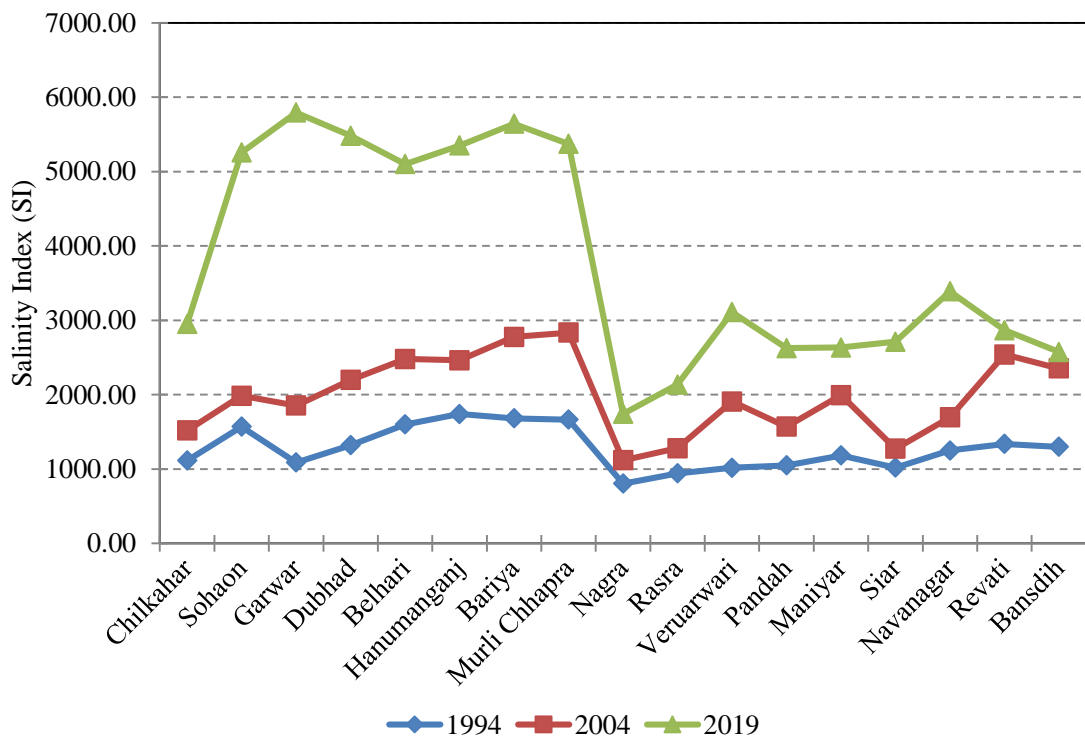


Figure 4.6: Spatio-Temporal Pattern of SI (1994-2019)

4.1.4 Normalized Difference Salinity Index (NDSI)

Spatial distribution of salinity from 1994 to 2019 derived using Landsat (TM/OLI) imageries at 30 m spatial resolution presented in Table 4.1 and Fig. 4.8. Variation range of NDSI for the month of October based on the annual mean in the study area was calculated as -0.448 to -0.119, -0.402 to -0.053 and -0.295 to -0.0237 for the year 1994, 2004 and 2019 respectively (Fig. 4.7). The NDSI value increased from northwest to southeast over the year from 1994 to 2019. Low negative NDSI value was observed from -0.143 to -0.117, was located in the southeast (Hanumanganj, Belhari, Murli Chhapra, Bariya,) of Ballia. NDSI is used for temporal and spatial trend changes detection in the soil salinity and its relation with vegetation. NDSI has a negative correlation with NDVI. High vegetation cover with lower value of NDSI was observed in the western Ballia (Pandah, Nagra and Rasra) of the Ballia, in the northwest region, which was detected as highest negative NDSI in Nagra -0.448. Whereas, in Nagra the high negative NDSI values (-0.448) was observed also in Pandah (-0.398) and Rasra (-0.389) showed a much higher decreasing value of NDSI from 1994 to 2019 caused to soil degradation due to increasing salinity.

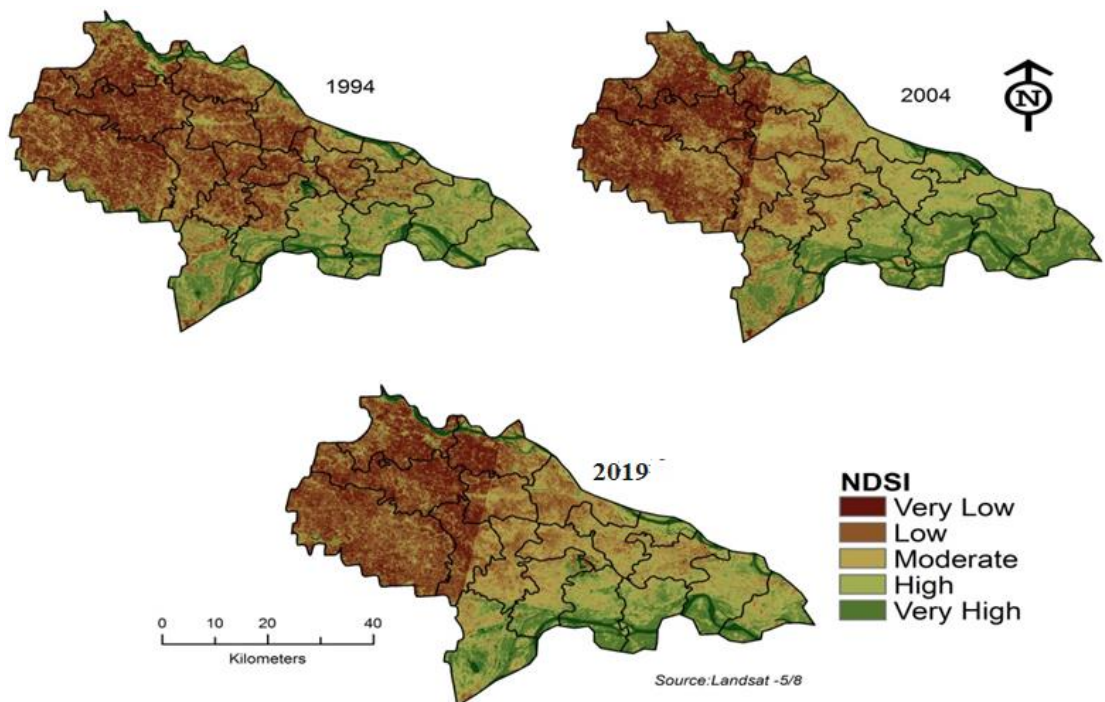


Figure 4.7: Normalized Difference Salinity Index (NDSI)

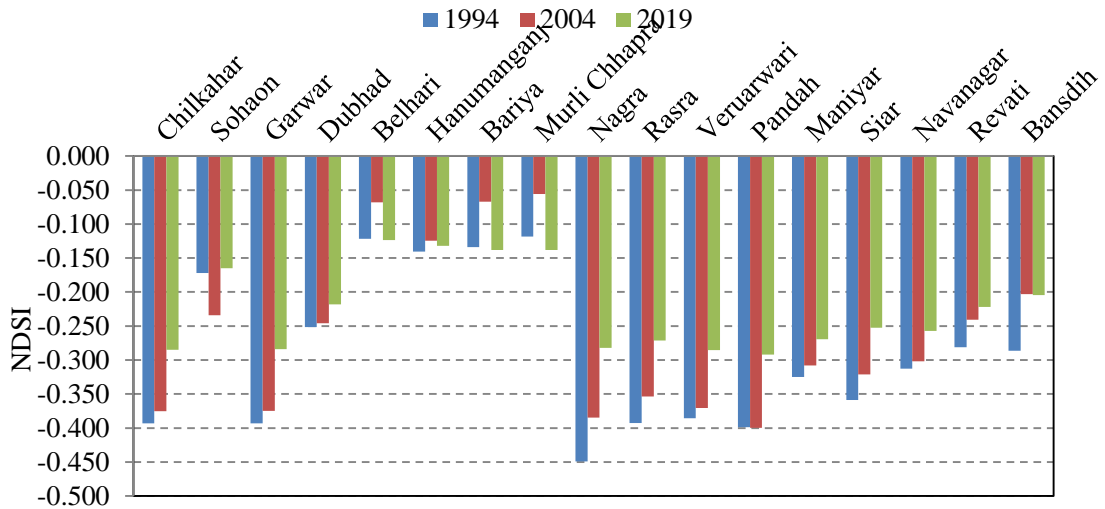


Figure 4.8: Spatio-Temporal Pattern of NDSI (1994-2019)

4.1.5 Normalized Difference Water Index (NDWI)

From high resolution, multi-spectral Landsat TM/ OLI imagery NDWI (Table 4.1 and Fig.4.10) was computed by using near infrared reflectance's tested as moisture stress, draught indicator and soil degradation. NDWI is used to measure the change in water table below the soil surface and it can also differentiate a water and non-water object clearly. The water content of the study area was increasing over the period from 1994 to 2019 with much higher mean value of NDWI that were -0.29, -0.28, and -0.18 respectively. In the study area variation range of NDWI value was measured as -0.38 to -0.14, -0.36 to -0.14 and -0.22 to -0.13 for the year 1994, 2004 and 2019 respectively. The highest value of NDWI was observed in Murli chhapra, Belhari & Bariya with the lowest NDWI value was detected in Rasra, Nagra, Pandah & Chilkahar (Fig. 4.9). NDWI showed an increasing manner from northwest to southeast of study area on the basis of its annual mean value.

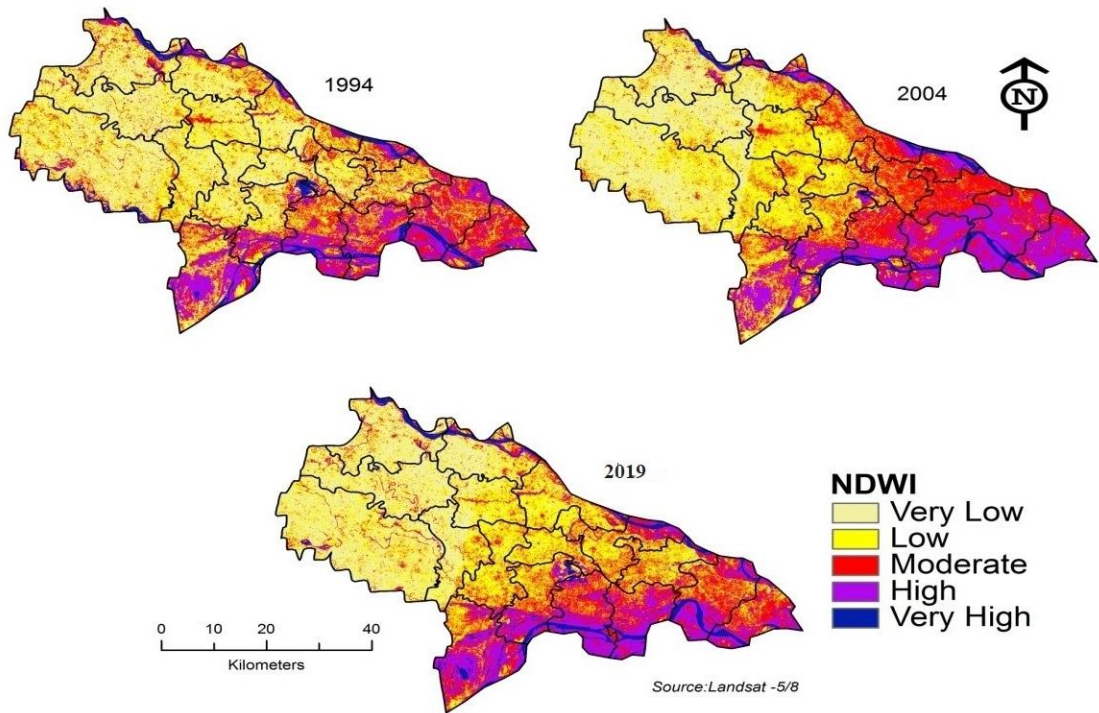


Figure 4.9: Normalized Difference Water Index (NDWI)

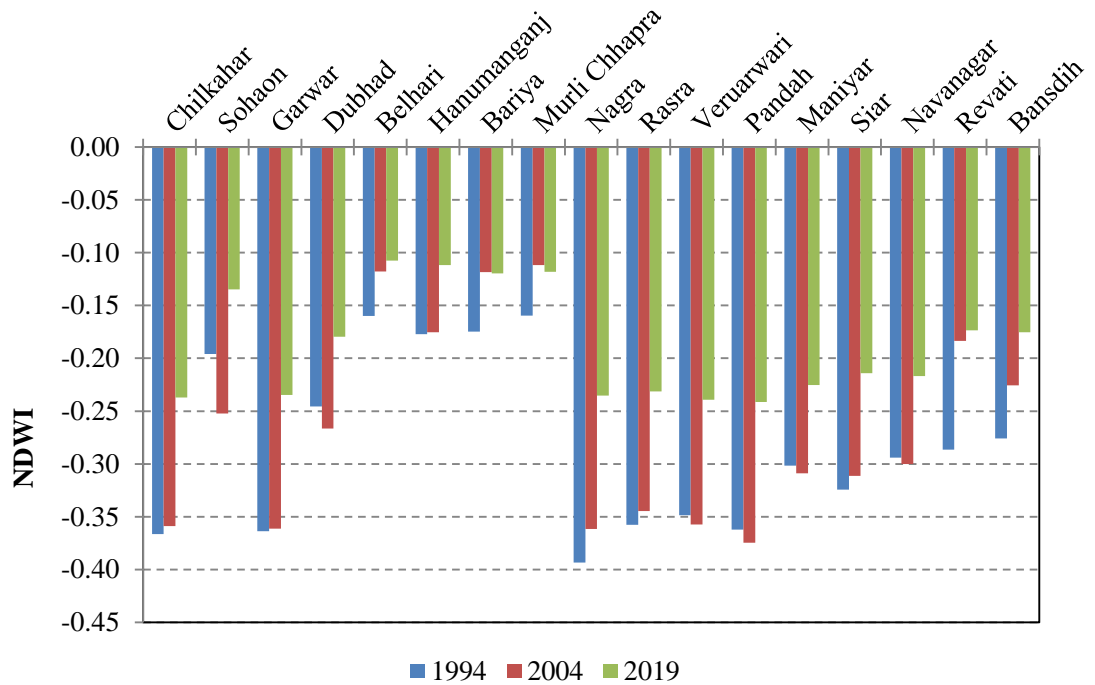


Figure 4.10: Spatio-Temporal Pattern of NDWI (1994-2019)

Table 4.1: Remote Sensing indices for different block of Ballia from 1994-2019 as computed using landsat (TM/OLI) imageries at 30 meter spatial resolution

BLOCKNAME	NDVI			NDWI			SI			NDSI (Soil)			NDSI		
	1994	2004	2019	1994	2004	2019	1994	2004	2019	1994	2004	2019	1994	2004	2019
CHILKAHAR	0.39	0.38	0.28	-0.37	-0.36	-0.24	1115.51	1519.53	2951.18	-0.021	-0.375	-0.285	-0.393	-0.375	-0.285
SOHAON	0.17	0.23	0.17	-0.20	-0.25	-0.13	1569.89	1984.85	5255.22	0.111	-0.234	-0.165	-0.172	-0.234	-0.165
GARWAR	0.39	0.37	0.28	-0.36	-0.36	-0.23	1088.90	1853.86	5792.69	-0.025	-0.375	-0.284	-0.393	-0.375	-0.284
DUBHAD	0.25	0.25	0.22	-0.25	-0.27	-0.18	1320.23	2198.63	5482.02	0.029	-0.246	-0.218	-0.251	-0.246	-0.218
BELHARI	0.12	0.07	0.02	-0.16	-0.12	-0.11	1600.25	2480.93	5101.29	0.131	-0.068	-0.123	-0.122	-0.068	-0.123
HANUMANGANJ	0.14	0.12	0.03	-0.18	-0.18	-0.11	1739.61	2462.55	5349.31	0.128	-0.125	-0.132	-0.141	-0.125	-0.132
BARIYA	0.13	0.07	0.04	-0.17	-0.12	-0.12	1682.93	2777.46	5642.17	0.145	-0.067	-0.138	-0.134	-0.067	-0.138
MURLI CHAPRA	0.12	0.06	0.04	-0.16	-0.11	-0.12	1664.94	2834.15	5371.78	0.144	-0.056	-0.138	-0.118	-0.056	-0.138
NAGRA	0.45	0.38	0.28	-0.39	-0.36	-0.24	804.70	1118.16	1741.93	-0.078	-0.385	-0.282	-0.449	-0.385	-0.282
RASRA	0.39	0.35	0.27	-0.36	-0.34	-0.23	942.12	1279.33	2135.85	-0.028	-0.354	-0.271	-0.393	-0.354	-0.271
VERUARWARI	0.39	0.37	0.29	-0.35	-0.36	-0.24	1018.55	1907.70	3109.52	-0.048	-0.370	-0.285	-0.386	-0.370	-0.285
PANDAH	0.40	0.40	0.29	-0.36	-0.37	-0.24	1050.21	1570.24	2625.48	-0.047	-0.400	-0.292	-0.399	-0.400	-0.292
MANIYAR	0.32	0.31	0.27	-0.30	-0.31	-0.23	1183.91	1994.19	2634.70	-0.021	-0.308	-0.270	-0.325	-0.308	-0.270
SIAR	0.36	0.32	0.25	-0.32	-0.31	-0.21	1020.11	1273.68	2712.63	-0.055	-0.321	-0.253	-0.359	-0.321	-0.253
NAVANAGAR	0.31	0.30	0.26	-0.29	-0.30	-0.22	1250.00	1694.66	3389.50	-0.028	-0.302	-0.257	-0.313	-0.302	-0.257
REVATI	0.28	0.14	0.10	-0.29	-0.18	-0.17	1337.13	2539.11	2867.79	0.065	-0.141	-0.197	-0.281	-0.241	-0.222
BANSDIH	0.29	0.20	0.20	-0.28	-0.23	-0.18	1298.61	2353.41	2575.01	0.005	-0.203	-0.205	-0.286	-0.203	-0.205

4.2 Interpolation for creating spatial variability maps of physicochemical properties of soil

In modern age of science interpolation technique is a method to determine the spatial variation in different physiochemical properties of soil such as particle size analysis(sand,silt,clay percentage),soil pH, electrical conductivity (EC), organic carbon (OC), organic matter (SOM) ,available nitrogen(N),available phosphorus(P),available potassium(K),bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), soil-Na, soil-S and cation exchange capacity(CEC) etc. In the experimental area “Ballia”, UP random locations are selected and total 77 soil samples are collected from different land use sites from different blocks of the study area. Soil samples are collected from the depth of 0-20 cm. To locate the exact co-ordinates of sites a portable global positioning system (GPS) was used. For spatial distribution of soil parameters Ordinary Kriging (OK) an interpolation method is used.

4.2.1 Interpolation for Soil Texture (Sand, Silt and Clay)

Statistical analysis of sand, silt and clay percentage of 0-20 cm of top layer of soil is done by statistical tools presented in Table (4.2). Ordinary Kriging method of distribution free approach was performed on sand, silt and clay content of the study area and spatial distribution of those parameters are mapped by interpolation technique (Fig. 4.11, 4.13 and 4.15).The range of soil particulates values are 49% to 67% for sand, 15% to 28% for silt and 16% to 31% for clay respectively. The mean values are 55%, 21% and 22% respectively for sand, silt and clay. These values are representing the spatial variability of the fractions respectively.

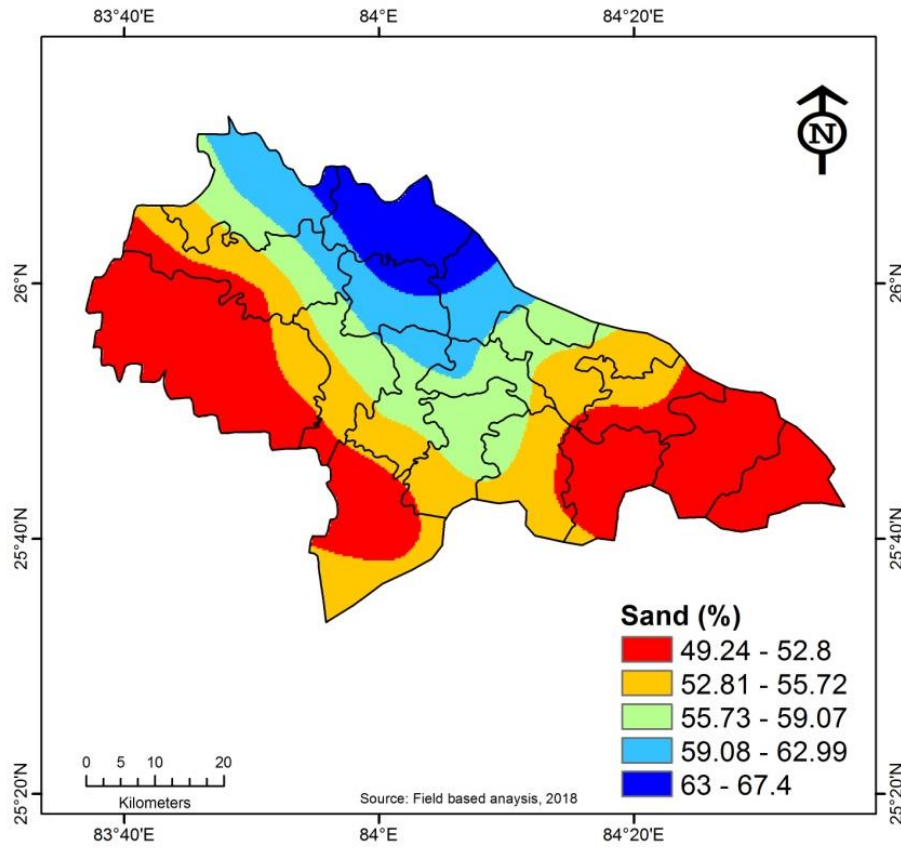


Figure 4.11: Spatial Variability Map for Sand Content (%)

It is clear from the descriptive statistics (Fig. 4.12) that average percentage of sand is highest in the Navanagar (75.66%) followed by Maniyar (65.50%), Siar (62.72%) and Pandah (59.23%) blocks whereas lowest in Nagra (43.30%).

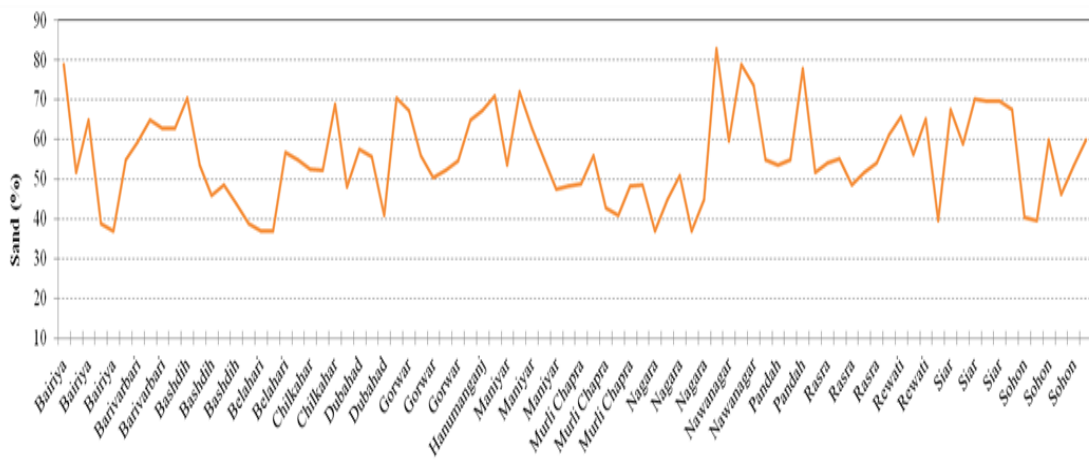


Figure 4.12: Spatial Distribution of Sand

It is clear from the descriptive statistics (Fig. 4.14) that average silt percent are highest in the Nagra (24.89%) followed by Rasra (26.50%), Bansdih (27.61%), and Chilkahar (27.37%) blocks however, lowest in Navanagar (6.55%).

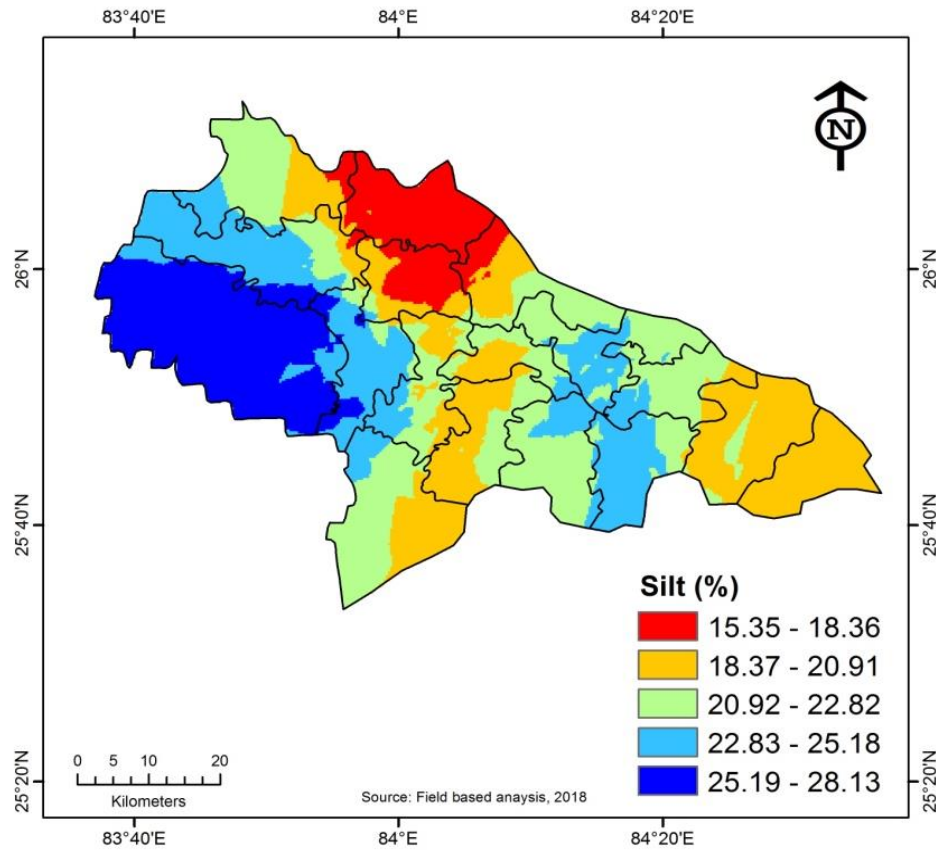


Figure 4.13: Spatial Variability Map for Silt Content (%)

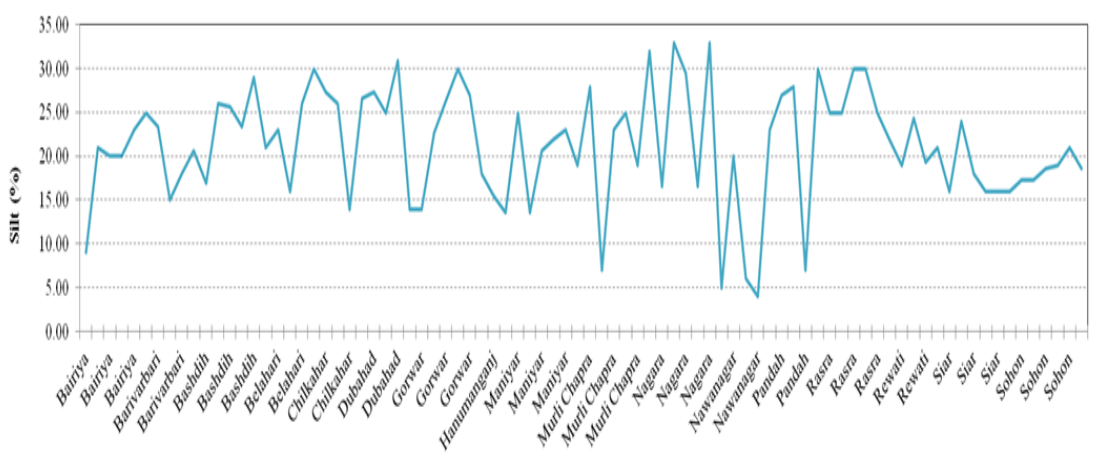


Figure 4.14: Spatial Distribution of Silt

It is clear from the descriptive statistics (Fig. 4.16) that average clay are highest in the Belhari (35.20%) followed by Sohaon (33.51%), Murli chhapra (30.33%) and Bariyar (25.20%), blocks whereas lowest in Siar (12.90%).

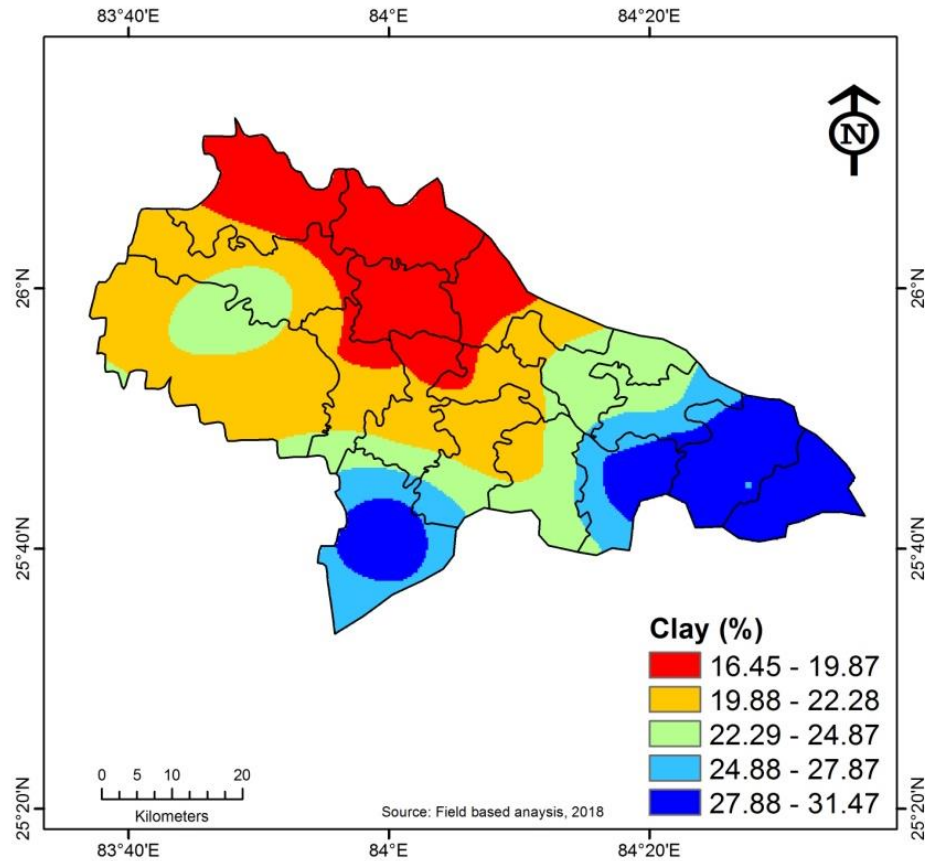


Figure 4.15: Spatial Variability Map for Clay Content (%)

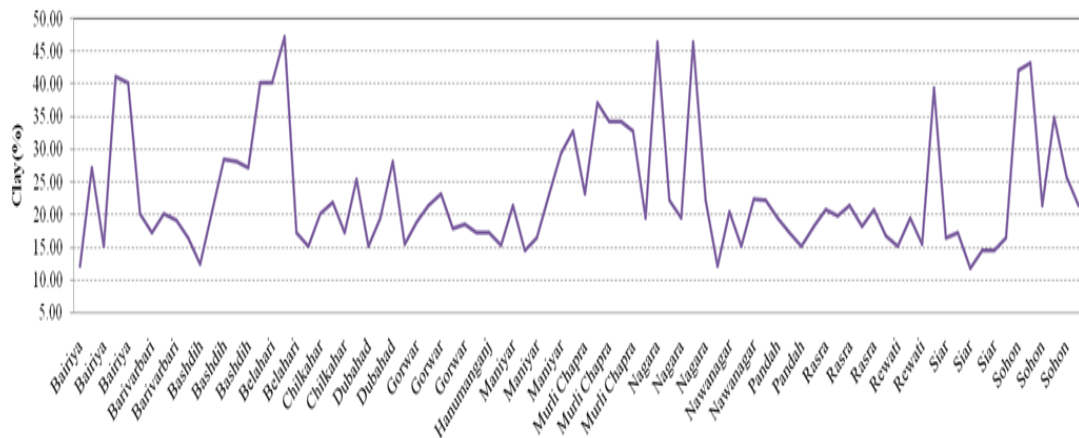


Figure 4.16: Spatial Distribution of Clay

It can be depicted from the map (Fig. 4.11) that the north of the study area shows a high percentage of sand content whereas low values are observed in the west and southeast of the study area especially. The interpolation maps of the silt content (Fig.4.13) in the western (north - south) part of the study area shows the higher values and low values are seen in the middle and southeast of the study area. Again, kriging represents a smaller variation over the silt content relative to the sand and clay. For the clay content, the interpolation maps (Fig.4.15) indicate that the high values of the clay content are distributed mainly in the southeast and in some southern corner whereas the low valued-areas are mostly located in the north and northwest corners of the study area.

Consequently, entire region divided into seven textural classes on basis of sand, silt and clay data analysis are: clay (C), clay loam (CL), loam (L), sandy clay (SC), sandy clay loam (SCL), loamy sand (LS) and sandy loam (SL). Around 47 % of the sample recorded with sandy loam (SL) textured soil, 32% sample tested with sandy clay loam (SCL) whereas rest 21% with other class of soil texture.

This data indicates that the dominant textural class in the study area is generally sandy loam, nutrient availability due to excessive leaching implying a low water holding capacity, poor soil structure and quality shows low productivity. These properties directly transferred to hydraulic property of the soil at the study area in term, put it on risk or susceptible to degrade or erode due occurrence of sand and silt at the study site.

4.2.2 Interpolation for Spatial Distribution of pH

A critical perusal of data pertaining to soil pH across the Ballia ranging from 7.2 to 7.4, 7.5 to 7.6, 7.7, 7.8 to 7.9 and 8.0 for each class respectively (Table 4.2 and Fig. 4.18). On the basis of pH values the study area is categorized into five classes: very low (dark red): low (yellow), moderate (light green), high (light blue) and very high (dark blue) indicating the spatial variability of pH (Fig. 4.17). Only 35% of the study area observed with lower pH value (7.2 -7.6) and 65% area under moderate to very high pH. The entire Ballia region is saline in soil type.

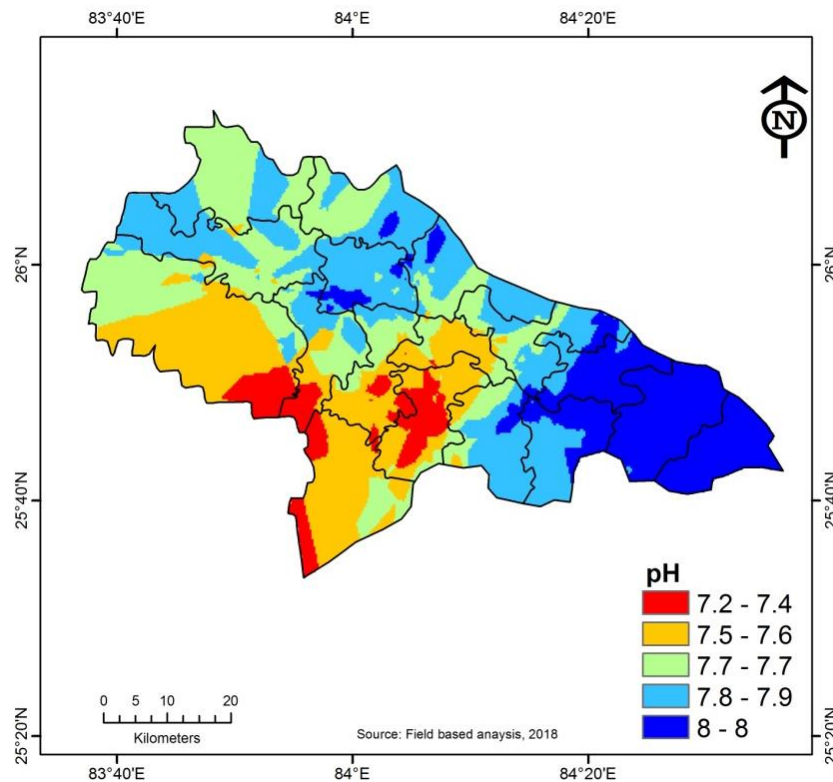


Figure 4.17: Spatial Variability Map for Soil pH

Fig. 4.17 shows the percent pH distribution at 0–20 cm depth analysis. In the interpolation map dark blue region showed that soil reaction (e.i. pH) is maximum in southeast sites (Revati, Murlichhapra and Bariya) followed by Hanumanganj and Belhari shown by light blue region in the map. However, the minimum soil pH recorded in the red and yellow region in map indicating western and middle of study area mainly in Rasra, Dubhad, chilkahar and Sohaon. Thus, pH follows an increasing trend from northwest and low pH value to southeast part is observed. Increase in pH would be related with gradual increase in salt or salinity that may be cause of soil degradation at the study area.

The spatial distribution of pH was analyzed (Fig.4.18). The average value of pH was 7.7 and the value decrease towards northwest. The pH value ranged from 7.2-8.0. Briefly, a good soil character is shown in Sohaon block with an average of 7.5 and ranged from 6.8 to 8.0 with no high pH area observed in the concerned soil samples collected in the study site and analyzed the parameter.

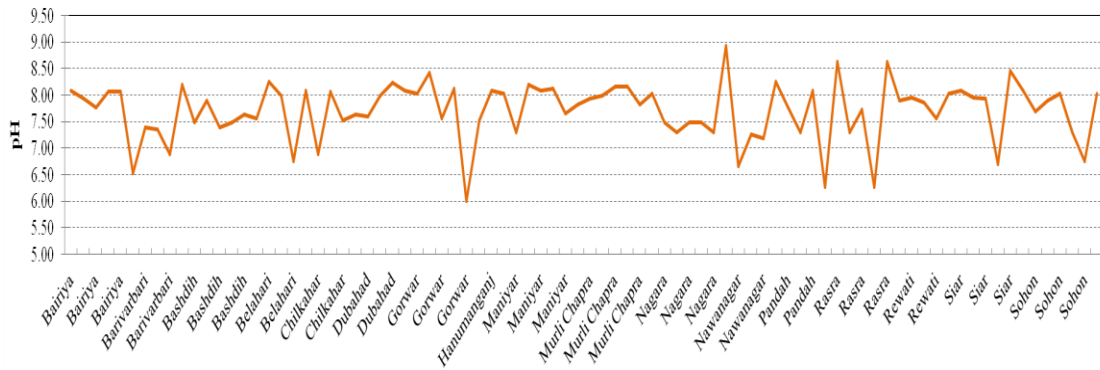


Figure 4.18: Spatial Distribution of Soil pH

4.2.3 Interpolation for Spatial Distribution of EC

Kriging interpolation performed to obtain spatial variability map of EC. On the basis of descriptive statistics (Table 4.2 and Fig.4.20) and spatial variability map (Fig. 4.19) of data observed the study area is categorized in three classes: slightly saline (dark orange, red), slightly alkaline (light yellow), moderately alkaline (light green and dark blue), representing the spatial variability of electrical conductivity value ranged separately 84.85 to 272.07 μSm^{-1} , 267.08 to 312.27 μSm^{-1} and 312.17 to 659.3 μSm^{-1} for each class respectively. Only 35% of the study area observed with lower EC value and consequently, 65% area falls under slight to moderately alkaline range of EC.

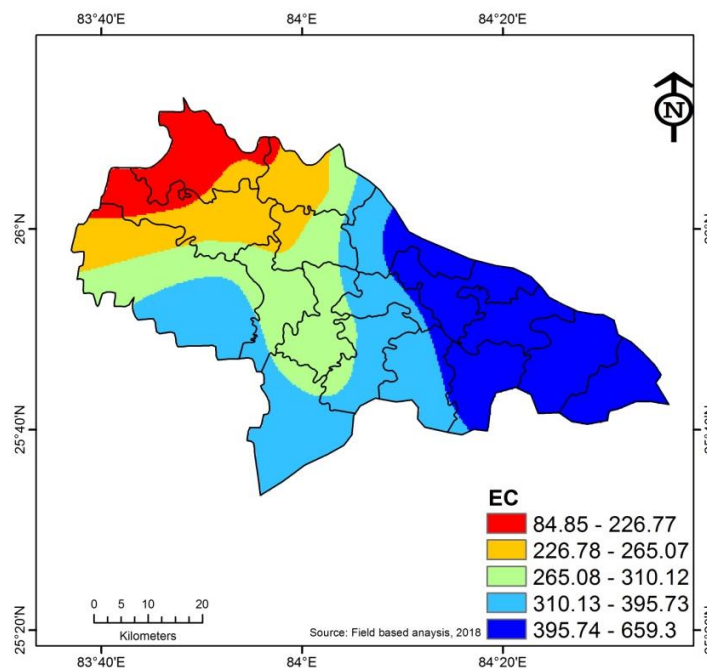


Figure 4.19: Spatial variability map for soil EC

The dark green region in the interpolation map represents that southeast site areas are found with moderate EC (Murlichhapra, Bariya, Belhari, Revati, and Bansdiah) followed by Maniyar, Veruarwari, Hanumanganj, and Dabhad indicated by light green region of map. Moreover, the red and yellow region in map indicating the slightly saline value of EC depicts in northwest sites of study area mainly in Siar, Navanagar, Nagra, and Rasra. However, middle light green region (Chilkahar, Pandah and Garwar) observed with slightly alkaline value of EC. Thus EC follows an increasing trend from northwest to southeast of the study area.

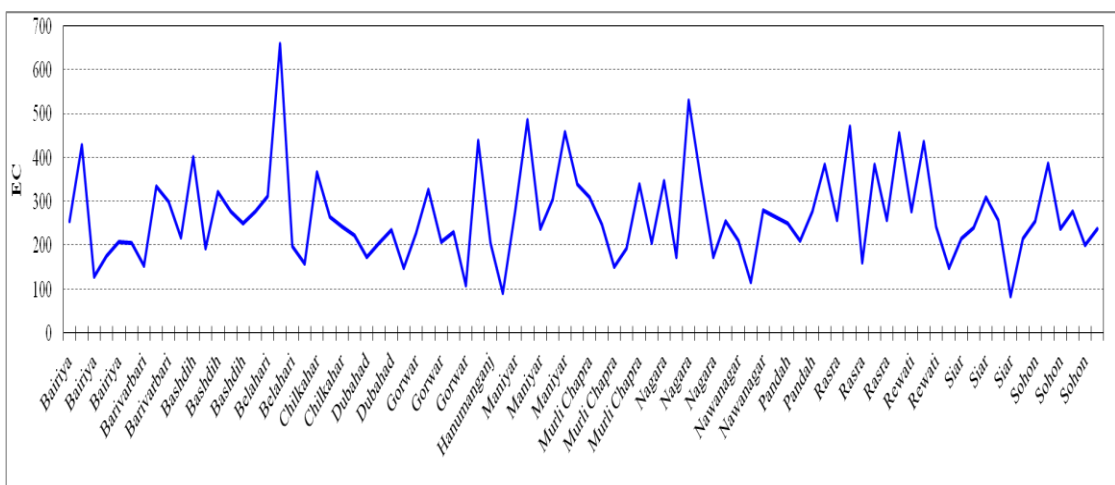


Figure 4.20: Spatial Distribution of soil EC

The average value of EC was 265.1 μSm^{-1} and the value decrease toward northwest of study area. The EC value ranged from 83.85 to 657.3 μSm^{-1} . Briefly, a better percent of soil EC is observed in Siar block with an average of 233.45 μSm^{-1} and ranged 230 to 262.0 μSm^{-1} among all the soil samples collected in the study area and analyzed the data. In contrast to Siar least value of EC is observed in Murli chhapra of Ballia.

Table 4.2: Physical characteristics of soil samples (mean)

Sample ID	pH	EC (μSm^{-1})	Sand (%)	Silt (%)	Clay (%)
1	7.7	254.0	40.44	17.36	42.20
2	7.9	386.7	39.44	17.36	43.20
3	8.0	238.0	59.88	18.64	21.48
4	7.3	276.7	46.16	19.00	34.84
5	6.8	201.7	53.16	21.00	25.84
6	8.0	227.7	67.16	14.00	18.84
7	8.4	327.0	55.88	22.64	21.48
8	8.1	208.0	50.44	26.36	23.20
9	6.0	229.3	52.16	30.00	17.84
10	7.3	109.7	54.52	27.00	18.48
11	8.2	277.0	53.52	25.00	21.48
12	8.1	485.0	71.88	13.64	14.48
13	8.1	236.7	62.88	20.64	16.48
14	7.7	303.7	54.80	22.00	23.20
15	7.5	457.7	47.52	23.00	29.48
16	7.9	217.7	62.88	20.64	16.48
17	7.6	402.7	70.52	17.00	12.48
18	7.4	192.0	53.52	26.00	20.48
19	7.5	321.0	45.88	25.64	28.48
20	7.6	278.7	48.44	23.36	28.20
21	8.1	250.0	43.80	29.00	27.20
22	8.0	215.7	67.52	16.00	16.48
23	7.9	240.0	58.80	24.00	17.20
24	6.7	311.0	70.16	18.00	11.84
25	8.5	258.0	69.52	16.00	14.48
26	8.3	84.0	69.52	16.00	14.48
27	7.8	264.0	54.80	23.00	22.20
28	7.3	249.3	53.52	27.00	19.48

29	8.1	211.0	54.80	28.00	17.20
30	8.2	278.7	77.80	7.00	15.20
31	8.0	206.0	48.52	32.00	19.48
32	7.3	174.0	36.88	16.64	46.48
33	7.5	347.0	44.80	33.00	22.20
34	8.9	173.0	51.02	29.50	19.48
35	6.7	530.7	82.80	5.00	12.20
36	7.3	255.0	59.52	20.00	20.48
37	7.2	211.0	78.80	6.00	15.20
38	8.1	117.0	73.52	4.00	22.48
39	6.9	280.0	54.80	30.00	15.20
40	8.1	157.3	52.44	27.36	20.20
41	7.5	366.3	52.16	26.00	21.84
42	6.3	266.0	68.80	14.00	17.20
43	8.6	242.7	51.80	30.00	18.20
44	7.3	384.7	54.16	25.00	20.84
45	7.7	257.7	55.16	25.00	19.84
46	7.5	471.0	48.52	30.00	21.48
47	8.1	160.3	64.80	18.00	17.20
48	8.0	440.0	67.35	15.45	17.20
49	6.5	206.0	70.98	13.64	15.38
50	7.4	90.7	54.80	25.00	20.20
51	7.4	206.0	59.44	23.36	17.20
52	6.9	152.7	64.80	15.00	20.20
53	7.8	333.7	62.80	18.00	19.20
54	7.9	300.7	48.16	19.00	32.84
55	8.0	338.7	48.80	28.00	23.20
56	8.2	310.0	55.80	7.00	37.20
57	8.2	247.7	42.80	23.00	34.20
58	8.1	151.7	40.80	25.00	34.20
59	7.9	192.7	78.80	9.00	12.20

60	7.8	256.0	51.80	21.00	27.20
61	8.1	428.0	64.80	20.00	15.20
62	7.9	128.3	38.80	20.00	41.20
63	7.9	176.7	36.80	23.00	40.20
64	8.0	207.0	61.16	22.00	16.84
65	7.9	457.0	65.80	19.00	15.20
66	7.6	436.0	56.16	24.36	19.48
67	8.0	241.7	65.16	19.36	15.48
68	7.6	149.0	39.52	21.00	39.48
69	8.3	278.7	38.80	21.00	40.20
70	8.0	312.7	36.80	23.00	40.20
71	6.8	659.7	36.80	16.00	47.20
72	7.6	197.0	56.80	26.00	17.20
73	7.6	222.0	47.88	26.64	25.48
74	8.0	205.7	57.44	27.36	15.20
75	8.2	236.0	55.52	25.00	19.48
76	8.1	148.0	40.80	31.00	28.20
77	8.3	148.1	70.52	14.00	15.48
Mean	7.7	265.1	55	21	22
Range	6.0-8.9	84-659.7	36.80-82.80	4-33	11.84-47.20

4.3 Chemical Parameters

4.3.1 Interpolation for Spatial Distribution of Soil Organic Carbon (SOC)

In the study area spatial distribution of SOC is obtained by kriging interpolation. On the basis of data analysed the study area is grouped into five classes: very low (dark red), low (yellow), moderate (light green), high (light blue) and very high (dark blue) shows spatial variability of organic carbon in soil of study area. Only 35-40% of the study area falls in the lower range of SOC and 55-65% area under moderate to very high range of SOC. Spatial variability in Organic matter content are analysed by given data of sampling sites followed a similar trend like SOC.

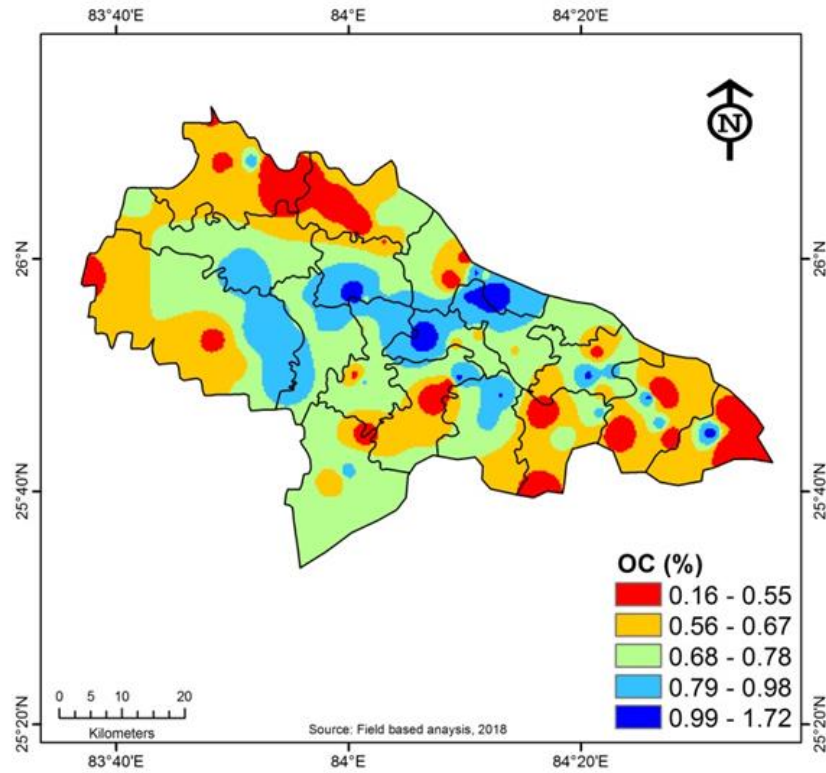


Figure 4.21: Soil Organic Carbon (OC)

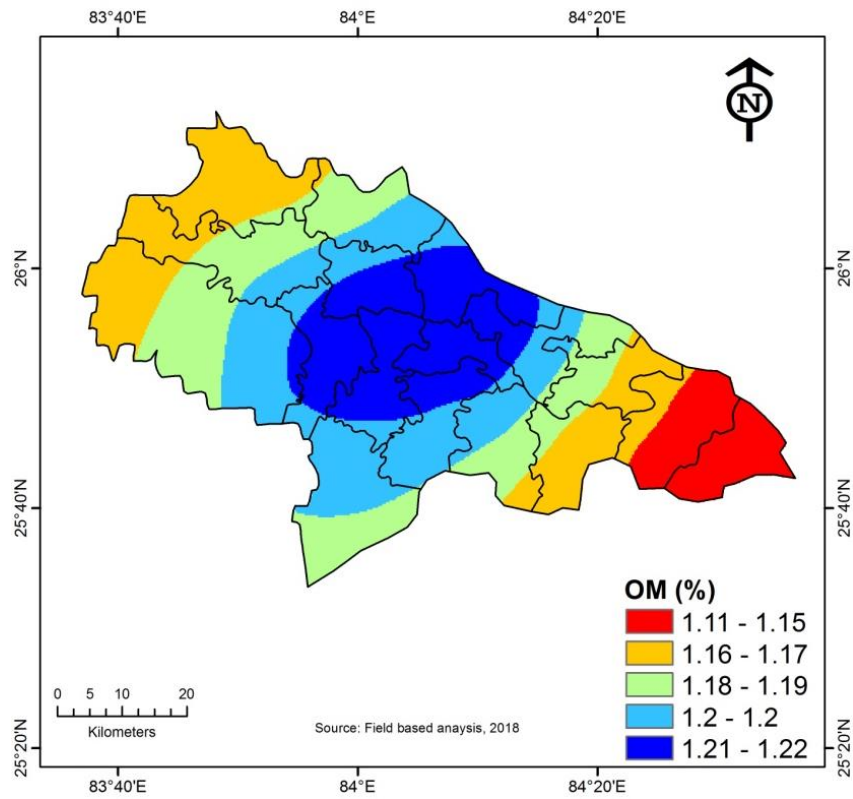


Figure 4.22: Soil Organic Matter (OM)

Fig 4.17 represents the spatial distribution of SOC of 0–30 cm depth analysis. The result represents concentration of SOC is maximum in Bansdih (1.76 %) block followed by Veruarwari (1.476%), Pandah (1.34 %) and most of block in northwest of study area and the minimum percent of Organic carbon is recorded in block Maniyar (0.14 %) and Belhari (0.12%). Consequently, SOC percent shows a decreasing type of trend from northwest having higher SOC % to southeast part observed with low SOC at 0-30 cm depth. The higher retention amount of carbon among all the blocks in the Ballia is higher in the pandah block of Ballia significantly from the rest.

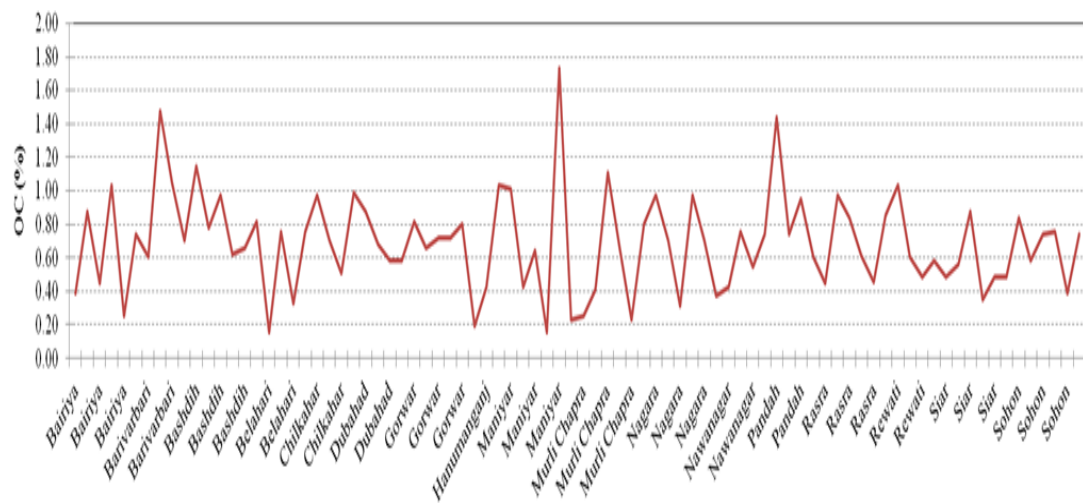


Figure 4.23: Spatial distribution of Soil Organic Carbon (OC)

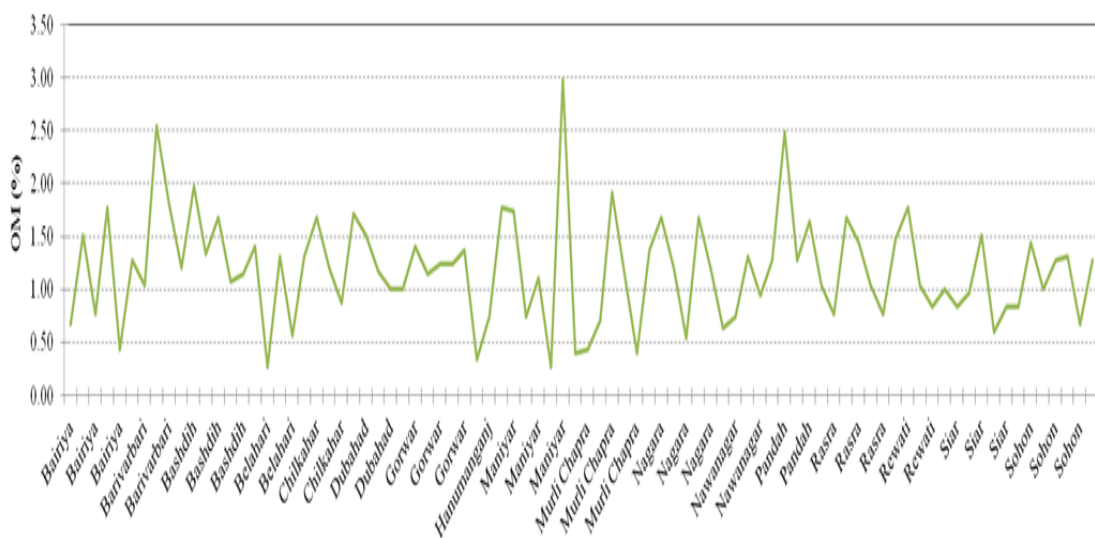


Figure 4.24: Spatial distribution of Soil Organic Matter (OM)

The spatial distribution of SOC percent is analyzed. The average value of SOC was 0.75 % at 0–30 cm depth, and the percentage of organic carbon decreased as move toward southeast. SOC content ranged from 0.14%-1.82%. Briefly, higher abundance of soil organic carbon is found in Pandah block with an average of 0.98 % and ranged from 0.72% to 1.64% with no lower carbon area observed in all the soil samples collected at 0-30 cm depth and spatial distribution is analyzed in the study site. Storage and abundance of SOC in upper soil layer has been linked with the root growth systems (Pillon, 2000) and with the addition of aboveground biomass on the soil surface (Burle *et al.*, 2005) indicating that the crop residues usually increase organic carbon content of soil.

4.3.2 Interpolation for Spatial Distribution of Potassium (K)

In the study area spatial distribution of potassium content of soil is analysed by kriging interpolation. On the basis of potassium content and its abundance the whole study area is divided into three classes: very high (light blue and dark blue), high (light green), medium (dark red, yellow) shows the variability of potassium content (Kg/ha) of soil in ranges of 425-515 Kg/ha, 335-425 Kg/ha, 135-335 Kg/ha respectively. 70% of study area falls under high to very high class and only 30% area under medium class of soil potassium content of that area.

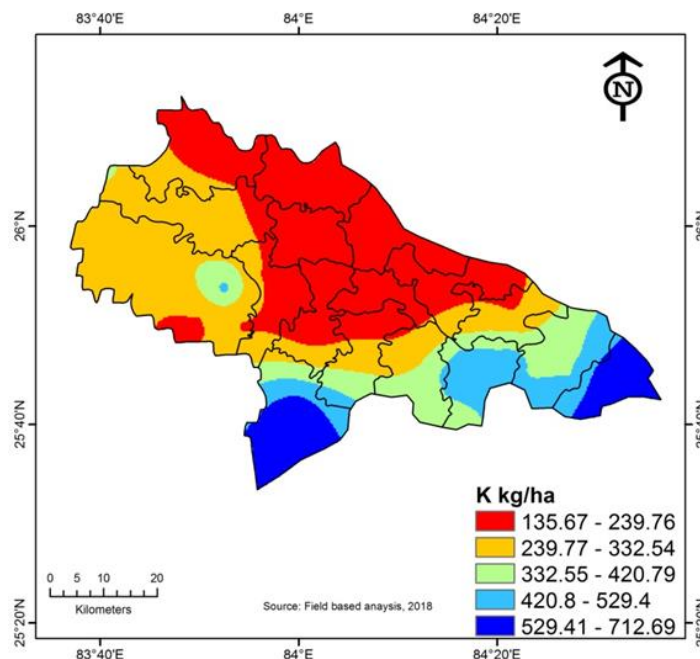


Figure 4.25: Kriging Interpolations of K
[58]

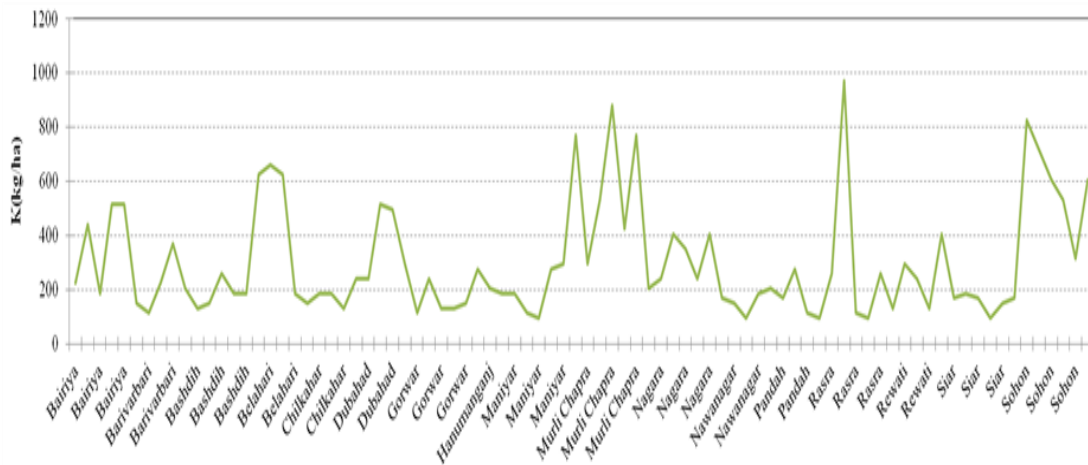


Figure 4.26: Interpolations of K

Fig.4.23 represents the distribution and analysis of K content in soil at 0–30 cm depth. In the interpolation map dark blue region showed that very high K-content observed in southeast sites of study area (Murlichhapra, Sohaon,) followed by Belhari, Bariya, Dabhad and Hanumanganj with high K content indicated by mainly in northwest and middle of study area of Ballia with light blue and green colour region of map. Moreover, the red and yellow region in map indicating the medium K-content observed in rest of the blocks of study area. However, K-content follows an increasing trend from northwest to southeast of the study area.

By the collected samples and data obtained from that spatial distribution of K content of soil is analyzed. The average value of K was 355.35Kg/ha and the value decreased towards northwest of study area. The K-content ranged from 130.67 to 715.69 Kg/ha. Abundance of K-content of soil is found in Pandah block of Ballia with an average of 226.82 Kg/ha and ranged 138.75 to 332.13Kg/ha within all the collected soil samples and analyzed the content of potassium in the study area. Very high K-content is observed in Murli chhapra of study area in Ballia.

4.3.3 Interpolation for Spatial Distribution of Sodium (Na)

In the study area spatial distribution of soil sodium content is analysed by kriging method of interpolation. On the basis of sodium content, the study area is grouped into three classes: low (dark red, yellow), medium (light green), high (light blue and dark blue) which shows the variability of sodium content in that area in a range of 77.75 to 232.67 Kg/ha, 232.68 to 348.80 Kg/ha and 348.80 to 745.28 Kg/ha

respectively. Among study area 75% area falls under low class, 15% falls under medium range of sodium content and 10% area falls under high class of sodium content range.

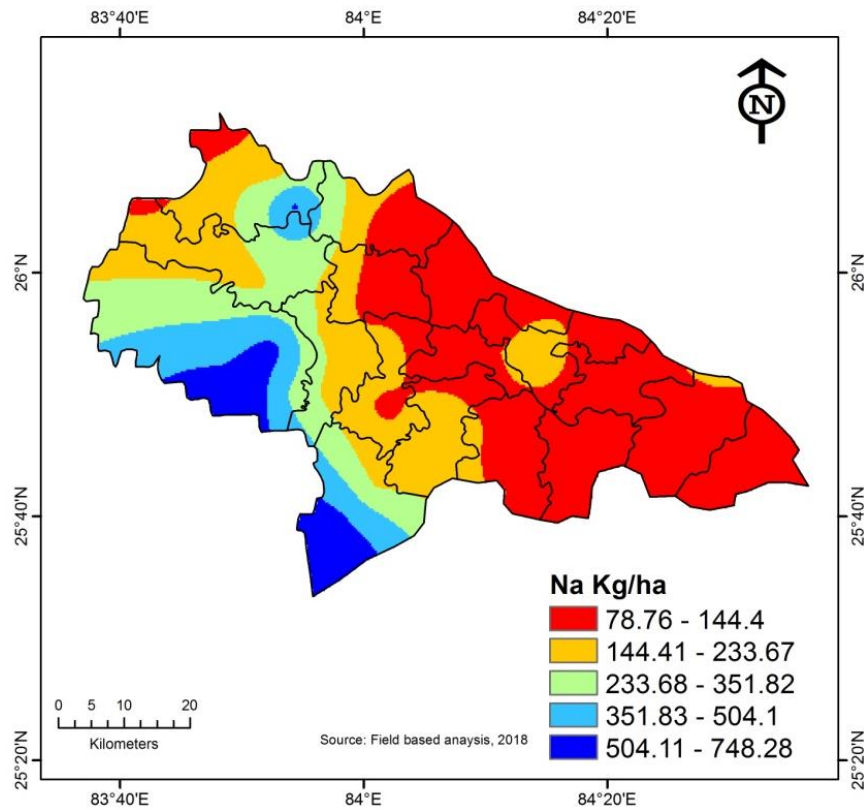


Figure 4.27: Kriging Interpolations of Na

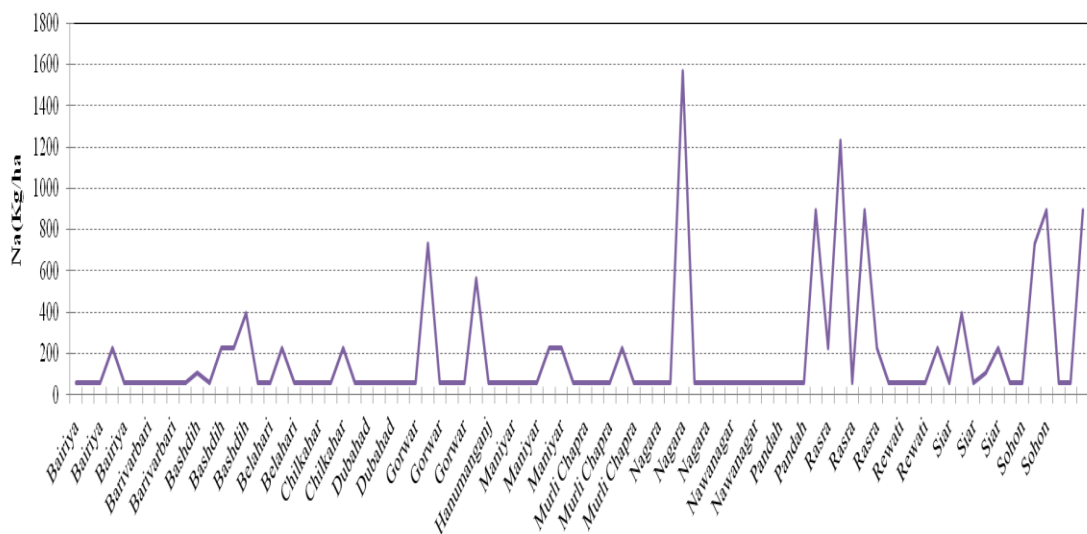


Figure 4.28: Interpolation of Na

Fig.4.25 represents the variability of Na content at 0–30 cm depth analysis. In the interpolation map the dark blue region showed that southeast sites which shows high Na-content (Sohaon, Murlichhapra and Rasra) followed by Siar and Nagra which have high Na content indicated by light blue and green region of map. And the red and yellow region in the map indicates southeast and middle of study area with low Na-content recorded in study area. Consequently, Na-content follows a different trend across the entire study area which shows increase in southern to decrease in north part of the area.

From the data observed the spatial distribution of Na content is analyzed. The average value of Na was 165.12 Kg/ha and the value decreases toward north. The content of sodium in that area ranges from 76.78 to 745.26Kg/ha. Abundance of Na-content of soil is found in Bansdih block with an average value of 195.90Kg/ha and ranges from 57.36 to 396.54 Kg/ha among all the collected soil samples and analyzed the sodium content in the study area. High abundance of soil-sodium content is observed in Sohaon and Rasra which is intolerable and effect soil health.

4.3.4 Interpolation for Spatial Distribution of Carbonate (CO₃²⁻)

In the study area spatial distribution of CO₃²⁻ is analysed by Kriging method of interpolation. On the basis of the data obtained and analysed the study area are grouped into five classes: dark red (12.15-13.76), yellow (13.76-14.53), light green (14.53-15.16), light blue (15.16-15.80) and dark blue (15.81-16.56) which shows the spatial variability of CO₃²⁻-content respectively. In the study area 70% area falls under strongly salinized area and 30% area falls under average salinized area.

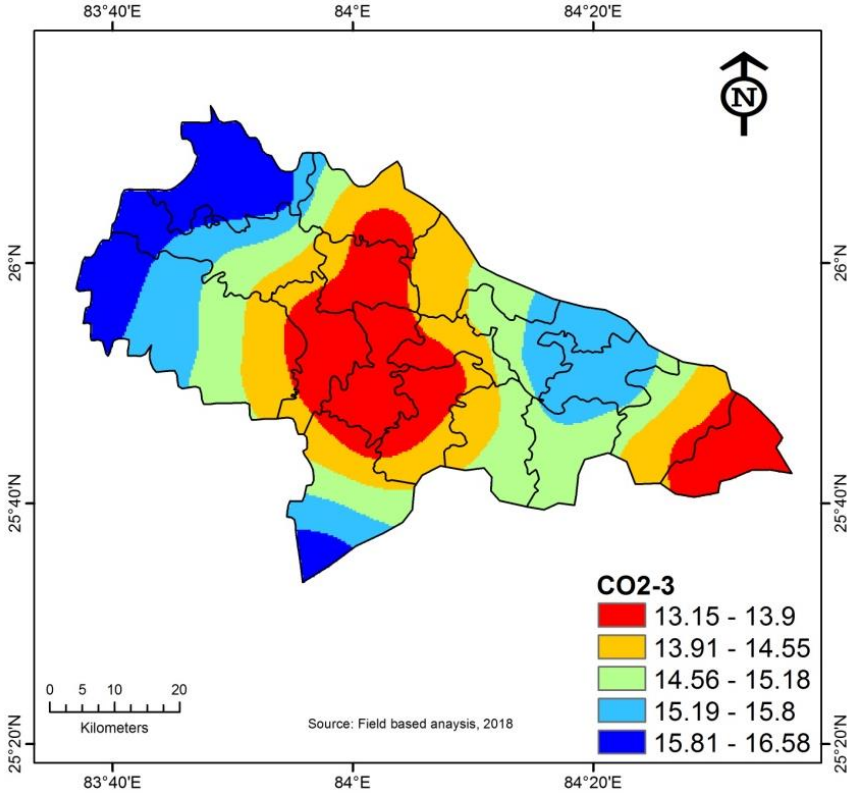


Figure 4.29: Kriging Interpolations of CO₃²⁻

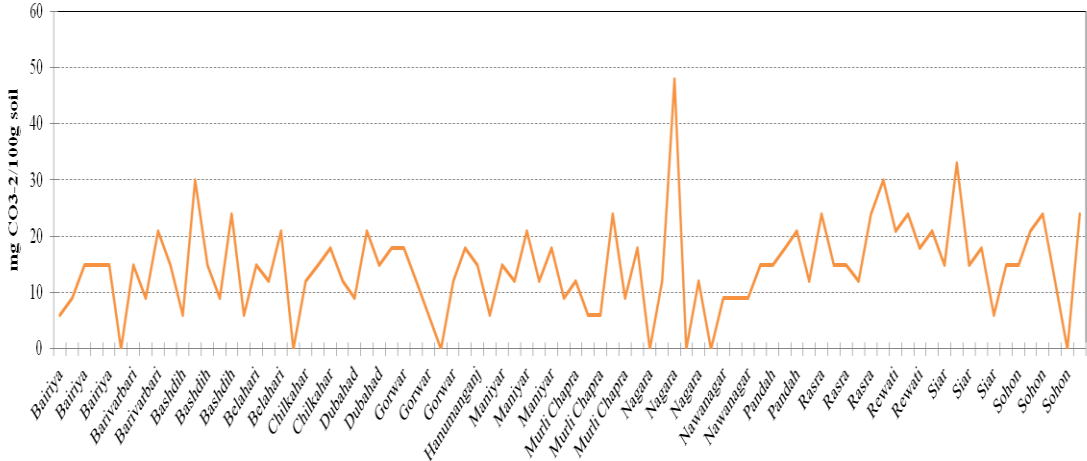


Figure 4.30: Interpolations of CO₃²⁻

Fig.4.27 shows the distribution of CO₃²⁻ content analysis at 0–30 cm depth of soil. From the interpolation map of study area we can observe that northwest sites of Ballia has very high amount of CO₃²⁻(Nagra, Siar and Rasra) followed by Sohaon in western site and Revati in southeast site of study area. The red and yellow region (Chikahar, Garwar, Pandah and Dubhad) in middle represent the average amount of salinity.

Thus, CO_3^{2-} content follows a different pattern across the entire study area increasing throughout the whole study area.

The spatial distribution of CO_3^{2-} content is analyzed. The average value of CO_3^{2-} is 0.016% and CO_3^{2-} ranges from 0.006% to 0.033%. By observing the analysed data CO_3^{2-} % is found highest in Nagra block with an average of 0.023 % and ranged 0.016% to 0.046% among all the collected soil samples and analyzed carbonate content of the study area. In Garwar area no salinization (nill CO_3^{2-}) is observed after data evaluation.

4.3.5 Interpolation for Spatial Distribution of Bicarbonate (HCO_3^-)

In the study area spatial distribution of HCO_3^- content is obtained by Kriging interpolation method. The entire study area is divided into five classes: dark red (1.35-23.52), yellow (23.53-40.15), light green (40.16-56.73), light blue (56.74-71.98) and dark blue (71.99-89.63) which shows the spatial variability of HCO_3^- for individual classes respectively. Thus within the entire area 65% area falls under non-salinised and 35% area falls under degraded alkali type of soil area.

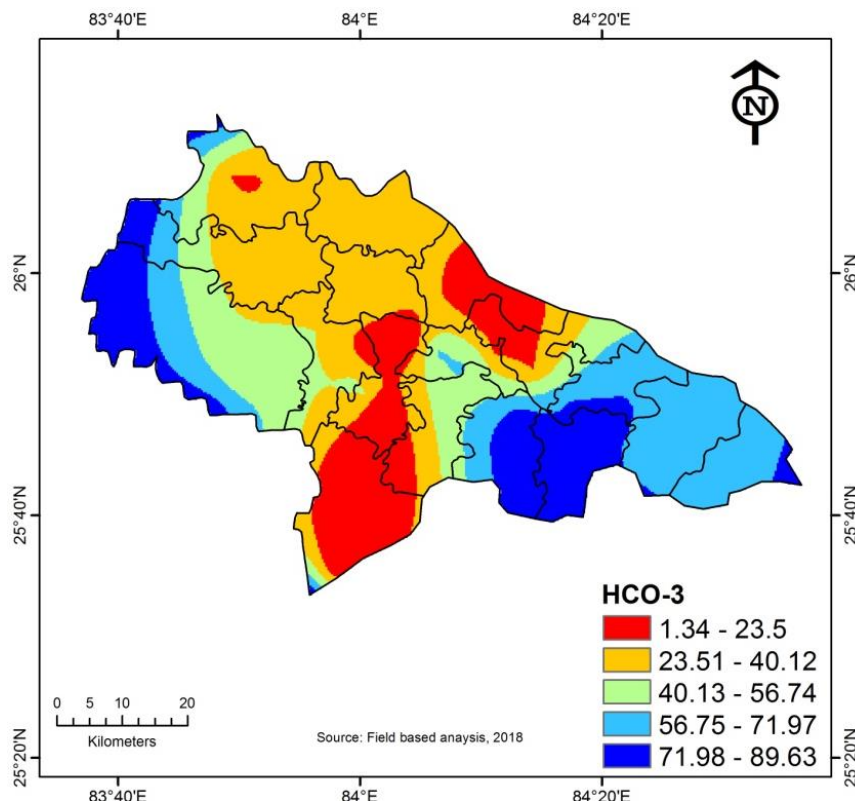


Figure 4.31: Kriging Interpolations of HCO_3^-

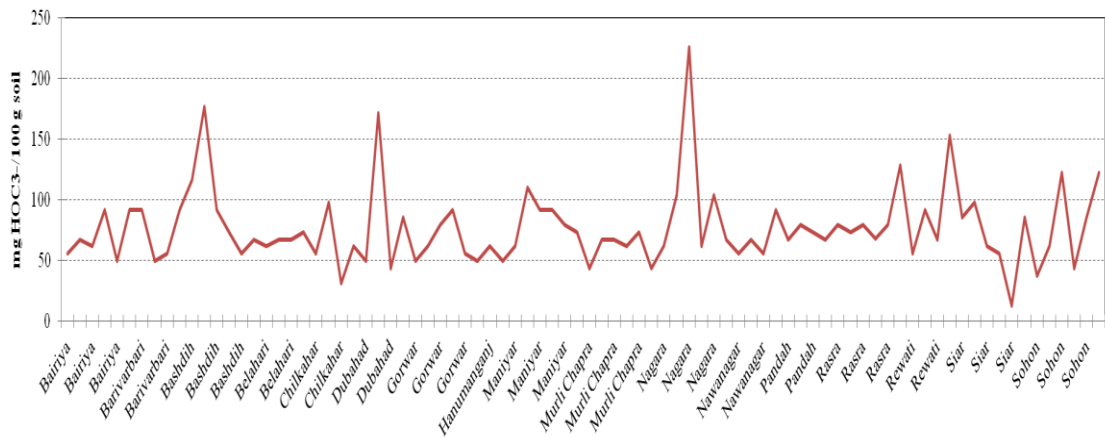


Figure 4.32: Interpolations of HCO₃⁻

Fig.4.29 shows the distribution of amount of HCO₃⁻ which is analysed at 0–30 cm depth of soil. Light and dark blue colour in interpolation map represents very high amount of HCO₃⁻ content which is observed in some blocks of northwest sites of study area (Nagra, and Rasra) and some southeast sites (Bariya, Murli, Chhapra, Revati, Belhari, and Hanumanganj) having high degraded alkali soil. The red and yellow region (Garwar, Chikahar, Pandah, and Sohaon) represents middle of the map shows the non salinized area. Thus, amount of HCO₃⁻ follows a decreasing trend across the entire study area.

The spatial distribution of amount of HCO₃⁻ content is analyzed. The average value of content of HCO₃⁻ is 0.075% and HCO₃⁻ ranges from 0.014% to 0.225% shows different ranges of salinity classes from non saline and saline to degraded alkali soils in the total study area is covering it all. Thus, HCO₃⁻ % is highest in soil of Nagra block area which has an average of 0.112 % and ranged 0.045% to 0.226% among all the collected soil samples and analyzed data of bi-carbonate content in the study area, Ballia. In Garwar area no salinization (<0.06%) is observed among the whole study area.

Table 4.3: Chemical characteristics of soil samples (mean)

Sample ID	Organic Carbon (%)	Organic Matter (%)	Potassium (Kg/ha)	Sodium (Kg/ha)	Carbonate (mg/100g of soil)	Bicarbonate (mg/100g of soil)
1	0.84	1.45	990.8	59.06	15.50	72.50
2	0.59	1.01	859.3	730.22	15.80	24.50
3	0.74	1.28	727.7	898.01	16.20	30.50
4	0.76	1.31	640.0	59.06	16.60	20.40
5	0.39	0.67	376.9	59.06	16.00	25.60
6	0.82	1.41	135.7	59.06	15.20	25.00
7	0.66	1.14	289.2	730.22	15.80	28.50
8	0.72	1.24	157.7	59.06	14.50	23.50
9	0.72	1.24	157.7	59.06	13.20	26.60
10	0.80	1.38	179.6	59.06	13.60	35.20
11	1.01	1.75	223.4	59.06	13.40	40.00
12	0.43	0.74	135.7	59.06	14.20	20.50
13	0.64	1.11	113.8	59.06	13.90	18.20
14	0.16	0.27	333.1	226.85	14.20	23.50
15	1.74	2.99	355.0	226.85	14.80	20.50
16	0.70	1.21	245.4	59.06	15.20	18.30
17	1.15	1.98	157.7	-	14.80	20.50
18	0.78	1.34	179.6	59.06	14.60	2.50
19	0.98	1.68	311.1	226.85	13.90	5.80
20	0.62	1.08	223.4	226.85	14.70	6.21
21	0.66	1.14	223.4	394.64	14.20	8.50
22	0.49	0.84	201.5	59.06	15.00	23.50
23	0.57	0.97	223.4	394.64	15.20	56.75
24	0.88	1.51	201.5	59.06	15.80	60.20
25	0.35	0.61	113.8	-	15.30	60.50
26	0.49	0.84	179.6	226.85	15.70	71.50
27	0.74	1.28	245.4	59.06	15.60	56.75
28	1.44	2.49	201.5	59.06	15.02	56.78
29	0.74	1.28	333.1	59.06	14.80	60.20
30	0.96	1.65	135.7	59.06	14.50	62.50
31	0.80	1.38	245.4	59.06	13.80	57.20
32	0.98	1.68	289.2	59.06	13.80	60.50
33	0.70	1.21	486.5	59.06	13.50	62.50
34	0.31	0.54	420.8	1569.17	13.20	68.20
35	0.37	0.64	201.5	59.06	13.60	69.20
36	0.43	0.74	179.6	59.06	13.40	72.90
37	0.76	1.31	113.8	59.06	13.50	70.50
38	0.55	0.94	223.4	59.06	14.70	69.20

39	0.76	1.31	179.6	59.06	15.10	73.00
40	0.98	1.68	223.4	59.06	15.20	75.80
41	0.70	1.21	223.4	59.06	14.80	72.50
42	0.51	0.87	157.7	226.85	15.10	75.20
43	0.60	1.04	113.8	898.01	14.60	76.30
44	0.45	0.77	311.1	226.85	14.62	72.90
45	0.98	1.68	1166.2	1233.59	14.56	74.50
46	0.84	1.45	135.7	59.06	14.40	80.20
47	0.20	0.34	333.1	562.43	14.52	71.20
48	0.43	0.74	245.4	59.06	13.90	56.20
49	1.03	1.78	223.4	59.06	13.70	54.70
50	0.74	1.28	179.6	59.06	13.82	54.20
51	0.60	1.04	135.7	59.06	13.20	40.12
52	1.48	2.55	267.3	59.06	13.52	56.72
53	1.05	1.82	442.7	59.06	13.90	54.50
54	0.23	0.40	925.0	59.06	13.20	23.50
55	0.25	0.44	355.0	59.06	13.95	20.50
56	0.41	0.71	640.0	59.06	14.20	18.20
57	1.11	1.92	1056.6	59.06	15.20	18.40
58	0.66	1.14	508.5	226.85	15.80	16.40
59	0.39	0.67	267.3	59.06	15.95	56.80
60	0.88	1.51	530.4	59.06	13.90	23.50
61	0.45	0.77	223.4	59.06	13.75	25.50
62	1.03	1.78	618.1	226.85	13.70	26.20
63	0.25	0.44	618.1	59.06	13.25	23.50
64	0.86	1.48	157.7	59.06	13.70	24.20
65	1.03	1.78	355.0	59.06	13.50	23.50
66	0.60	1.04	289.2	59.06	13.50	25.60
67	0.49	0.84	157.7	59.06	13.40	35.60
68	0.59	1.01	486.5	226.85	13.70	32.60
69	0.82	1.41	749.6	59.06	13.65	32.80
70	0.16	0.27	793.5	59.06	13.55	40.10
71	0.76	1.31	749.6	226.85	13.90	38.20
72	0.33	0.57	223.4	59.06	13.91	40.50
73	0.99	1.71	289.2	59.06	13.80	42.60
74	0.88	1.51	289.2	59.06	13.95	50.60
75	0.68	1.18	618.1	59.06	14.20	54.20
76	0.59	1.01	596.2	59.06	15.12	72.20
77	0.59	1.01	355.0	59.06	14.50	40.20
Mean	0.70	1.21	353.35	168.02	14.40	43.24
Range	0.16-1.74	0.27-2.99	113.8-990.8	0-1569.17	13.20-16.60	2.50-80.20

Table 4.4: Other chemical properties of soil samples (mean)

Sample ID	Nitrogen (Kg/ha)	Phosphorus (Kg/ha)	CEC (meq/100g of soil)
1	69.20	19.20	8.00
2	120.20	17.50	16.00
3	124.36	15.2	12.00
4	137.02	6.9	16.00
5	82.60	7.29	10.00
6	75.72	7.42	8.00
7	72.60	8.15	12.00
8	73.20	7.96	10.00
9	56.70	8.15	12.00
10	152.60	7.96	8.00
11	117.20	6.82	14.00
12	106.50	6.53	14.00
13	93.67	6.62	8.00
14	82.60	8.15	10.00
15	125.60	8.06	18.00
16	142.50	8.29	18.00
17	187.20	7.02	14.00
18	160.60	7.29	16.00
19	172.71	6.92	20.00
20	164.20	6.92	20.00
21	156.20	7.24	16.00
22	163.50	8.40	18.00
23	105.60	6.20	16.00
24	112.24	6.21	14.00
25	152.30	5.92	14.00
26	118.20	5.96	18.00
27	149.20	4.90	20.00
28	122.40	5.64	18.00
29	119.60	6.10	22.00
30	109.60	4.86	16.00
31	115.60	5.02	18.00
32	98.20	10.50	22.00
33	115.20	5.91	20.00
34	89.50	5.52	22.00
35	121.25	6.35	20.00
36	101.50	5.96	18.00
37	146.60	4.92	18.00
38	108.20	5.25	20.00

39	123.60	5.19	22.00
40	107.25	5.29	16.00
41	116.40	5.67	12.00
42	106.62	6.23	12.00
43	112.20	7.52	14.00
44	119.50	6.95	12.00
45	156.20	6.50	16.00
46	120.70	6.22	16.00
47	139.60	6.59	14.00
48	130.20	18.52	14.00
49	108.20	19.50	14.00
50	105.60	12.42	16.00
51	140.20	11.02	18.00
52	144.60	16.20	16.00
53	186.72	9.20	20.00
54	125.70	13.20	18.00
55	129.20	13.25	16.00
56	131.34	15.91	16.00
57	121.20	17.20	18.00
58	122.24	15.21	14.00
59	126.40	9.61	10.00
60	132.60	7.20	14.00
61	131.34	11.50	18.00
62	102.80	12.25	14.00
63	142.50	9.20	18.00
64	118.60	11.25	16.00
65	128.68	10.25	18.00
66	132.40	6.03	20.00
67	115.25	8.56	18.00
68	159.40	6.24	22.00
69	169.40	7.27	24.00
70	163.50	6.95	18.00
71	121.20	7.57	20.00
72	123.50	11.72	20.00
73	129.50	9.20	22.00
74	116.40	13.54	16.00
75	124.20	15.24	20.00
76	118.90	11.82	18.00
77	103.52	10.40	14.00
Mean	123.76	9	16.21
Range	56.70-187.20	4.86-19.50	8-24

Table 4.5: Pearson correlation matrix for soil physico-chemical properties

	pH	EC	OC	OM	N	P	K	Na	S	CO ₃ ²⁻	HCO ₃ ⁻	CEC	Sand	Silt	Clay
pH	1														
EC	.490**	1													
OC	-.042	.042	1												
OM	-.042	.044	1.000**	1											
N	-.024	.053	.773**	.773**	1										
P	-.604**	-.497**	.006	.005	-.101	1									
K	.203	.618**	.012	.013	-.088	-.080	1								
Na	-.522**	-.232*	-.093	-.093	-.096	.344**	.125	1							
S	.164	-.135	-.316**	-.318**	-.214	-.019	-.101	-.008	1						
CO ₃ ²⁻	.032	-.055	-.189	-.189	-.108	-.007	-.016	.210	.084	1					
HCO ₃ ⁻	.396**	.604**	-.179	-.178	-.185	-.193	.412**	-.175	.051	.056	1				
CEC	.248*	.268*	.419**	.420**	.435**	-.157	.163	-.121	-.012	-.315**	.092	1			
Sand	-.173	-.592**	-.127	-.129	-.056	.071	-.630**	-.110	.063	-.021	-.478**	-.457**	1		
Silt	-.359**	.122	.130	.132	.072	.199	.011	.421**	-.273*	.089	.127	.122	-.475**	1	
Clay	.404**	.602**	.069	.071	.021	-.196	.709**	-.119	.087	-.028	.468**	.448**	-.860**	-.040	1

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

4.4 Rainfall Trend Analysis (1994-2019)

Using the satellite data from CHIRPS at 560 km spatial resolution maps of rainfall trends of the study area are created. Monthly precipitation climatology is used to delineate difference in mean annual rainfall (MAR) from 1994 to 2019 on decade basis. The mean annual rainfall (MAR) is higher in northwest side of the area than southeast side of Ballia.

4.4.1 Rainfall Trend in 1994

In 1994 as per the satellite data the MAR value of the study area ranges from 61.58 mm to 86.69 mm (Table 4.5 and Fig. 4.33 & 4.34). It can be observed that the maximum amount of rainfall occurred in Siar (86.69 mm) block followed by Navanagar (84.39 mm) and Nagra (83.12 mm) and in the Hanumanganj block (61.58 mm) minimum rainfall amount is recorded. Mean monthly rainfall ranged from 2.66 mm to 325.57 mm based on monthly precipitation climatology and based on data the mean monthly rainfall was maximum in month of august. It was observed maximum in Siar (326.50 mm) and minimum is observed in Bariya (226.30 mm). Thus, in kharif (June-September) season high mean rainfall was observed, greater than in summer (March-May) followed by in rabi (November-December) season or in winter.

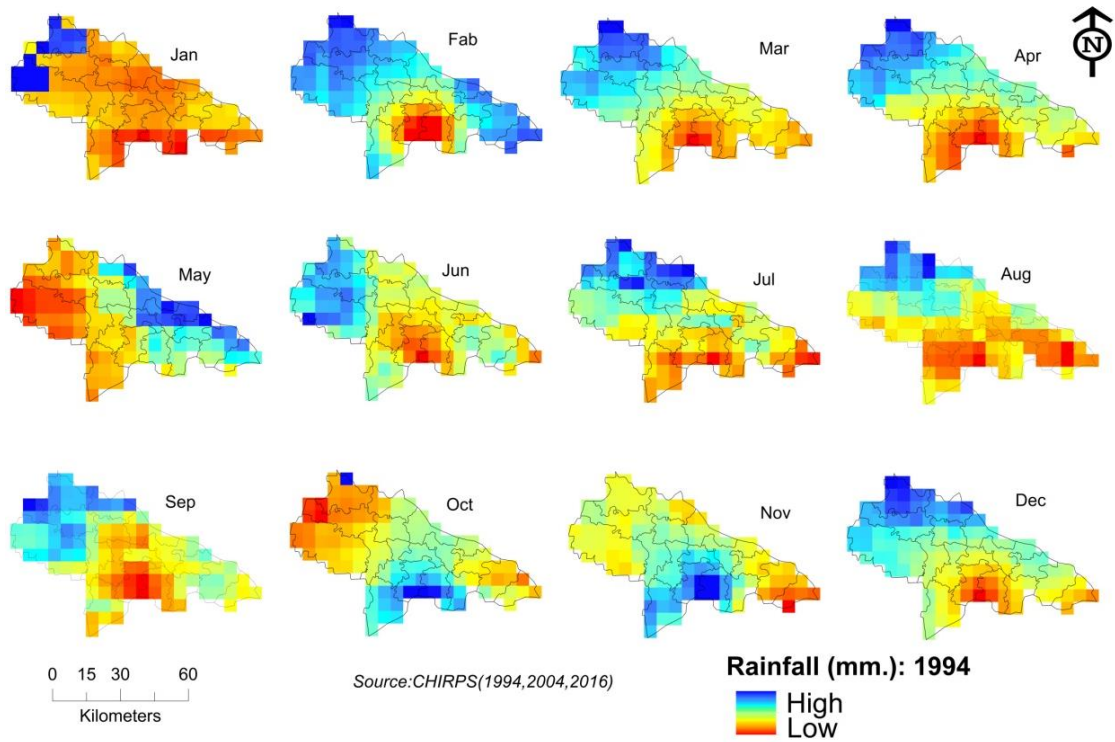


Figure 4.33: Mean Annual Rainfall (1994)

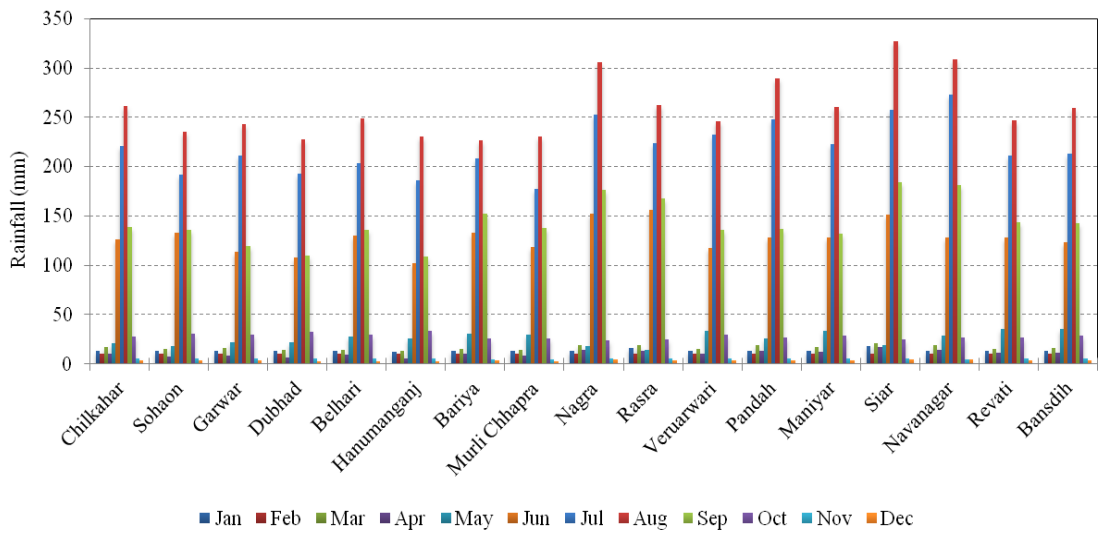


Figure 4.34: Blocks Wise Spatial Statistics of Mean Annual Rainfall (1994)

Table 4.6: Mean Monthly Rainfall (MMR) and Mean Annual Rainfall (MAR) of different block of Ballia district for the year 1994 from CHIRPS

BLOCK NAME	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAR
CHILKAHAR	13.5877	10.4340	17.4940	10.6109	21.1185	126.5308	220.3742	261.6718	138.6150	27.4983	5.5934	3.5952	71.4270
SOHAON	13.3444	10.4340	15.6239	7.2810	18.0389	133.3191	191.7077	234.9021	135.5582	30.9757	5.8128	3.4959	66.7078
GARWAR	13.5526	10.4340	16.1215	9.0514	21.7307	113.5272	211.3474	243.2064	119.4135	29.7718	5.6408	3.4723	66.4391
DUBHAD	13.0239	10.4340	14.2620	6.9050	22.1102	107.5519	192.5918	227.5555	110.3491	32.3144	5.9272	2.9623	62.1656
BELHARI	13.1090	10.4340	14.6531	9.2752	27.9465	130.4088	203.3286	248.5297	135.8366	29.8720	5.5429	3.2016	69.3448
HANUMANGANJ	12.6444	10.4340	13.3240	6.0672	26.1560	102.6809	185.7035	230.3818	109.0227	33.8445	6.1567	2.6526	61.5890
BARIYA	13.7060	10.4340	15.3290	10.5537	31.1463	133.1820	207.8562	226.3068	152.5636	25.9724	5.0853	3.5133	69.6374
MURLI CHHAPRA	13.2590	10.4340	14.5222	8.6007	30.1662	118.5928	177.0574	230.4792	138.2727	25.8163	4.8763	3.0104	64.5906
NAGRA	13.5839	10.4340	19.4120	14.8394	17.8758	152.7787	252.7390	305.3947	176.7035	23.9877	5.3943	4.3370	83.1233
RASRA	15.9116	10.4340	18.8330	13.3131	14.1338	156.0926	224.1283	262.6678	167.4185	24.6750	5.2994	4.0717	76.4149
VERUARWARI	13.2316	10.4340	15.8643	10.2460	33.8686	117.4994	232.4969	246.2162	136.1867	29.8035	5.7505	3.3928	71.2492
PANDAH	13.1186	10.4340	18.8616	13.0671	25.6253	128.1663	248.0357	289.5621	137.1584	26.9398	5.5177	4.0741	76.7134
MANIYAR	13.0477	10.4340	17.6101	12.5948	33.3093	127.8484	222.4001	260.5169	131.8682	28.9307	5.3898	3.9908	72.3284
SIAR	17.8758	10.4340	20.8757	16.8608	18.8082	151.5336	257.9814	326.5046	184.2578	25.0581	5.3125	4.8159	86.6932
NAVANAGAR	13.7192	10.4340	19.3019	13.9552	28.9848	127.7937	272.5672	308.1521	181.1226	26.7910	5.2635	4.6057	84.3909
REVATI	13.7671	10.4340	15.8299	11.3233	35.3646	128.6493	210.7554	247.3719	144.0241	27.0366	5.3267	3.7554	71.1365
BANSDIH	13.3121	10.4340	16.1902	11.8815	36.0752	123.8905	212.7250	259.8502	142.6947	28.8051	5.4430	3.6876	72.0824

4.4.2 Rainfall Trend in 2004

Critical analysis of Mean annual rainfall (MAR) for 2004 indicates that MAR of area ranges 74.77mm to 89.89 mm (Table 4.6 and Fig. 4.35 & 4.36). It can be observed from the available data that the mean annual rainfall in 2004 was observed maximum in Navanagar (89.89 mm) while found minimum in the Hanumanganj block (74.77 mm) of study area. Mean monthly rainfall ranged from 2.60 mm to 435.67 mm based on monthly precipitation climatology and in the month of July the maximum mean monthly rainfall was recorded. Maximum rainfall was observed in Navanagar (432.68 mm) however, minimum was recorded in Sohaon (318.90 mm). Thus in Hanumanganj block (2.65 mm) overall minimum mean monthly rainfall was recorded. In kharif (June-September) season higher mean rainfall was recorded which was greater amount than rainfall of summer (March-May) season followed by in winter (November-December) season.

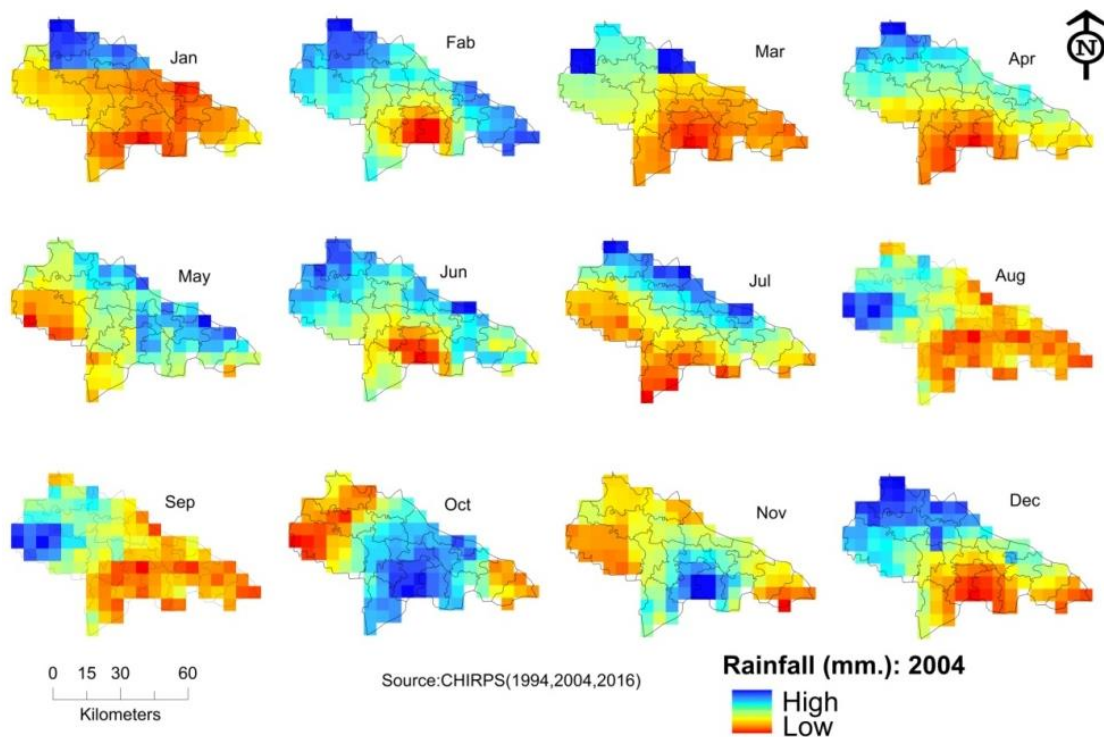


Figure 4.35: Mean Annual Rainfall (2004)

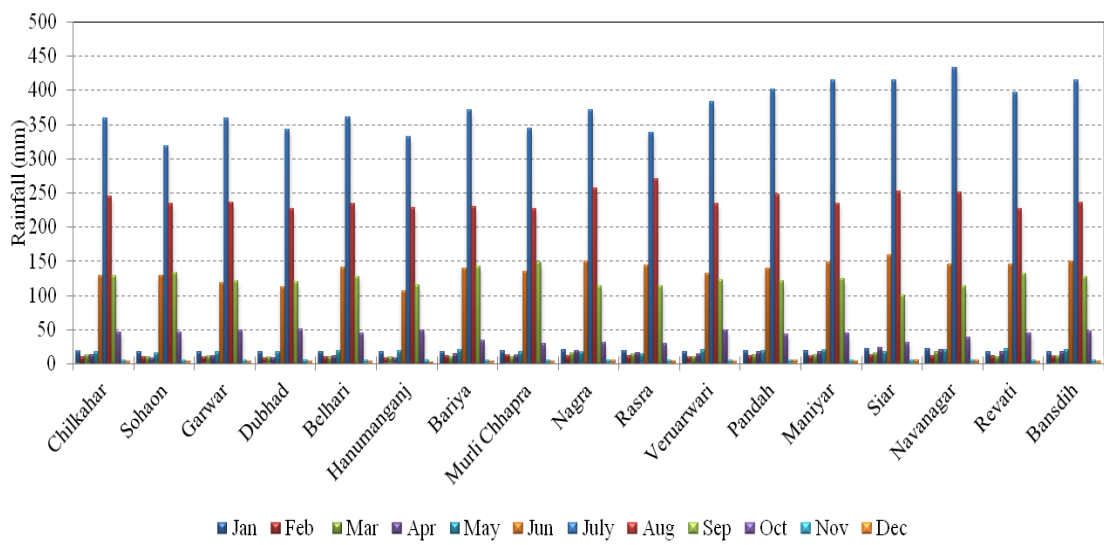


Figure 4.36: Blocks wise Spatial Statistics of Mean Annual Rainfall (2004)

Table 4.7: Mean Monthly Rainfall (MMR) and Mean annual rainfall (MAR) of different block of Ballia district for the year 2004 from CHIRPS

BLOCK NAME	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	MAR
CHILKAHAR	17.84904	9.94737	12.30929	12.96743	17.00105	129.21044	358.30173	244.87009	127.81690	45.06794	4.88721	3.78029	82.00073
SOHAON	17.46068	10.00491	10.30298	8.12489	14.85435	128.72451	318.90718	233.79563	132.40448	45.64712	5.06364	3.49590	77.39886
GARWAR	17.75542	9.45852	10.56834	11.06766	17.19345	117.56170	358.50700	235.84508	121.16656	48.22477	5.07048	3.47232	79.65761
DUBHAD	17.19015	8.09798	9.35271	8.60406	17.44702	112.47554	342.50794	225.75563	119.37561	50.80838	5.36037	2.96230	76.66147
BELHARI	17.16186	9.93576	9.74729	11.44958	18.14089	140.47823	360.43226	233.88791	127.37728	44.10878	5.12497	3.20158	81.75386
HANUMANGANJ	16.89567	7.44877	8.89149	7.35939	19.00848	105.15760	331.63925	227.75616	115.55777	49.34450	5.56296	2.65259	74.77289
BARIYA	17.49924	11.61578	10.09332	14.00712	20.08185	138.58327	371.41679	229.00757	142.47835	33.52741	4.73214	3.51330	83.04635
MURLI CHHAPRA	18.26138	12.28815	9.92375	11.86299	16.65553	135.14371	344.30338	226.31945	148.59266	29.30332	4.53450	3.01038	80.01660
NAGRA	19.55289	11.54439	14.83550	18.91665	16.40474	149.35830	371.57747	256.58750	112.87251	31.27625	4.78515	4.57634	84.35731
RASRA	18.12719	11.02301	13.46557	15.94038	13.38354	143.16923	337.42313	269.54911	113.48559	29.86863	4.61631	4.07169	81.17695
VERUARWARI	17.43325	9.44224	10.21874	13.46748	19.83056	131.86678	383.24712	234.53529	122.86309	48.31927	5.20523	3.39278	83.31849
PANDAH	18.68583	11.11926	12.84130	16.89339	18.49415	138.49935	401.69417	247.56852	121.10050	42.08266	4.91629	4.45376	86.52910
MANIYAR	18.20764	10.59422	12.94054	17.35221	19.47957	148.23583	414.59446	234.17596	124.50853	44.89318	4.87335	3.99075	87.82052
SIAR	21.58868	12.33244	15.10361	22.95449	17.38260	158.14855	415.01393	252.59287	100.24141	30.08267	4.75076	5.46929	87.97178
NAVANAGAR	21.41886	11.21984	16.81720	19.84513	20.27451	145.58821	432.68663	250.37618	113.41476	37.58905	4.72840	4.82847	89.89894
REVATI	17.03832	11.18066	10.24453	16.75581	21.24916	144.91751	396.49261	226.56188	131.50594	43.86520	4.96040	3.86746	85.71996
BANSDIH	17.06636	10.87563	10.45425	17.07276	19.49831	148.86806	414.36644	235.55384	127.50261	47.69191	4.99576	3.68760	88.13613

4.4.3 Rainfall Trend in 2019

MAR of the study area of 2019 is 79.61mm to 96.26mm (Table 4.7 and Fig. 4.37 & 4.38). It is observed that higher amount of mean annual rainfall in northwest region than southeast area of Ballia. It is observed from the analysed data that in Siar (96.26 mm) the mean annual rainfall (MAR) in 2019 are recorded maximum followed by Navanagar (95.65mm), Pandah (94.68mm) and Maniyar (92.46 mm). Thus the Hanumanganj block (79.61mm) recorded with minimum rainfall. Mean monthly rainfall ranged from 2.82 mm to 435.67 mm based on monthly precipitation climatology and in September month the maximum mean monthly rainfall is recorded. It was observed maximum rainfall in southeast block Murlichhapra (385.32 mm) and minimum rainfall was observed in Dubhad (293.42 mm) of the month of September. Moreover in Hanumanganj block (2.82 mm) minimum mean monthly rainfall was recorded. Overall, in kharif (June-September) higher amount of mean rainfall is recorded which is greater than rainfall amount in summer (March-May) followed by rainfall amount in winter (November-December) season.

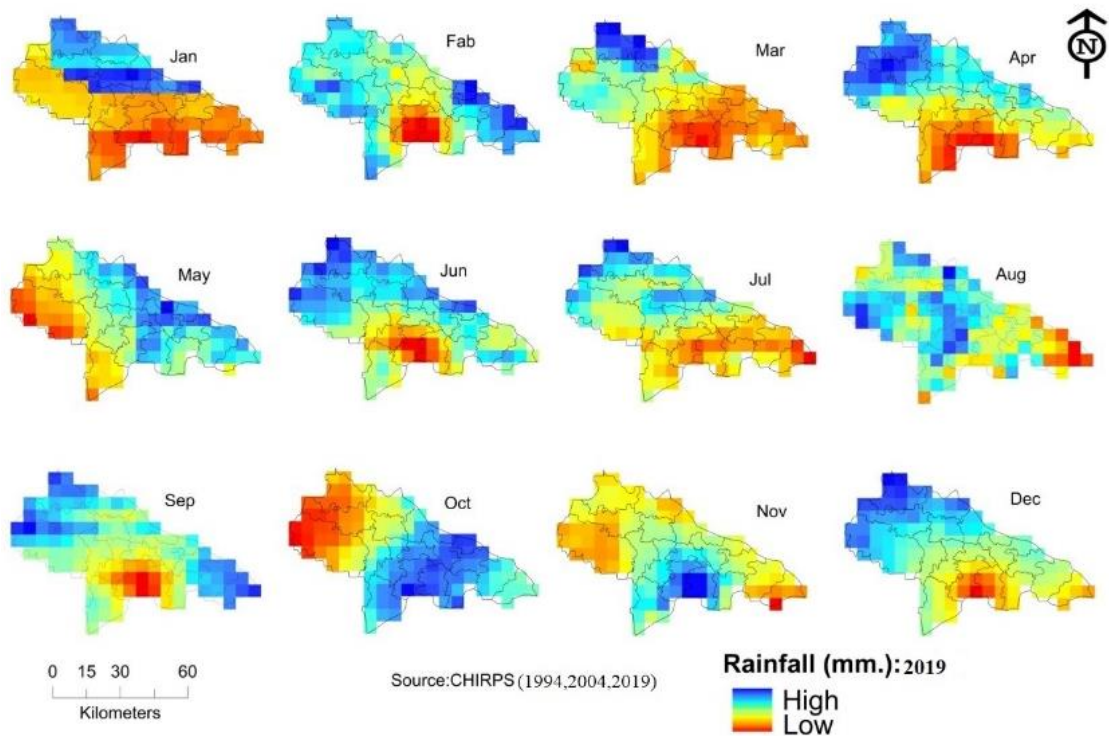


Figure 4.37: Mean Annual Rainfall (2019)

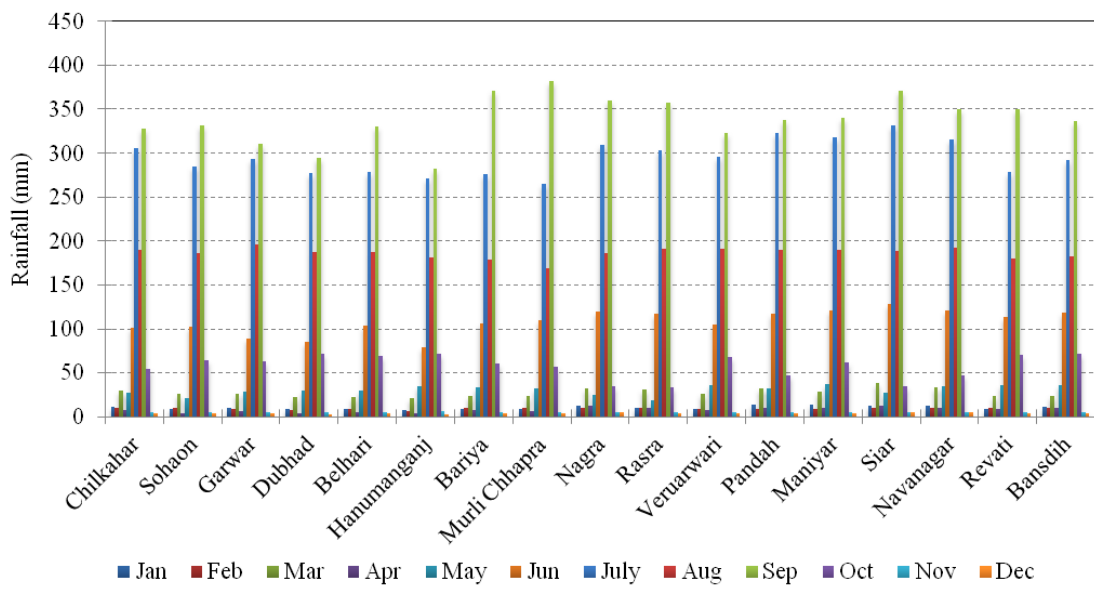


Figure 4.38: Blocks wise Spatial Statistics of Mean Annual Rainfall (2019)

Table 4.8: Mean Monthly Rainfall (MMR) and Mean Annual Rainfall (MAR) of different block of Ballia district for the year 2019 from CHIRPS

NAME	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	MAR
CHILKAHAR	11.012631	9.687967	29.215734	7.378293	27.643526	100.855723	305.803975	189.680473	327.836884	53.888921	5.333781	3.924115	89.36
SOHAON	8.663348	9.624330	25.467114	4.341254	21.662916	102.511662	284.597388	186.204021	331.070398	64.220994	5.465794	3.736532	87.30
GARWAR	10.155642	8.555261	25.979187	5.844805	28.905717	89.400430	293.684149	196.285117	310.886017	63.291322	5.466311	3.725515	86.85
DUBHAD	8.608853	7.259315	22.889517	4.365072	29.843154	85.644145	277.218994	187.761101	294.148254	71.763110	5.716028	3.179250	83.20
BELHARI	8.349565	9.112762	22.307323	5.606355	29.757224	104.274542	278.358136	187.361475	330.050958	68.632310	5.430243	3.449452	87.72
HANUMANGANJ	8.181952	6.932846	20.929127	3.438365	34.484256	79.424987	271.383565	181.550423	282.793981	71.506780	5.933635	2.824045	79.61
BARIYA	8.707114	10.624121	23.989853	7.385491	33.024006	106.509202	276.765850	178.332666	370.964359	61.115350	5.077971	3.768336	90.52
MURLI CHHAPRA	8.651671	10.647691	24.019330	6.145769	31.810254	110.269942	265.464471	169.609604	382.233826	56.500152	4.871700	3.267075	89.46
NAGRA	12.474172	9.640098	31.653820	12.325916	24.939618	119.768258	309.986979	185.852142	360.553104	34.143689	5.102360	4.592454	92.59
RASRA	9.545153	10.097581	31.110633	10.079881	18.549519	117.370096	303.583459	190.981432	357.162787	32.848477	4.963026	4.467684	90.90
VERUARWARI	8.972512	8.274808	25.884938	7.809685	35.799288	105.265658	296.109121	191.244883	322.661265	68.115863	5.548961	3.759919	89.95
PANDAH	13.579809	9.011835	31.874617	10.175931	32.048796	117.603086	322.706960	189.616755	337.785807	47.457453	5.299703	4.335195	93.46
MANIYAR	13.443800	8.887514	28.561698	9.873572	36.767976	120.384924	318.452347	189.987265	339.916168	61.576672	5.226117	4.252324	94.78
SIAR	12.957037	9.913180	38.252015	12.014148	27.030245	128.277010	332.001703	189.063860	371.706631	34.975160	5.102921	5.026738	96.26
NAVANAGAR	12.796656	9.574657	33.729574	10.031736	34.958472	120.454356	315.623798	192.688837	350.653583	47.442493	5.043013	4.708591	94.81
REVATI	9.370285	10.491931	23.472839	8.384613	35.884290	113.905111	278.663994	179.730473	350.638840	70.739264	5.257463	3.914771	90.87
BANSDIH	11.451984	10.154984	23.811666	9.596694	36.191781	117.869535	291.941116	182.023997	336.104116	72.013360	5.293675	3.919966	91.70

4.5 Comparison among different Indices (NDVI, NDSI (soil), SI and NDWI)

4.5.1 Comparison between NDVI and NDSI (soil)

Comparison between NDVI and NDSI (soil) carried out to depict the relation between NDVI trends to NDSI(soil) (Fig. 4.39). It is done by plotting the NDVI time series and NDSI(soil) time series of the study area for a selected pixel range. When NDVI values are much higher than NDSI(soil), it is observed that in 1994 there is a positive trend of the study area, but the trend deviated from 2004 to 2019. In Ballia, it is observed that with decreasing value of NDVI, the NDSI(soil) value decreases within these time series. In 1994, lower NDVI value is observed in Belhari (0.124), Murli chhapra (0.119) and Hanumanganj (0.142) corresponding with the higher NDSI value 0.142, 0.134 and 0.125 respectively and in Nagra (0.42) highest NDVI is observed correspond for lowest NDSI (-0.09). Within time series of 2004 and 2019 NDVI decreases with increase in NDSI.

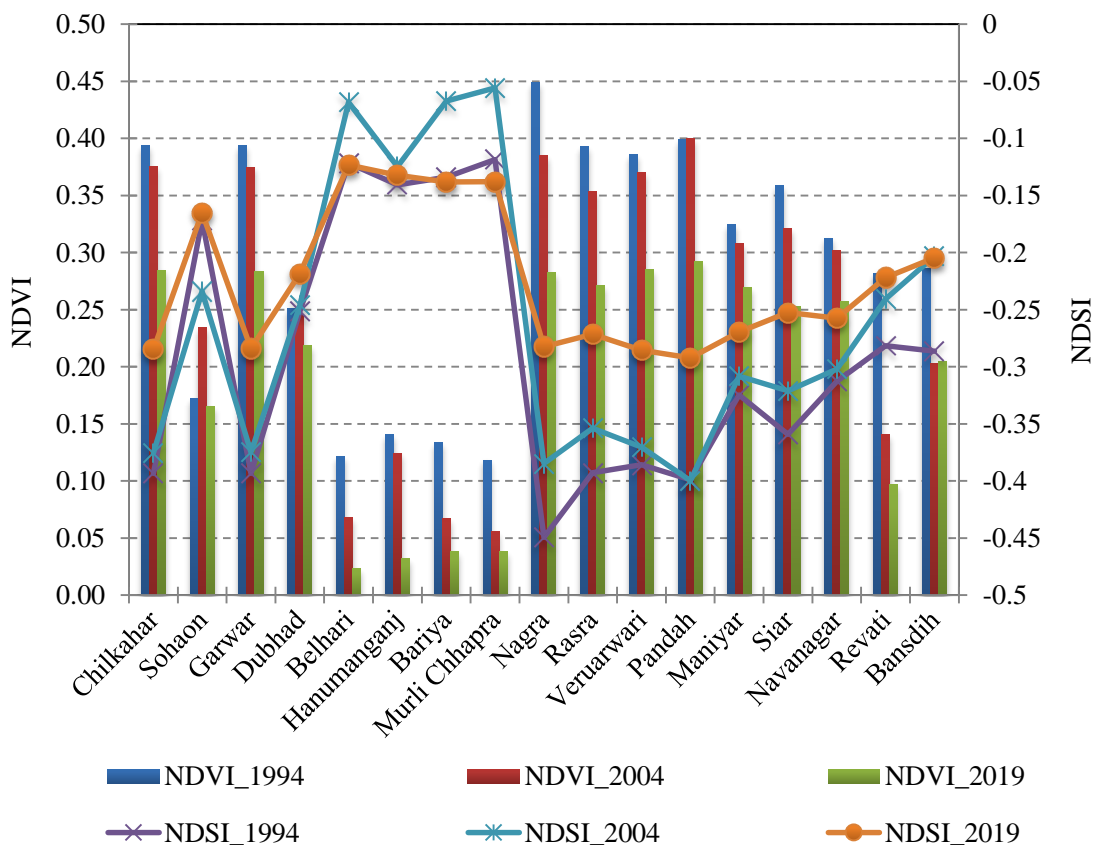


Figure 4.39: Comparisons between NDVI and NDSI [79]

The relation between the two it is obtained that vegetation index is higher with lowering soil index. NDVI and NDSI (soil) is related with vegetation, moisture content and soil condition. High soil index and lower moisture content decrease the vegetation growth and soil index.

4.5.2 Comparison between NDVI and SI

NDVI time series and SI time series are plotted in specific pixel range to compare the relationship between NDVI and SI (Fig. 4.40). The relationship between these two depicts the salinity problem as well as vegetation growth of the study area. It is observed that from 1994 to 2019 within 26 years there is lower value of NDVI which shows low vegetation variability of that study area.

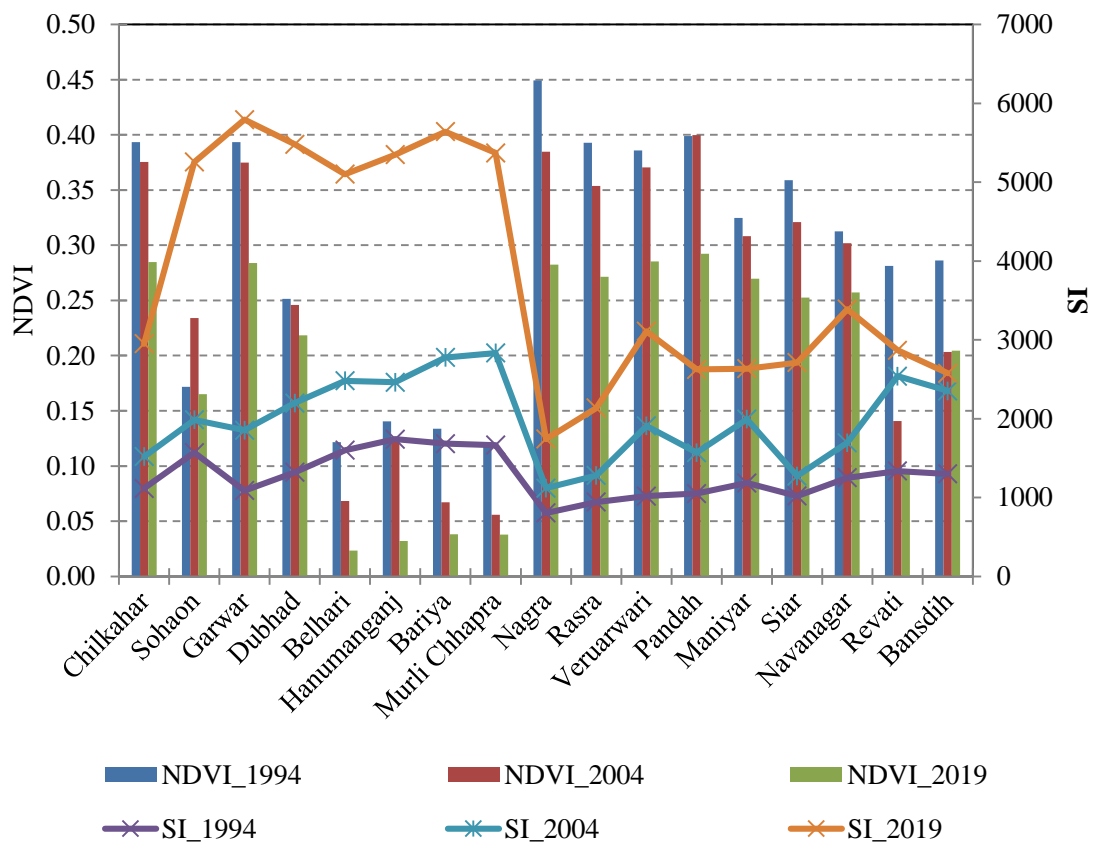


Figure 4.40: Comparisons between SI and NDVI

It is observed that there is a decreasing trend of NDVI with respect to SI value in Ballia from 1994 to 2019. While for some specific year it is observed that with higher the NDVI value the SI value becomes less. In 1994, NDVI value is lower mainly in Murli chhapra (0.116), Bariya (0.135) and Hanumanganj (0.143) corresponding to the

higher SI value 1652.94, 16892.96 and 1743.67 respectively and highest NDVI value is observed at Nagra (0.451) with respect to lowest SI value (802.75). With higher values of salinity of soil vegetation growth decreases compared to 2004 and 2019 with decrease of NDVI value of SI increases.

It is observed that NDVI and SI follow an opposite trend. With higher value of salinity index, vegetation index may be decreases. The main cause of vegetation growth reduction is the degradation of soil due to accumulation of salt in soil.

4.5.3 Comparison between NDVI and NDWI

NDVI time series and NDWI time series are plotted to compare the relationship between these two from particular pixel range of the study area (Fig. 4.41). These study shows that there is a positive relationship between vegetation growths to water availability within the 26 years' time series from 1994 to 2019. The relation between NDVI and NDWI shows opposite trend from 1994 to 2019.

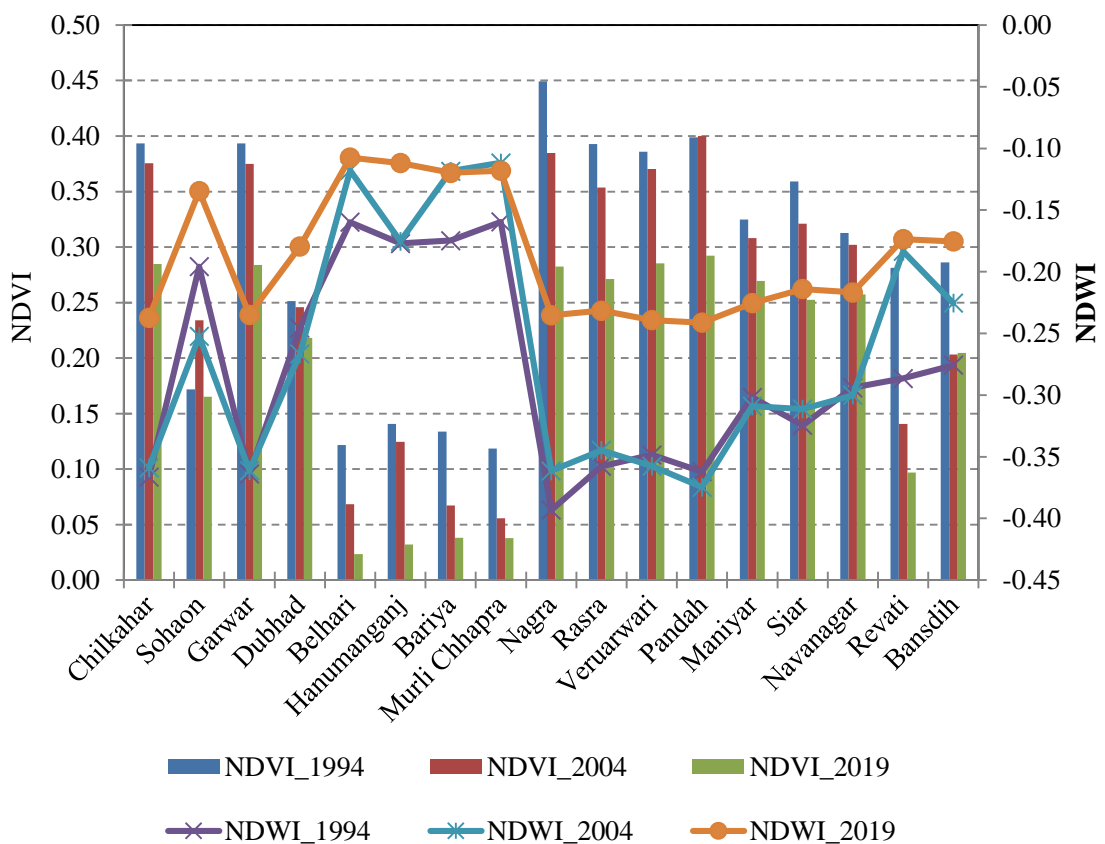


Figure 4.41: Comparisons between NDVI and NDWI

It is observed that NDVI value decreases with increase in NDWI value of the area in the following time series. In 1994, lower NDVI value is observed in Murli chhapra (0.116), Bariya (0.135) and Hanumanganj (0.143) respect to the higher NDWI value - 0.17, -0.18 and -0.19 respectively and in Nagra (0.449) highest NDVI value is observed in respect to lowest NDWI (-0.38). Due to decreased water content vegetation cover is lowered compared from 2004 and 2019 or NDVI decreases with increase in NDWI.

Thus the NDVI and NDWI follows an opposite trend, with higher vegetation index, water index becomes lower gradually.

4.5.4 Comparison between NDVI and Rainfall

NDVI time series and rainfall time series are plotted to compare these two with particular pixel range of that time period from 1994 to 2019 of the study area (Fig. 4.42). The relationship of both of these depicts the vegetation variability of that area within the time series of 26 years.

NDVI shows a decreasing trend with increase rainfall amount within Ballia from 1994 to 2019.

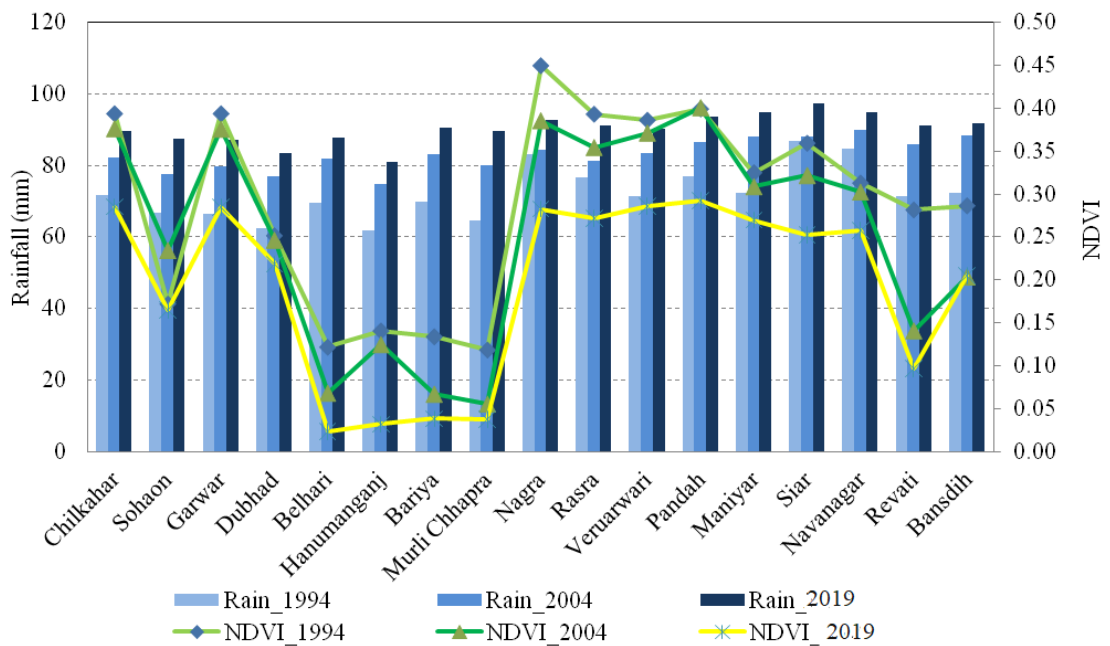


Figure 4.42: Comparisons between NDVI and Rainfall

For particular year due to high occurrence of rainfall NDVI value becomes lower. In 1994, lower value of NDVI is observed in Murli chhapra (0.119), Bariya (0.135) and Hanumanganj (0.146) with respect to the lower NDWI value 63.58, 68.71 and 59.58 respectively and in Nagra (0.449) highest NDVI with respect to higher rainfall (86.12). With decrease of water content, vegetation cover becomes more which is observed from 2004 and 2019 or NDVI decreases with increase the value of NDWI.

Thus, the value of NDVI and NDWI value follows an opposite trend, higher the vegetation index due to lower value of water index. The reason of this problem is the textural type of soil with respect to water retention and vegetation growth. Vegetation growth is strongly depends on rainfall, i.e. in dry lands, declining of vegetation is due to soil degradation. In humid areas, where vegetation is not as strongly depends on variations in rainfall, NDVI in itself is strongly correlated with vegetation growth and may become the cause of soil degradation.

4.6 Correlation Matrix between Soil Properties and Heavy Metal Concentration

Descriptive statistics performed using IBM SPSS (version-20) for correlation analysis presented in table 4.8 for the year 2019. Shows that there is significant correlation exists between physico-chemical properties. The high correlation co-efficient (near +1 or -1) means a good relation between two variables, and its concentration around zero means no relationship between them at a significant level of 0.05% level, it can be strongly correlated, if $r > 0.7$, whereas r values between 0.5 to 0.7 shows moderate correlation between two different parameters. It is depicted from the analysis that some sort of negative and positive correlation was observed. There is no significant correlation was found between some of the soil properties.



SUMMARY AND CONCLUSION

Land as natural asset encompasses all physical elements, best owed by nature, to a specific area or piece of property—the environment, fields, forests, minerals, climate, animals, and bodies or sources of water (**Grewal and Dogra, 2000**). It serves the socio-economic needs by providing various sources of their survival by its different physical, chemical and biological properties. Land degradation is a process of any change or disturbance of land by human induced deleterious or undesirable activity occurs due to decrease in qualitative and quantitative properties of soil of arable land (**Sharma et al., 2000**).

Land degradation may change the ecological balance and causes economical insecurity. Without use of technology the naturalistic nature of soil is deteriorated. Remote sensing in conjunction with ground truthing is emerge out as potential tool to study the kind, degree, extent and causative factors of soil degradation in spatial and temporal series of all regions of global study basis (**Anon, 2000, sited in Saini et al., 2000**). In Geographical Information System (GIS) the primary source of information is given by remote sensing data.

To assess the data of soil degradation and for mapping of an area interpretation of the satellite data should be an effective technique. Ground truthing with the help of physiographic information implementation of mapping could be more useful. Ground testing and feedback from users of the degradation assessment methodology is vital to the evaluation and improvement of the role of remote sensing in soil degradation evaluation (**Edige Nand Peterse G.W., 1997**).

Datasets produced from Landsat (TM/OLI) imageries at 30 m spatial resolution for the month of October over a period from 1994 to 2019 for the identification and mapping of degraded soil resources in the study area to mark decadal changes over a period of 26 years.

The procedure adopted for soil degradation and soil resource inventory consisted of selection and acquisition of data, pre-field visual interpretation, ground truth

verification and post field Interpretation, including laboratory analysis of soils and digital image processing. Landsat-8 (TM/OLI) geocoded cloud free False Colour Composite (FCC) data products (Path No 141-142); Row No 42; of date 15th 24th October) at 1:50,000 scales were used. Corresponding Survey of India (SOI) Top sheet at scale 1:50,000 were used as secondary data for delineation of area boundary, generation of information on elevation, slope, topography, ground truth verification and registration of images.

77 representative samples at 20 cm depth from 17 blocks with different land use and physiographic units of study area were collected as per guidelines laid out in the Soil Survey Manual (Soil Survey Staff, 1975). Soil samples were collected for detailed analysis of physical and chemical properties. ERDAS IMAGINE 9.2, Arc GIS 10.5 and ArcView software were used for image processing and generation of different thematic maps of the study area. The summary of the results of the investigations is given below.

It has been recorded that seven textural classes identified throughout the entire study area. Sandy loam was dominated over 45% area followed by sandy clay loam in 28% area. The textural classes in rest of the area ranged between sandy clay to loam sandy. Variation in soil texture is mainly associated with variation in CEC, amount of clay, silt, sand and lime concentrations.

Study area ranged from slightly acidic to strongly alkaline in terms of soil reaction (pH 6.9-8.6). Alkalinity in the study area is due to the calcareous nature of parent material. Soils in the study area have electrical conductivity (EC) ranging from 84.20 to 659.7 μSm^{-1} . Murlichhapra accounted for high pH and EC having strongly saline-alkali soil followed by Revati, Bariya and Belhari. However, Rasra block have lowest value for the same. This is related to poor drainage, high water table and water logging occurring in this area.

Organic carbon content varied from 0.16% to 1.74% i.e. low to very high. Organic carbon found higher mostly in northwest (Bansdih, Veruarwari and Pandah) of study area and low in southeast (Belhari and Maniyar) part so the organic matter. Poor organic carbon content of the study area could be due to low accumulation of organic

matter (0.27% to 2.99%) and because of prevailing climatic conditions of low rainfall and high temperature which is conducive for rapid decomposition of organic matter.

Exchangeable K^+ was observed to be the dominant (70% of study area) base followed by Na^+ (7% of study area) in all of the soil samples in the study area. Mean value of Na^+ ranging from 0 to 1569.17 Kg/ha and of K^+ ranging from 113.8 to 990.8 Kg/ha. Considering the criteria of <136, 136-337.5 and > 337.5 K_2O Kg/ha as low, medium and high respectively (Baruah and Barthakur, 1999), all the blocks in the study area in general could be grouped into high in available K except Nagra, Rasra and Pandah block which could be grouped into low in available K. further, 70% of study area mainly in southeast part grouped into high Na^+ concentration and northwest part 30% grouped into low Na^+ concentration.

CO_3^{2-} and HCO_3^- were the prevalent dominant anion in the study area on which basis whole area categorized into two broad classes of salinity: average salinized (30%) and strongly salinized (70%). HCO_3^- found maximum in Nagra, while CO_3^{2-} in Siar followed by Rasra. Both the anion found maximum in northwest block and some block in southeast of study area.

Landsat data were used for Image interpretation to compute different indices relevant for soil degradation assessment such as NDVI, NDWI, NDSI (soil), NDSI, and SI for a period of 26 years from 1994 to 2019. The mean value of NDVI, and NDWI decreased down from 1994 to 2019 for each block, however it was highest in northwest (Nagra, Rasra and Pandah) and low in southeast (Murlichhapra, Bariya and Belhari). Low water and vegetation index is highly correlated with decreasing trend of rainfall for above said period. Moreover, NDSI (soil), NDSI and Si showed increasing trend from 1994 to 2019 for each block, however it was highest in southeast (Murlichhapra, Bariya and Belhari) and low in northwest (Nagra, Rasra and Pandah). This might be associated with high salt content lower the vegetation growth and approaching more barren land fraction as indicated by linear spectral unmixing (LSU) for decadal period from 1994-2004 to 2019.

An attempt was made to carry out visual as well as digital image processing to extract required information about various land degradation types.

Soil degradation in the study area was assessed for its types, degree, extent, rate and causative factors. The dominant one was observed to be chemical followed by physical deterioration from northwest (60%) to southeast (33%) respectively. The causative factors of land degradation in the study area were found to be both natural and human induced. Subsequently, the rate of degradation was found to be slowly increasing (-1).

Using Geographical Information System (GIS) a number of interpolation maps or single theme map such as pH, EC, OC, OM, HCO_3^- , CO_3^{2-} , soil-Na and Available K, soil texture, along with different indices such as NDVI, NDSI (soil), NDSI and NDWI were prepared by reclassification of the basic soil map using appropriate attribute data sets. The thematic maps generated in the GIS environment provides the spatial distribution pattern of several physical and physico-chemical properties which will be highly useful for Farmers, researchers and planners in the study area as a soil information database for future studies.

From the present study, the following conclusions can be drawn:

- Remote sensing and Geographical Information System (GIS) techniques were found to be valuable tools in collaboration with ground truthing for studying and mapping of soil resources and degradation assessment.
- Laboratory analysis made it possible to verify the result obtained from processing of satellite images to approve its validation by Kriging interpolation tool. Digital Image Processing techniques are much better than visual interpretation in delineation of types, degree and extent of soil degradation. Many a time's two or more different objects appear alike in tone leading to wrong inference.
- Sandy loam and Sandy clay loam were found to be the dominant among the seven textural classes observed. Dominated Sandy fraction leads to lowered WHC and poor retention of nutrients from agriculture point of view. All the soils have medium to low organic carbon and medium to high K; low to high Na; mild to strong in soil reaction; slight to strong in soil salinity; strong in alkalinity; slight to strong carbonate content.

- Vegetation (NDVI) and water index (NDWI) decreased as Salinity (NDSI and SI) increased so on the NDSI (soil) from 1994 to 2019 highly associated with rainfall's down trend and ultimately lowered crop yield and deteriorated soil. Ground testing best fit to stand in explaining the soil degradation and results are in accordance with indices opted from Landsat data.
- Alkalinity has been found in majority of area however some sort of salinity was also noticed in southeast region mainly in Murlichhapra, Belhari and Bariya. Degraded soils were found to be the least suitable for growing crops while the block Pandah and Bansdih were found to be the best suitable followed by Siar's block soil.
- Major soil degradation was found in the study area i.e. chemical deterioration (alkalinity, salinity), physical deterioration (water logging) and physical drought. The dominant degradation type was found to be alkalinity, salinity followed by physical drought and water-logging.
- Remarkable changes were noticed in entire region of Ballia from 1994 to 2019 due to the influence of intensive agriculture, intermittent drought and fluctuating rainfall accounted massive degradation to soil quality. The most degraded soil was found to be of southeast part mainly Murlichhapra, Belhari and Bariya followed by moderate degraded soil of Revati and Hanumanganj. While, the soil of Nagra, Rasra and Siar block found prone to degradation due to above said causes.



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