ASSESSMENT OF SOIL SALINITY USING GEOSPATIALTECHNIQUES AND GROUND DATA IN CENTRAL PUNJAB, PAKISTAN

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A thesis submitted to Bahria University, Islamabad, in partial fulfillment of the requirement for the degree in B.S. in environmental sciences.

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ABSTRACT

Soil salinity is among the cruelest and vicious environmental factor, affecting yield of most of the salinity sensitive crops due to excessive concentration of salts in the soil. Throughout the globe more than 100 countries are facing salinity problems and no continent is totally free of it. Hence it is important to devise a method for assessing and mapping soil salinity that are both rational and reliable. The current study was conducted on Shorkot and Toba Tek Singh tehsil of Central Punjab. Laboratory analysis data was acquired for 32 different soil samples from the study area and a relationship was developed between ground data and satellite data. Laboratory analysis for Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR) were performed for the selected samples. Landsat satellite (i.e., Landsat 4-5 and Landsat 8 OLI) imageries were used for indices development. Based on the ground data set (EC & SAR) and indices of 2020, the EC and SAR values for the past years (1996-2020) were calculated and classified into different classes. Inverse Distance Weighed (IDW) technique was used for mapping and soil classification was performed based on the ranges set earlier. The results after mapping confirm a major rise in salinity which disclose that the maximum EC and SAR values, in 1996 and 2020 were 4.94 dS/m and 10.01 mmol, and 8.23 dS/m and 59.73 mmol respectively. The minimum values of EC and SAR in 1996 were 3.44 dS/m and 7.16 mmol respectively, while oppositely in 2021 the minimum values analyzed were 5.28 dS/m and 11.11 mmol. On the other hand, the mean values of EC and SAR during 1996 were 4.74 dS/m and 23.24 mmol. A rapid increase in salinity level was observed during 2020 as the mean value of EC and SAR were 6.58 dS/m and 27.22 mmol. Overall, the percentage change in the mean value of EC and SAR were 38.8% and 17.2% respectively.

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ABBREVIATIONS

bcm	Billion cubic meters
dS/m	Deci siemens per meter
EC	Electrical Conductivity
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GDP	Gross Domestic Product
IDW	Inverse distance weighed
IJWRAE	International Journal of Water Resources & Arid Environments
IRD	Indus River Delta
ISIB	Indus Basin Irrigation System
MLR	Multiple Linear Regression
mmol	millimole
Mha	Million hectares
RBOD	Right Bank Out-fall Rain
RS	Remote Sensing
SAR	Sodium Adsorption Ratio
SOM	Soil Organic Matter
TDS	Total Dissolve Solids
USGS	United States Geological Survey
WAPDA	Water and Power Development Authority

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CHAPTER 1

INTRODUCTION

1.1 Background

Soil is a vital part of the environment. Our nation's agro-ecosystem is based on soil. It supports human life as it provides us feed, fuel, and food through the cycling of nutrients. Soil holds most of the nutrients, water, and support plants. It is home to many micro-organisms which help in the production of humus which is the foundation for soil fertility, as well as the worldwide agriculture and forestry sectors.

Soil is formed by the process of natural erosion and weathering. It consists of mostly organic matter but the exact healthy amount of organic matter present in the soil is 1.29% whereas in Pakistan the organic matter in soil falls within a range from 0.52 to 1.38% and most soils falls lower than 1% in organic matter. Pakistan's soils are categorized as pedocals, a dry soil category with high calcium carbonate concentrations and low organic matter content that is the characteristic of land with limited and unpredictable precipitation. Indus basin soil, mountain soil, and sandy desert soil are the three principal soil types (Syed and Shah, 2020).

About more than 100 countries are facing salinity problems and no continent is free of it. Pakistan is one of those countries that are facing salinity problems.

As soils of Pakistan are termed as pedocal, the major soil issues faced are waterlogging and salinity. These are the twin evils of irrigated agriculture in semi-arid and arid areas which reduces the yield of agricultural lands undesirably. Sindh and Southern Punjab have a worsening situation than the rest of the country (Chaudary, 2003). The state is deteriorating faster than the rest of the country especially in Sindh and Southern Punjab. Dealing and managing soil salinity is a long-term process that takes a lot of time and where an asset of sustainability is utterly required for irrigated land to minimize the environmental impact.

In Irrigated lands salinization is a universal issue, a huge quantity of water for irrigation is used and on the other side is poorly drained. A report by Food and Agriculture Organization FAO (1990); about 60 to 80 Mha (million hectares) are affected to a certain degree and around 20 to 30 Mha are affected harshly by salinity worldwide. Figure 1.1 (Shahid, 2018) shows a world map indicating salinity problems in different countries

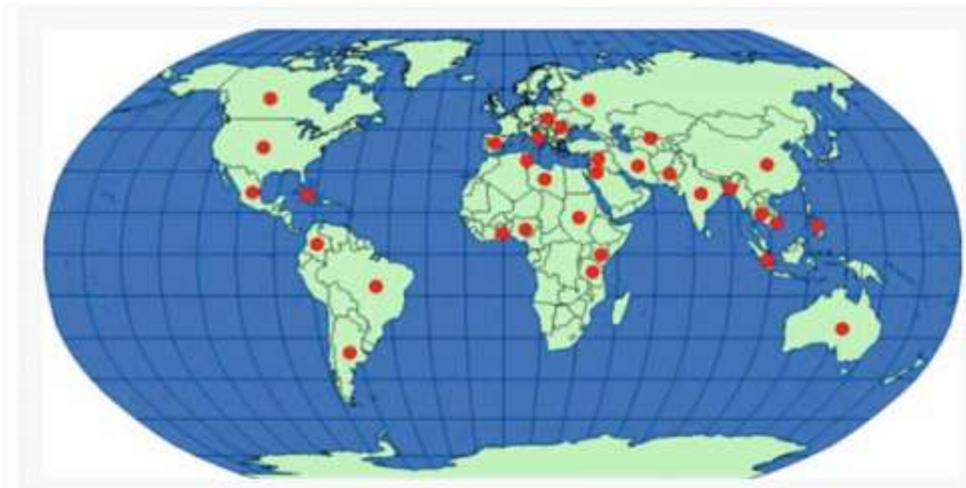

Figure 1.1 World map showing countries with salinity problems (Shahid , 2018)

Soil salinization is spreading at a rate of 2 Mha per year on a global scale, which offsets a large portion of the crop production that could be achieved by employing best management practices and expanding irrigation at the system level. Pakistan's agricultural land is affected by salinity for about 21% (Qureshi and Perry, 2021). In recent years due to the prevalence of soil salinity, many farmers have been forsaking their rice fields. Engineering controls, biological measurements, and agronomics are taken into practice to remove the stress on the environment and food security (FAO, 2011). Water-saving technologies are being developed, and high-water-use-efficiency plants are being developed. Leaching and drainage cause soil salinity and it is a very expensive long-term solution to eliminate drainage and leaching problems, attempts have been undertaken to learn to live with salinity and make economic use of saline land and water resources.

1.2 Facts Regarding Soil Salinity by FAO

The excessive build-up of soluble salts in the root zone of soil is called salinity and the soil affected by it is called salt-affected soil. More than 100 countries are suffering from the condition of salt-affected soil and their worldwide scale is approximately equal to 1 billion ha. Sodium chloride, sodium sulphate, some neutral and soluble salts are the main components of saline soil. The major role of these salts is to reduce or decline water availability, increase osmotic pressure and slow down plant growth to a dangerous extent. Overall sodic soils have a low salt percentage but they do have a high content of ESP, which may result in the corrosion of the structure of soil and is a source of clay particles dispersion. These soils have a pH of 8.5 and above, they have low air and water permeability.

In 2006, the world's irrigated land was 301 million hectares. Irrigated agriculture currently accounts for roughly a 1/5th of all arable land in developing nations, but it produces over ½ of all crop production and 60% of grain production. Around 70% of the world's irrigated land is in Asia, which also accounts for 39% of the world's agricultural land (FAO, 2015).

Even with very little information on it, salinity is regarded as a universal problem faced timely throughout the world. In many regions, soil salinity is increasing rapidly both in non-irrigated and irrigated regions. FAO has reported some human-induced and natural sources of salt:

- Poor on-farm management of water resources and land
- Poor drainage systems
- Use of brackish groundwater for irrigation
- Replacement of deep-rooted perennial vegetation
- Weathering of rock
- Accession of salt in marine sediments and sea water
- Atmospheric deposition

According to FAO annual report (2015) some of the major responses that can sustain soil salinity threat are:

- Leaching of salts, directly
- Plantation of Salt tolerating plant
- In the agro-pastoral system domesticate native wild halophytes can be used.

- Bioremediation (phytoremediation)
- Use of organic content
- Chemical amendments

1.3 Causes and Types of Salinity

Pakistan's Indus Basin Irrigation System (ISIB) is spread over an area of 16Mha. IBIS is a source of distribution of river water of 172 billion cubic meters (BCM) per year. Groundwater levels are increased due to introduction by IBIS at the rate of 15-75 cm/year. The progression of evapotranspiration accumulates salts and as a consequence causes salinization of water and soil (Aslam and Prathapar, 2006). Over 30% of the saline groundwater of the Indus Basin is majorly employed by Punjab and Sindh. Fresh groundwater in amounts of very nearly 200 BCM has been collected in saline groundwater spaces of the Indus Basin. In these saline groundwater regions, more than 20 billion cubic meters of new groundwater is being refreshed every year (Qureshi,2004). Water getting distracted from the Indus River reaches canal system for irrigation carrying 33 million tons of salts along with it, whereas only 16.4 million tons of salts are destined to release into the sea. It is assessed that yearly overall, the salt put away in the Indus Basin is about 16.6 million tons. Once irrigation is done, the water is utilized by the crops or vanishes straightforwardly in the air leaving behind the salts. In a word, around 1 ton/ha of salts is added to flooded land. Subsequently, in the Indus Basin, saline soils have become the principle natural issue (Qureshi, 2011).

A review by Ahmed and Qamar, (2004) states that following are the areas where salt-affected soils exit in:

- Semi-arid and sub-humid Indus fields including every one of the four regions.
- Coastal and deltaic districts in the territories of Sindh and Balochistan
- Irrigated semi-arid and arid districts in Punjab, Sindh, Balochistan, and KPK (Khyber Pakhtunkhwa). A portion of these regions are flooded by low-quality ground water.

The primary driver of the spread of water-logging and salinity in Pakistan are, the arid environment, level geology, helpless water-the board rehearses, deficient arrangement of waste, lacking water system supplies for draining of salts, not confining water system supplies during times of no interest, insufficient utilization of substantial alterations to recover sodic and saline soils and utilization of low-quality water system water without legitimate administration rehearses. There are two major types of processes that lead towards soil salinity (Ahmed and Qamar, 2004).

1.3.1. Primary salinity

Primary salinity is the natural salinity which is a consequence of salt accumulation for extensive periods in groundwater and soil, caused generally by following natural routes.

- **Weathering**

Weathering of parent materials containing dissolvable salts discharge dissolvable salts of different kinds, principally chlorides of sodium, calcium, and magnesium, and less significantly, sulfates and carbonates of which Sodium chloride is the most dissolvable salt (Munns, 2009).

- **High water table**

Sub-soil water in the Indus basin has ascended close enough to the regular surface level to make the dampness ascent by capillary activity. The blistering sun vaporizes this dampness, leaving the salts in the soil profile, just as on the top hull. The extent of saltiness relies on the kind of soil structure, which works with capillary activity from the groundwater (Ahmed and Qamar, 2004).

- **High temperatures**

Hot dry temperatures cause more prominent vaporization and, since yearly precipitation is considerably less than yearly vaporization, the filtering activity by precipitation is ostensible. To recover the salt balance, normal precipitation needs to be increased with a water irrigation system. If the amount of irrigation water stream is equivalent to evapotranspiration, at that point the surface and profile saltiness gets washed down underneath the root zone, given sufficient seepage is accessible (Ahmed and Qamar, 2004).

- **Oceanic salt deposition**

Oceanic salts are 'Cyclic salts' conveyed inland by wind and deposited by precipitation, furthermore, are mostly sodium chloride. Water contains from 6 to 50 mg/kg of salt, the grouping of salts diminishing with distance from the coast. On the off chance that the fixation is 10 mg/kg, this would add 10 kg/ha of salt for every 100 mm of precipitation each year. Aggregation of this salt in the soil is extensive over centuries (Munns, 2009).

1.3.2. Secondary salinity

Secondary salinity in contrast to primary salinity is caused due to human actions. Several most frequently occurring reasons are:

- **Poor drainage system**

In many irrigated regions, the water table has ascended because of unreasonable measures of applied water coupled with helpless drainage. Irrigation water enhances apparent measures of salt, even with great quality irrigation system water containing just 200–500 mg/kg of dissolvable salt. Irrigation water with a salt substance of 500 mg/kg (for example 500 mg/l) contains 0.5 t of salt per 1,000 m^3. Since crops require 6,000–10,000 m3 of water per hectare every year, one hectare of land will get 3–5 t of salt. Since the measure of salt eradicated by crops is irrelevant, salt will amass in the root zone and should be drained by providing more water than is needed by the crops. On the off chance that seepage isn't satisfactory; the abundance of water causes the water table to rise, assembling salts that amass in the root zone (Munns, 2009).

- **Inadequate irrigation supplies**

Because of the deficiency of water system water supplies, ranchers resort to thin watering of the fields, prompting deficient filtering, and, subsequently, the salts are not washed down beneath the root zone. The necessity of this boundary is that the water system supply ought to surpass the evapotranspiration, particularly during the hot dry time frame (Ahmed and Qamar, 2004).

- **Improper slope**

Except if the sub-soil water is beneath the root zone, the filtering water won't convey the salts beneath the root zone. In the Indus basin, the land is by and large level, the normal slant being 1:5000. Productive regular seepage is an issue. Counterfeit waste can be as costly as the level of trouble in removing and gathering the saline profluent and arranging it through a gravitational or siphoned drainage system (Ahmed and Qamar, 2004).

- **Over irrigation**

The overabundance of water from rainfall and over-irrigation raises water tables and assembles salts recently put away in the dirt and brings them up to the root zone. Plants utilize the water and abandon the salt until the ground water turns out to be excessively pungent for additional water take-up by roots. The water table proceeds to rise, and when it approaches the surface, the water vanishes and leaves salts behind on a superficial level, framing a salt burn. The assembled salt can likewise move underneath the soil, and into water courses (Siyal, 2002)

The agriculture area of Pakistan is enormously dependent on the Indus Basin Irrigation System for its GDP job in the country. Indus Basin Irrigation System is one of the principal explanations behind saltiness because of the ineffectual drainage framework (Qureshi and Perry, 2021). Water accessibility per section of land is diminishing because of the diminished stockpiling limit of dams. Consequently, for the need of inundating crops, the agriculturalists are fixing an enormous number of tube wells. This is additionally the justification saltiness. Saltiness is on the top in many spaces of Punjab and Sindh (Ali, 2010).

Farid, (2018) stated in their review article that In Pakistan, tube-wells have expanded over 900,000. It is assessed that in Pakistan, around 61 billion cubic meters of groundwater have been driven yearly. As per a gauge, over 70% of salty groundwater is siphoned by tube-wells in the flooded farming of Pakistan which are actuating anthropogenic salinization issues. Farmers need to utilize minimal to salty in quality groundwater due to the lack of trench water supplies which may bring about sodification (because of sodium salts) and additionally optional salinization (because of dissolvable salts) (Qureshi and Perry, 2021)

1.4 Classification and Characteristics of Salt-Affected Soils

Salt-affected soils based on their sodicity, and salinity can be broadly categorized into three categories: saline soils, sodic soils, saline-sodic soils.

1.4.1 Saline soils

In saline or 'white alkali ' soils, the convergence of salts has expanded to the level at which crop development is unfavorably influenced. The surfaces of these soils have a white outside layer of salts from October to March. Be that as it may, the arrangement of the soil isn't unfavorably influenced. The soil's remaining parts penetrable and has great seepage attributes. In these soils, the electrical conductivities of the immersion separate (EC) are more noteworthy than 4 ds/m, the pH, for the most part, goes somewhere in the range of 7.5 and 8.5, and the sodium adsorption proportions are under 13 (Qureshi, 1998).

1.4.2 Sodic soils

Sodic or 'dark alkali' soils have high replaceable sodium fixations, which disintegrate the natural matter present in the soil and give it a dim earthy colored or dark tone (Siyal, 2002). In these soils, soil structure has decayed, porousness has diminished, and root development is confined. The recovery of this sort of soil is relatively troublesome. These soils have EC esteems under 4 dS/m, pH esteems more prominent than 8.5, and sodium adsorption proportions more noteworthy than 13 (Qureshi, 1998).

1.4.3 Saline-sodic soils

Most salt-influenced soils in Pakistan are saline-sodic in nature; they along these lines have the qualities of both saline and sodic soils. The investigation of such soils shows that EC esteems are more noteworthy than 4 dS/m, pH esteems are generally under 8.5 and sodium adsorption proportions are more prominent than 13. At first, these soils have great porousness. Nonetheless, their arrangement falls apart and their water-powered conductivity is decreased on the off chance that they are recovered (drained) without alterations like gypsum (Qureshi, 1998).

1.5 Effects of Salt-Affected Soils

1.5.1 Low production and socio-economic impact

Soil saltiness seriously influences the horticultural usefulness since high salt fixations are harmful to plant development (Manzoor, 2019). Over 100 Mha of agrarian land is delivered uncultivable because of salt and supplement pressure (Athar and Ashraf, 2009). It is assessed that as of now, saltiness has influenced about 20% of the flooded grounds on the planet (Shahzad, 2017). The most significant impacts are mentioned below (Shahid, 2013) :

- Farm waivers are diminishing the number of farmers and causing financial misfortunes.
- Because of low reaction to contributions, there is little production which at last prompts financial misfortunes.
- Scattering of soil requires more modifications.
- Noteworthy expenditure for the land reclamation purpose
- Monetary weight on farmer
- Farmer’s movement to metropolitan regions

1.5.2 Environmental impacts

The issues from this are most noteworthy in drier conditions, where paces of dissipation are normally exceptionally high. Salts are less inclined to be drained from the soil in low precipitation regions and in this manner low-quality irrigation water with undeniable degrees of salts will greatly affect the dirt. Exorbitant measures of water applied by irrigation may move past the root zone and add to rising water tables. Spillage from water system channels may likewise add to rising water tables. Sodic water system water contains a significant degree of sodium salts contrasted with calcium and magnesium salts. It might bring about soil scattering, resulting in soil surface fixing, crusting, disintegration, helpless water section, and helpless seedbeds (Queenslanders, 2015).

1.5.3 Effect on nutrient availability

Niste, (2014) Describes salt-influenced soil seriously influences the accessibility of plant supplements. The fundamental purposes behind consumption in the fruitfulness of such soils are:

- Undeniable levels of specific particles like sodium, carbonates, and bicarbonate overpower the availability of different particles like calcium, phosphorous, potassium, zinc, manganese, iron, and boron.
- The general accessibility of phosphorus and micronutrients are diminished because of an increment in soil pH (particularly in sodic soils)
- Microbiological movement is shortened generally.
- During the recovery interaction, draining of salts is additionally joined by filtering of supplements.
- Diminished water take-up by the plants in salt-influenced soils eventually prompts diminished supplement take-up because of physiological inaccessibility of the water

1.5.4 Effect on plant growth

Plant development can be straightforwardly influenced in the sodic soils because of the great alkalinity and harmfulness of sodium carbonate, bicarbonate, and different anions. This at last makes harms plant nourishment and digestion. Sodium adsorbed to just 15% or a greater extent a soil earth adsorption locale can confine the root development and, in this way, make culturing rehearses much tricky. There are a few adverse consequences of high saltiness and high EC of soil that causes lack of hydration of plant cell, decrease in plant development and maybe demise in less open-minded plants (Shahzad , 2017). Saline soils have unsafe impacts that relate to the diminished osmotic capability of soil arrangement bringing about healthful irregular characteristics, explicit particle harmfulness, physiological dry spell, or the gathering of every one of these variables. Carbon obsession can be restrained by the salt pressure since high salt focus may result in the conclusion of stomata which at last decreases the carbon dioxide accessibility in the leaves (Aslam, 2011). Saltiness can oblige waterlogging as it is regularly brought about by an ascent in water tables. Waterlogging itself decreases the root's capacity to eliminate salts and builds the pace of salts take-up. It collects the salts in shoots in this manner meddling with plant/crop development (Munns, 2009). Some particular side effects of salt-influenced soils are restricted root development, hindered blooming, peripheral, or leaf tip cooking/consumption, diminished power, and low harvest yield (Sonon, 1980)

1.5.5 Effect on plant yield

In salt-influenced soils, high salt focus influences the prolongation cycle of new cells of a plant because the overabundance of salts collects in the plant parts prompting the decrease in the cell divider versatility. Extreme salts in the dirt decrease advancement of tissues just as therapists the cell substance. Every one of these variables brings about a decrease in harvest yield (Aslam , 2011).

1.5.6 Effect of sodium on soil properties

Abundance sodium (Na^+) collection in soil influences the interchangeable and soil arrangement particles, soil pH, decay of soil water-powered properties, and disturbance of soil structure. Consequently, soils become more vulnerable to crusting, air circulation, spillover, and disintegration (Qadir and Schubert, 2002).

1.6 Soil Salinity Interrogation using Geographical Information System (GIS) and Remote Sensing (RS)

Remote sensing technique for soil salinity monitoring, identification, quantification, and mapping has reportedly been utilized when aerial photographs in black-white color in the 1960s were acquired to extract information regarding soil salinity. Along with aerial photographs, RS also embraces the utilization of thermal infrared or multispectral data as well. The technique of Remote Sensing involves the capturing of reflected electromagnetic energy from the surface of the earth, originally from sunrays via multiple satellites such as Landsat 4-5, 7, 8 satellite and sensors such as hyper-spectral sensors in space to receive information and different levels of details for various objects on earth's surface (Azabdaftari, 2016).

Both the RS and GIS can effectively map soil salinity on either larger scale areas or minor ones thus aiding with new opportunities for evaluation in agricultural dominant regions. They predict the sites exposed to or under salinity by merging information on areas and other relevant factors. All the data achieved and expressed in terms of their geographical location are stored electronically, immediately examined, retrieved, and presented on the computer-based application of GIS and Map is the most known form of spatial data (Azabdaftari, 2016).

Ijaz and Ahmad, (2020) defines RS imagery technique as the best option to widely study soil salinity all over the world as it constructively maps the surface countenance of salt-effected soils by taking vegetation cover, health, groundwater level, and visible salt crusts into consideration intended to indicate soil salinization risks and trends followed in the selected area. Various Indices specific to different factors are availed in this technique to detect soil salinity and green vegetation cover of cropped sectors. NDSI (Normalized Difference Salinity Index) is one of the salinity indices which directly monitor soil salinity by capturing prominent salt crust patches on the surface of mostly higher elevation areas where salts are left behind as residue after high evapotranspiration. BI (Brightness Index) is also embodied in tracing soil salinity and keeping track of cropped area by detecting brightness. Higher brightness would indicate the greater levels of leaf moisture under soil salinity thus overall indicating the exacerbated magnitude of salinity on the soil. Similarly, NDVI (Normalized Differential Vegetation Index) is a vegetation index that indirectly tracks soil salinity by monitoring green cover health status and the presence of halophytic plants adapted to grow in the salty environment.

Remote sensing with its advantage of giving updated information for the large extended area over past decades on salt-effected soils directly also provides other benefits by recording information on rainfall pattern, types of vegetation, their yield, extension, and evapotranspiration parameters as well in the field of soil salinity mapping. Besides these advantages the technique also has few limitations such as the sensor functions only to highlight surface salinity of the soil, subsurface salinity cannot be determined by inexpensive optical RS data which makes the use of RS necessary with other methodologies. The most adopted technique to be used in parallel with RS is a field survey for soil sampling. The results from both are correlated to forecast their relation and how efficient one was in monitoring salinity (Asfawa, 2016).

1.7 Existential Situation of Soil Salinity in Pakistan and its Provinces

Pakistan, one of the third world nations is residing at 30.3753° N, 69.3451° E occupying approximately 881,913 km^2 of earth's surface with three distinct geographical distributions, mainly named as Baluchistan Plateau, Highland Northern region, and Indus River plain. Pakistan exists on coordinates lying amid arid and semi-arid climatic zones, therefore; the latter constantly suffers from the repercussion of massive evapotranspiration exceeding the average precipitation of 100mm-700mm thus leading to accumulation of salts on soil's surface. The country with the above-mentioned climate relies heavily on an irrigation system and so is Pakistan. A very well maintained 62,400 km long canal system runs along 19.43 million hectares of Indus River plain to irrigate 16 Mha of soil allocated to practice farming while permitting the country to contribute and support 21% GDP via nourished agricultural precinct. So, in consequence of intensive irrigation, the average temperature of 40°C during the summer season, lack of rainfall accompanying unacceptable shallow groundwater levels the salts gather on the land surface, therefore, disturbing soil health and fertility, particularly in Indus River plain (Ishfaq, 2017).

Out of 6.30 Mha of salinity intruded soil in Pakistan (Hussain and Zahir, 2010) 1.89 hectares of soil is Saline in nature, permeable saline-sodic have ruptured 1.85 Mha, non-porous saline-sodic has made 1.02 Mha of soil unproductive whereas 0.28 million hectares of land has become terrifyingly sodic in temperament. 0.45 Mha in the province of Punjab, 2.5 Mha in Sindh and 0.5 Mha in KPK up till now are greatly attacked by the problem of soil salinity intrusion in Pakistan (Ennaji, 2018).

Pakistan's irrigated agriculture specifically while the soil, in general, is under constant threat to soil salinity for the past few decades. Despite climatic factors, inefficient drainage and inappropriate irrigation practices have also led to the vast difference in salt quantity entering and exiting the soils in the country. 120 million tons of salt makes its way into canal water and groundwater annually (Alam, 2000).

1.7.1 Condition of soil salinity in Punjab

Rehman, (2010) directed a study on soil fertility and salinity in the Attock district of Punjab, by collecting 20711 soil samples from all subordinate regions of the latter to enhance crop production in the area by guiding relevant fertilizers to farmers based on soil elements analyzed and climatic factors. Soil sampling was performed to classify and testify pH of the soil, soil texture, SOM (soil organic matter content), EC (Electrical Conductivity) also taken as dissolved salts and phosphorus available for crop utilization. 21.15 % soil was found to be sandy loam in Attock while the remaining 78.7% of the soil was loam in texture followed by 99.60% soil samples were examined to be non-saline with EC of (< 4dS/m) and pH ranging (7.5-8.5) measured to lie within the permissible limits for 94.62% soil samples gathered. Not only the loamy nature but high gradient topography and intense rainfall in the district also prohibit the accumulation of salts.

Akram, (2014) conducted study on soil salinity and health condition via collecting 3325 samples of soil in total from all precincts of the district of Muzaffargarh, Punjab to assess the reasons behind lower crop yield in the area. The latter is regarded as a productive source for agricultural benefits due to its significant location between River Chenab and Indus. 112.7 and 1.17 thousand hectares of district land were previously declared to be charged by massive salt intrusion and water logging. Soil samples were examined in the laboratory for pH, EC, SAR (Sodium adsorption ratio), and SOM. 75% of soil samples presented acceptable pH ranges betwixt 8.5-9, 95% soil samples were analyzed to be salinity free with EC less than 4 dS/m, and 74% soil samples constituted trifling sodicity with SAR < 15 by collaborating with available criteria of parameters.

Another study conducted on the extent of natural and human-associated causes of desertification in dry areas of Southern Punjab i.e., Rajanpur, Rahim Yar Khan, and Bahawalpur. According to a response received through 399 attempted questionnaires indicated that soil salinity is increasingly triggering and driving desertification in Rahim Yar Khan (Mazhar and Shirazi, 2020).

1.7.2 Condition of soil salinity in Sindh

Solangi, (2019) took the focus to conduct research, review, spatially evaluate, and analyze the status of soil salinity in Indus River Delta (IRD) geographically coordinated at the south of Sindh. The latter like other coastal zones also remains a victim of one of the most attention-gaining muddles of soil Salinization. Saline water penetration into the IRD soil from the Arabian Sea in consequence of the diminished flow of freshwater on 15 of its creeks, reduce rainfall and human performances have drastically degraded most of the agricultural lands in the region. 375 geo-referenced soil samples to a depth of 60 cm were gathered through random sampling technique from 125 different points all over the IRD and physio-chemically examined for EC, dry density, soil texture, pH, and ESP (exchangeable sodium percentage)/sodium concentration. Portable equipment known as Garmin GPS was utilized to record the exact location of points of sample collection. From 0cm-60cm the outcome for particularly EC and ESP values were tested to be exceeding the permissible standards set by FAO. For 57-66% soil samples EC accelerated the threshold limit of 4 dS/m, ESP value was greater than 15 for 73-79% soil samples and pH exacerbated the safe 8.5 limit value.

The spatial distribution of salinity impacted soil was determined through salinity maps. Interpolated maps were formulated by incorporating the analysis results of soil texture, EC, pH, and ESP into ArcGIS 10.5 software which overall indicated that 50% and additional soil of IRD was chemically and physically modified by salinity (Casadei and Albert, 2015).

Hussain, (2017) has deliberately made efforts to study and enable understanding of the degree of soil salinization during prevailing months of pre-monsoon and post-monsoon in Shah Bandar Tehsil of Thatta region, Sindh with an arid climate. One-third of the fertile soil of the latter was determined to have lost its productivity and deteriorated health by salt accumulation due to frequent flooding and seawater penetration. The tehsil constitutes intensely saline groundwater where some of its lands have also been negatively impacted by water logging as well. About 48 soil samples were collected at a depth of 0-24cm to analyze them for EC, texture, ESP, SAR, and pH. The physiochemical and spatial analysis of area terminated the Pre-monsoon season favors high salinity and sodicity due to both arid conditions and reduced canal irrigation supply of water. On the other hand, Post monsoon encourages minimized salinization as not only salts leach into the soil, but the content gets diluted too.

1.7.3 Condition of soil salinity in Khyber Pakhtunkhwa

Soil salinity status in the province of KPK is not very well studied and defined in Pakistan and the province seems not to face the muddle to the extent to serve as a threat to the latter as salinity arises more due to lack of management skills, dependency on canal systems and irregular rainfall patterns. KPK Irrigated Agriculture Improvement Project has been launched in KPK intended to aid highly efficient irrigation water supply which further will reduce the chances of emergence of salinization in the province (Imam, 2017)

1.7.4 Condition of soil salinity in Balochistan

Chandio, (2017) conducted a study to acquire details about the soil salinity status in regions of Baluchistan where Right Bank Out-Fall Drain-III and few others such as Miro Khan Drain joins and drain water. The major reason behind the excessive salinization was the absence of an irrigation system in Baluchistan so hopelessly water for irrigation was extracted from RBOD which is recognized as a reservoir of the array of salts. Soil samples were collected and analyzed for measuring EC, pH, and Total Dissolved Solids (TDS), and the results stipulated the soil of area under study has been harshly modified for the last 20 years.

1.8 Soil Salinity Management in Pakistan

Shrivastava and Kumar, (2015) have reported that due to salinity about 40000 hectares of agricultural soil ran out of cultivation every year in the early sixties because of this emerging problem. Many soil salinity surveys have been carried out for the past 4 decades by various agencies to obtain knowledge about the extent of salinity. The very first survey was conducted by the Colombo plan in 1953-54. The second was done in 1977-79 by the master planning and review division, WAPDA covering about 16.711mha of land. The most recent survey was held by SMO, WAPDA covering an area of about 16.797mha during 2001-2003. The data obtained from various surveys at the Pakistan level shows the status of the Indus basin like in 1977-79 the salt-free lands has raised from 56% to 72% while 73% in 2001-2003 although in Baluchistan and Sindh the patterns of salinity were different i.e., the salinity was more in 2001-2003 than in 1977-79.

The repetitive use of agricultural lands in irrigated areas leads to salinization in soil due to repeated water cycle reuse. This accretion of salts becomes dangerous for plant growth as well as for soil so different methods are used for managing these salts. The 3 main methods for the removal of salts are as following (Qureshi and Lennard, 1998):

- Reclamation of saline salts
- Development of cultural practices beneficial for plant growth under saline condition
- Selection of salt-tolerant plants

1.8.1 Engineering control

Reversing salinity in the irrigated area using a drainage scheme is an engineering approach. Through salinity control and reclamation project about 7.8mha have been treated so far. Many measures are taken to control this evil problem and the approaches have been very helpful but still, some of the salt-affected lands are not treatable and the sustainability to tackle this evil is questionable. A report by the International Conference on irrigation and drainage despite all drainage techniques soil salinity was not properly treated and controlled during the project. This dilemma was due to a lack of funds for running and maintenance of the project (INACID, 2017).

1.8.2 Reclamation approach

The small-scale interventions to improve soil conditions are the basis of the reclamation approach. This approach is suitable where soils are saline because of low rates of water infiltration and their high sodicity (lack of soluble calcium). Other reclamation approaches include the use of chemical amendments, leaching of salts, directly and use of organic content to enhance the soil condition (Shah et al., 2011).

1.8.3 Bio-saline approach

In the bio-saline approach, useful products can be attained from salt-affected wasteland but without reclamation. The major aim is economic utilization of the land while in saline and sodic condition. There will be a high level of benefits and improvements in soil conditions. Pakistan has been using this approach that is why it is not too old. It involves the re-vegetation of salt-tolerant plants, grasses, trees, shrubs, and saltbush that will increase food and fibre for the increasing population. The salt-tolerant grasses will help to improve the grazing practices likewise trees and saltbushes will help to fulfil the local needs for forage and fuel wood in Pakistan. The use of these approaches will improve soil stability (Shah et al., 2011).

1.9 Literature Review

Numerous but not enough case studies have been narrated by various authors after tremendous research on Soil Salinization covering various areas of third world nation, Pakistan to improve not only knowledge among the related professionals but how to combat the muddle and create awareness as well. Their overall research intended to particularly aid upgraded information to policy makers, land-use and managers, the awakening of associated authorities for monitoring activities, and for government employees to develop, employ and implement strategies and measures to mitigate and control soil salinity in the country as well as to sustain agricultural fertility.

Research studies were conducted to justify that problem of soil salinization has originated more due to increasing industrialization, urbanization, deforestation to fulfill the rising demands of the growing population which has surprisingly impacted the crop production intensity, loss of soil structure and environmental health, inhibited plant growth, degraded water quality, diminished arable land and economic instability (Gholizadeh et al., 2018; Zhu, 2001).

Lal, (2018) conducted research in Pakistan stating the country has to face extended and drastic circumstances as compared to developed countries vulnerable to the same salinity problems with similar severity despite its arid to semi-arid and inflated evapotranspiration climatic conditions. Soil salinity has greatly reduced Pakistan's principal agricultural output by physio-chemically destroying 25% of its irrigated land

and abandoning 1.4 Mha of soil under its entire agricultural precinct. The economic instability of Pakistan drags it even weaker to overcome the problem of soil salinization. The rural population parallel to the environment also faces serious threats, diseases, and declined standard of living conditions as well.

Solangi, (2019) reported that among the divided four provinces of Pakistan, Sindh is at the most worsening situation in response to the flow of salt water from higher elevated regions to lower ones. Most districts in the south of the province remains highly exposed to drought and flood-like occurrences because of abrupt flow from the Indus River, which ultimately leads to seawater intrusion in Sindh. The constant threat and suffering from salt accumulation have led to disruption is not the only socio-economic status of latter but in significantly contributing agricultural productivity as well.

Qureshi, (2008) conducted research in Pakistan which conceptualized that not only Sindh but other connected provinces such as Punjab to Indus River and its irrigation canal system originally designed to exacerbate cropping intensity and prevent famine has been facing the same issue but not to extent and intensity as faced by Sindh itself due to its location and presence of Indus River Delta at the bottom. According to a study, 54% of soil sitting at the bottom of the basin is vigorously saline in nature as compared to other geographical divisions of Pakistan. The low rainfall, leakage of salt water from vast underground canal network, raised salty groundwater level due to high inefficient irrigation water distribution and seasonal variations and due to excessive evapotranspiration has increased the ratio of soil salinity quite alarmingly in the area.

Qureshi and Shah, (2003) have described in their study that drought, climatic hazard in Pakistan not only impacted soil at basin but also reduced surface water supplies by 46% in Punjab which greatly disturbed all the depending irrigated areas in latter and Baluchistan as well. To continue irrigation of agricultural lands the over-extraction of groundwater led to declined levels beneath the surface thereby further deteriorating the condition of water availability. Huge capital investment thereafter took place by the Pakistani government in form of service of advanced private tube wells to exploit deeper residing water which led to an unintended mess of waterlogging as evaluated by various studies conducted. The secondary salinization made millions of hectares of irrigated soil goes unproductive in Punjab. Waterlogging in Indus Basin makes 40,000 hectares of fertile soil useless per annum as the saline groundwater table ascends. Moreover, the inherent characteristic of soil in the Indus Basin also encourages the deposition of massive amounts of salts at its basin and flow to both Sindh and Punjab thereby extending deterioration of irrigated areas in provinces.

Ghumman, (2012) directed research in Pakistan which proved that regardless of much-appreciated efforts by the government it was still realized that not much was invested in private tube wells. The government simultaneously opted to install public tube wells under Salinity Control and Reclamation Projects (SCRAP) but the drawback and lack of responsibility of proper intermixing of fresh groundwater supply and slightly saline with canal water supply for agricultural purposes, technical and functioning issues, and extracting saline water via deeper wells led to the failure of the project aimed to control salinity.

Apart from both natural and anthropogenic causes of high soil salinization in individual provinces of Pakistan, it is dictated that irrigation water supply via canal system of Indus River is principally contributing to soil salinity in areas (Qureshi, 2008).

The studies conducted in Pakistan and worldwide administered that the reasons for soil salinization are of two distinct types i.e., Natural and Anthropogenic. The natural causes which impose Primary salinization include climatic hazards such as drought, low precipitation, and extensive evapotranspiration from water bodies and plants, parent rock material from which soil has formed, and soil erosion. The geographical location such that areas located at lower elevations will receive a greater flow of salts than upstream areas. Secondary salinization is the type that results from the performances of anthropogenic activities. The latter incorporates the high utilization of slightly saline irrigation water, excessive groundwater utilization, irregular irrigation water supply, inefficient and improper farming techniques, and lack of awareness (Hayat, 2020; Huang, 2018).

Soil salinity is mostly monitored, analyzed, and mapped by conducting traditional physio-chemical analysis through soil sample collection as evident by a research conducted in China (Brunner et al., 2007). The extent of soil salinization is measured and inspected on a scale of both physical parameters and chemical parameters in associated labs. The physical analysis is done to investigate the type and class of soil texture since it plays a major role in salt accumulation while, the chemical analysis is done to quantify the EC, pH, ESP, SAR, and dry density mostly. The chemical parameters if examined to exceed the permissible limits the area under study is then allocated as soil salinized, suffering from drastic salinity circumstances. However, soil sampling technique or field survey is considered economically expensive, time-consuming, and greater muscular effort acquiring as well as highlighted in numerous studies (Guo, 2019).

On the other hand, a research conducted in Sudan stated that Remote sensing (RS) technique is taken as monetary feasible, more authentic in terms of identifying the spatial distribution of salt-effected soil, and less time-consuming as well (Babiker, 2018). Soil salinity can be studied with accuracy both spatially and temporally as well via remotely sensed data. One of the few methods of RS is to make use of results of soil sampling conducted by randomly marking locations of samples using GPS into different software's such as ArcGIS 10.3/10.5 to determine soil salinity's spatial distribution or by bringing RS data in front of field data for comparison. Most of the researches have greatly emphasized the incorporation of geo-referenced data which involves various sensors and satellites such as Landsat 4-5 operating to monitor soil salinity by producing images of high resolution. The latter along with the monitoring of topsoil's salinity also detects salinity-related problems using the whole soil profile of the area under study. The entire procedure of mapping soil salinity and quantifying it via remote sensing technology is advantageous for the adoption of soil rehabilitation processes for reclamation, appropriate planning of land, and measures for sustaining and prevention of soil deterioration (Farifteh, 2006).

Various studies have highlighted mitigation techniques, strategies being carried out in Pakistan, or recommendations on what should be adopted to overcome the problem of soil salinization to reclaim not the original but remediate soil to the extent capable of nurturing crop production. Soil reclamation involves the continuous impoundment of large amounts of water to wash salts out of the soil. The process can be carried out via physical techniques such as deep plowing for correcting EC, chemical modifications such as by adding Gypsum, hydrochloric acid, or any other chemical element aiming to neutralize the pH, or by biological methods such as by incorporating massive quantities of organic matter. Multiple efforts and work are being done by Pakistan to carry out Afforestation on wastelands to enhance forest cover of latter and eradicate soil salinity (Ahmed and Qamar, 2003; Siyal, 2002).

It is reviewed in conclusion that the above-mentioned studies regardless of their difference in time conduction, authors and preferences overall have presented the condition, causes, impacts, analysis, mapping, and mitigation and control measures of soil salinity in Pakistan. It is noted how major the problem of soil salinity is and how disturbing it is for a developing country like Pakistan. Soil salinity is a dynamic phenomenon that continuously requires monitoring and attendance to attain updated information of its status to lay out measures effective enough to solve the problem.

Table 1.1 Summary of Literature Review

Sr.	**Study**	**Region**	**Method**	**Study Topic**
01	Gholizadeh, (2018)	Prague, Czech Republic	Research and Experimental study	Using proximal and remote sensing techniques to monitor selected soil contaminants
02	Lal, (2018)	Pakistan	Research	Managing Agricultural Soils of Pakistan for Food and Climate
03	Solangi, (2019)	Sajawal district, Pakistan	Case study	An Assessment of the Spatial and Temporal Distribution of Soil Salinity using both Field and Satellite Data
04	Qureshi, (2008)	Indus Basin, Pakistan	Case study	Managing salinity and waterlogging in the Indus Basin of Pakistan
05	Qureshi, (2003)	Pakistan	Survey	The comprehensive survey for groundwater economy of Pakistan
06	Ghumman, (2012)	Pakistan	Monitoring survey	Socio-economic and environmental effects of pipe drainage in Pakistan
07	Hayat, (2019)	Pakistan	Research	Overcoming soil salinization by utilizing saline agriculture and phyto-management with salt tolerant plants
08	Brunner, (2006)	China	Experimental study	Producing soil EC maps by incorporating filed data and satellite data
09	Bing Guo, (2019)	Yellow River Delta, China	Experimental study	Extraction model dependent on VI-SI features of river of Soil Salinization based on Landsat 8 OLI image acquired
10	Babiker, (2018)	Sudan	Experimental study	Using Remote Sensing and Geospatial techniques to exacerbate spatial variability of Soil Salinity Indicators
11	Siyal, (2002)	Pakistan	Experimental study	Reclamation of identified saline impacted soils

1.10 Research Justification

The purpose of carrying out this study was to critically, theoretically, and statistically analyze and compare the Ground datasets and Remotely Sensed data for the last two decades on Soil Salinity status in Toba Tek Singh and Shorkot residing in Central Punjab. The research was done to know more about soil salinity in general and in areas under study. The number of studies quoted in the literature review also indicates the status of soil salinity in various regions of Pakistan. The data were collected for two important physio-chemical parameters of soil: EC and SAR. The data from both sources were then processed into soil salinity maps using ArcMap 10.4.1 software for assessing the past and present soil salinity differences and overall trends. This study incorporates software-related calculations as well to study soil salinity in detail. The scope of study further extends its significance by stating the environmental circumstances the regions have to face due to varying salinity conditions and thus the principal requirement of continuous monitoring, improvement implementation, and follow-up since lack of studies has been conducted on latter in Pakistan.

1.11 Objectives of the Study

- To develop a model based on the Ground dataset and satellite imagery of 2020 as well as to study the soil salinity of the past two decades.
- Evaluate the spatial extent and classify the severity of salinity in targeted areas to provide a platform for sustainable agricultural planning.

CHAPTER 2

MATERIALS AND METHODS

2.1 Description of Study Area

The study area constitutes Central Punjab’s tehsil Shorkot of district Jhang lying at a distance of 56 km from Jhang and district Toba Tek Singh of Faisalabad division, lying at North-East of Shorkot at a distance of 35 Kms. Figure 2.1 shows the location of the study area. Geographically Shorkot is bound by latitude 30˚30' N and longitude 72˚24' E, whereas Toba Tek Singh is located from 30˚33' to 31˚2' N latitudes and 72˚08' to 72˚48' E longitudes (Spark, 2016).

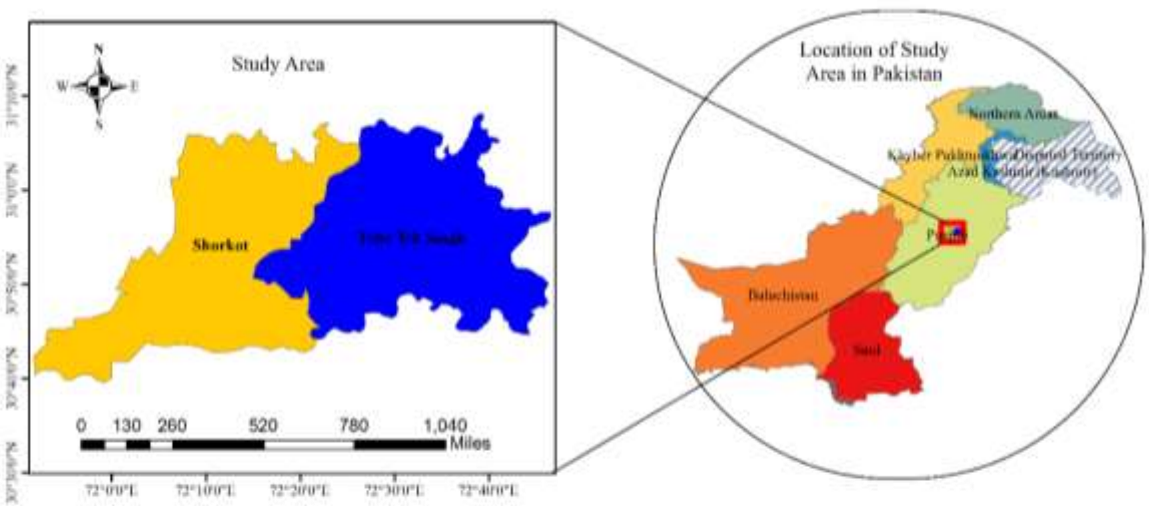

Figure 2.1 Location of the study area

2.1.1 Climate of Study Area

The climate of the area under study comprises generally short, cool, and clear winters as compared to boiling temperatures of summer. The temperature shifts are commonly from 5°C to 41°C throughout the year. The rainy period starts from the 4th of February and lasts till 2nd October, with at least 0.5 inches sliding 31-day precipitation. The humid time period lasts for at least 3 months, whereas the windier part of the year goes on for 4.2 months with normal wind velocities of more than 6.1 miles each hour (Spark, 2016).

2.1.2 Topography of the Study Area

The geology of the area under study is level with a gentle incline from North to South with a normal rise of 500 meters over the sea level. The soil present in the study area is part of Rechna Doab. The soil of Rechna Doab contains alluvial deposits which get transported by the Indus River and its tributaries. The soil surfaces are prevalently medium to decently coarse with ideal porousness qualities with stunted levels of organic matter for the most part and show relatively similar characteristics all through the study area (Ahmad, 2002).

2.1.3 Agriculture and irrigation system

The principal sources of water in the study area are River Ravi and River Chenab. The canal and other extensions from these two sources lay the formation of a fundamental irrigation system framework in the study area. The Jhang Branch, originating from Lower Chenab Canal is the longest. In combination with Upper Gugera Branch, the above-mentioned branch forms a significant irrigation system framework for the study area (Shakoor, 2015). The Rechna Doab soils are adapted to a varied range of crops. In the study area wheat, fodder and sugarcane, rice, cotton, potato, and fodder are cultivated as Rabi and Kharif crops respectively (NHA, 2015).

2.2 Methodology

Our current research work carried out is based on assessing and analyzing the Regression Correlation and Multiple Linear Regression (MLR) between ground truth data and its corresponding salinity index value, all of which has been derived from the satellite images. Therefore, the synchronization of ground truth data collection and satellite bypass was accurate and precise. The complete methodology flow chart is shown in Figure 2.3.

2.3 Methodological Framework

2.3.1 Data acquisition via laboratory analysis (Secondary data)

Surface Soil Samples were collected based on physical appearance of soil, thirty-two soil samples were collected with visible white patches and samples were taken based on previous data review, Surface soil samples from 0-15 and 15 -30cm were collected at each selected point. Around one kg of soil was taken as sample and thoroughly mixed and packed into plastic bags. The samples bags were also labelled with identification marks separately The GPS of each point was also recorded. Toba Tek Singh and Shorkot were the main points from where the samples were collected. The figure 2.2 shows the sampling points.

Soil auger was used to obtain the soil samples. Soil was boring to depth of 15cm using soil auger and the samples were taken after that the soil samples were passed through 2mm sieve. A supervisor was hired from the Soil Salinity Research Institute located in Pindi Bhattian. EC, SAR parameters and N, P, K fertility standards were analyzed at Soil Salinity Research Institute.

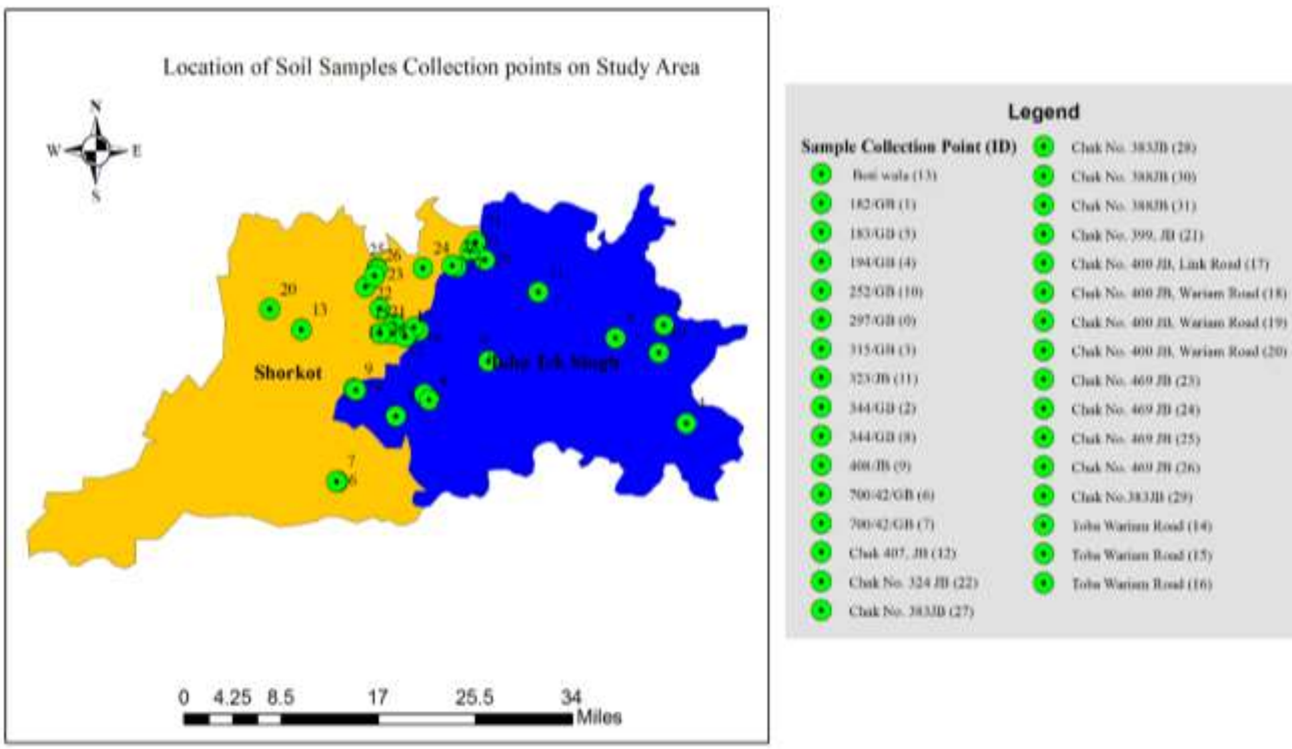

Figure 2.2 Sample collection points

2.3.1.2 Data acquisition via satellite data and processing

The Landsat imagery was downloaded from a database forum United States Geological Survey (USGS). First a region of interest was created by importing a shapefile (in a zip file). The years selected were 1996, 1998.2000,2008,2009,2010,2015,2017 and

2020 whereas the months were from October till November. From the year 2000 till 2020 the inconsistent of the Landsat imageries were due to greater cloud cover i.e. more than than 50% so the atmospheric correction could not be applied to the images to get a clear picture. Next remote sensing datasets were selected depending on date and time. The Landsat imagery selected was Landsat 4-5 and Landsat 8 OLI. Following Landsat imagery, data was filtered out in the additional criteria by setting the cloud cover to less than 10% to get the perfect cloudless image. The images were downloaded from the result tab in Geo-TIFF data product, which has the largest file size. The images covered path (Longitude) 150, row (latitude) 38, path (Longitude) 150, row (latitude) 39 (the details are given in the table 1). The USGS has categorized images into tiers based on their quality and amount of processing. After the study area was added to the layers in Arc GIS, the tiles downloaded from USGS were added.

For each band individually, the Spatial Resolution Enhancements, Radiation, and the typical Atmospheric corrections were performed. The establishment of a link or relationship between the measured physical amounts at the sensor field of view, the radiation flow reflected by Earth's atmospheric system, and the apparent digital number DN (λ) at the end exit of the instrument towards reception units or stations, is all part of an operation/function known as the "Radiometric Calibration of the Sensor" (Chen, 2017). It is a crucial step that involves correcting the radiometric sensor drift to derive authentic and accurate data from the image. The raw data from the DN (λ) was converted into spectral radiance L (λ) using the sensor's the calibration coefficients (gain and offset).

The L (λ) was calculated using equation 1:

Whereas;

$L(\lambda) = G(\lambda) \times DNL(\lambda) + O(\lambda)$ ... (1)

DN (λ): Digital number at the sensor's aperture

L (λ): Spectral radiance at the sensor's aperture [W/ (m2sr μm)].

O (λ): Offset.

G (λ): Gain.

Speaking in terms of the atmospheric effects, it is overshadowed by the absorption due to the gases (water vapor, carbon dioxide, and ozone) and the dissemination or diffusion of the aerosols and the molecules (Ward, 2013). To remove or reduce the dominance of the atmosphere, the atmospheric correction was applied. When linkage between field measurements and spectral reflectance values is needed, this type of correction is given more preference in studies (Selch, 2012). Reflectance calibration is applied by deriving the reflectance value from the DN and calculating the top of atmosphere reflectance (TOA). Atmospheric correction was calculated using Equation 2.4.

$L(\lambda) = A\rho\ 1 - \rho eS + B\rho e\ 1 - \rho eS + La(\lambda)$ ... (2)

Where: ρ: Pixel surface reflectance

ρe: Average surface reflectance for the pixel and a surrounding region

S: Spherical albedo of the atmosphere

La (λ): Radiance back scattered by the atmosphere.

A and B: Coefficients that depend on atmospheric and geometric conditions but not on the surface.

Every year had 2 titles but the years 2015, 2017 and 2020 had only one tile becaues these years were encompassing the whole study area. The mosaic tool was applied to the years having 2 tiles by using Mosaic to New Raster tool to combine two tiles together by making it one and then Extract by Mask tool was applied to every year. Each tile from every year was copied using the Copy Raster tool to permanently remove the black background from tiles.

Table 2.1: Landsat's Path-Row

Serial No.	Satellite	Data Acquisition	Path-Row
1.	Landsat 4-5	17/10/1996	150-38; 150-39
2.	Landsat 4-5	23/10/1998	150-38; 150-39
3.	Landsat 4-5	28/10/2000	150-38; 150-39
4.	Landsat 4-5	02/10/2008	150-38; 150-39
5.	Landsat 4-5	05/10/2009	150-38; 150-39
6.	Landsat 4-5	25/11/2010	150-38; 150-39
7.	Landsat 8 OLI	06/10/2015	150-039
8.	Landsat 8 OLI	27/10/2017	150-039
9.	Landsat 8 OLI	19/10/2020	150-039

2.3.2 Indices development

Images that are fabricated by using multiband images are widely referred to as image Indices. A single phenomenon is made prominent by such images thereby diminishing the participation of other contributing factors which aids in enabling disturbing effects in the image. The necessity of comparing and assessing the difference of spectral reflectance of saline soils from non-saline soils urges the researchers to jot spectral reflectance of varying degrees of soil salinization in selected regions (Abuelgasim and Ammad, 2019). Saline soils give greater reflectance values due to white salty patches on the surface as compared to non-saline soils as proved by numerous studies for visible and NIR regions of the electromagnetic spectrum. 9 Indices were established in total comprising and classifying relevant three types: **Soil Salinity Indices, Vegetation Indices, and Water Indices**. Out of 9, 5 most appropriate indices were selected. The higher range of values for Vegetation indices indicates high green plantation density/biomass in the area whereas the higher range of values oppositely for Salinity indices generally indicates high soil salinization muddle.

The indices are quoted in Table 2.2:

Table 2.2: Salinity and Vegetation Indices utilized for contriving soil salinity maps

Index	Formula	References
Normalized Difference Moisture Index (NDMI) (Water index)	$\frac{(NIR - SWIR)}{(NIR + SWIR)}$	(USGS, 2019)
Salinity Index 1 (SI1)	$\frac{(B - R)}{(B + R)}$	(Douaouia and Walterb, 2006)
Salinity Index 3 (SI3)	$\frac{(G \times R)}{B}$	(Douaouia and Walterb, 2006)
Normalized Difference Soil Index (NDSI)	$\frac{(R - NIR)}{(R + NIR)}$	(Khan et al., 2005)
Normalized Difference Vegetation Index (NDVI)	$\frac{(NIR – R)}{(NIR + R)}$	(Azabdaftari and Sunar, 2016)

The indices are satellite-derived and were developed by either incorporating or subtracting associated bands from multiband images utilized for each year from 1995 to 2020. The layers of Blue (Band 2), Green (Band 3), Red (Band 4), Near Infra-Red/ NIR (Band 5) and SWIR/ Short Wave Infra-Red (Band 6) for Landsat 8 OLI images and Blue (Band 1), Green (Band 2), Red (Band 3), NIR (Band 4) and SWIR (Band 5) from Landsat 4-5 images were added to ArcMap 10.4.1 software. Using Spatial Analyst tool of Raster Calculator, the indices were constructed thus resulting with the range of pixel values for each. The value for index SI3 was corrected by multiplying with scale factor. The pixel values for each year image and each index were then extracted using Extract values to point’s tool to receive values for EC, SAR, and Raster values of indices.

The values from attribute table of each extracted layer of indices in ArcMap 10.4.1 was then copied to Microsoft Excel Sheet to compile EC, SAR, values of indices with exact longitude and latitude of sample points selected. Following, the Ground datasets values calculated of same coordinates were brought in comparison with values calculated from software. These were then made use of to generate soil salinity map by inserting output image in GIS environment. Besides plotting salinity maps, the relationship developed amid the salinity indices extracted from Landsat satellite images downloaded and ground dataset of similar locations in field is also utilized for forecasting classifying salinity levels.

2.3.3 Multiple Linear Regression Model

Regression models are appropriate for researching the current connections among dependent and independent factors particularly in small sample sizes dependent on least squares fitting. In this study the relationship among dependent ground datasets (EC and SAR), and independent satellite data (Indices) is shown by using MLR model. As a direct function the execution of stepwise regression model, MLR analysis was performed for different salinity estimates in the area under examination (Ouma, 2020).

In multi linear regression we use 'x_j' (j= 1, 2, 3……. n) as a multiple predicted variables to model the response of 'y' variable. The equation is given below:

$y = c_o + \sum_{i=0}^{n} c_i x_j + \varepsilon_o$

Where,

x_j= model predictors

y= model output

c_i= co-efficient regression

c_o= constant

ε_o = model error term

2.3.4 Predicting soil salinity via Inverse Distance Weighed (IDW) mapping based on EC and SAR

The principle, significant and finest way to predict, interpolate and map soil salinity parameters, spatial distribution, salinity extent, and salinity-related hazards via

GIS is the utilization of IDW technology (Hamad, 2016) .The method of IDW technology fundamentally assumes the points in the area under study closer to predicted points are more alike rather than those which are distant and thus have a greater influence and weight. While simultaneously, the influence and weight for points further from the predicted points reduces thus the technology widely is referred to as inverse distance weighted. IDW makes use of measured values of points surrounding the unknown to forecast approximate value for that unspecified location while deducing the parameters such as soil salinity being mapped based on EC and SAR, in this case, will diminish with increasing distance from sampling coordinates.

The values for predicted points were calculated by adding measured values to following equation.

$$(S_o) = \sum_{i=1}^{N} ƛ_i Z(S_i)$$

Where:

$Z(S_0)$ = value needs to be calculated for unknown location

N = represents the total number of measured samples that will be incorporated to forecast value gathered from adjacent to undefined placement

ƛi = represents the weights allocated to measured values intending to diminish with distance

Z (Si) = refers to perceived value for Si placement

For Soil salinity mapping the EC and SAR excel sheets were tabulated and added to ArcGIS 10.4.1 to convert the measured values of EC and SAR to shapefile preparing for IDW mapping. The files were constructed for all years: 1996, 1998, 2000, 2008, 2009, 2010, 2015, 2017, and 2020. Following prediction maps of soil salinity in accordance with EC and SAR were formulated using the IDW Spatial Analyst tool.

IDW enhanced the ability for soil salinity prediction in the entire Toba Tek Singh and Shorkot regions with 31 samples collected in total due to spatial and temporal variability of salinity. The method is also preferred as gathering a large number of samples is not costly, extremely time-consuming but demands immense manpower as well (Pulatov, 2020). Thus, soil salinity measurements became comparatively easier to quantify the variables i.e., EC and SAR and soil acidity level in general with IDW.

2.3.5 Soil salinity classification based on EC and SAR

Following the formulation of IDW maps on ArcGIS 10.4.1, the next step heeded towards the fabrication of the most significant element of study which is layering of Soil Salinity maps by classifying EC and SAR into various groups allocated with digital values to depict the intensity and severity of soil salinization in study areas. The classes are defined in Tables 2.3 and 2.4:

The maps for both EC and SAR were constructed separately for each selective 9 years. The idw_ec_year and idw_sar_year shapefiles were subsumed into software where soil salinity was broken down manually into four categories for EC by (Hammam and Mohamed, 2020) and four USSL classifications for SAR (Zaman, 2018).

The soil salinity maps on EC and SAR will be discussed under Results section.

Table 2.3 EC classification

EC (dS/m)	**Salt concentration level**	**Interpretation**
1-2	Low saline	The plants/crops in areas might be observed to depict very minor chance of disease
2-4	Moderate saline	The crops can still grow in slightly saline conditions
4-7	High saline	The salt sensitive plants in such cases are likely to suffer from severe diseases while non-salt tolerant crops in highly saline patches to agonize from level of associated injuries
>7	Excessively high saline	Very few salt-tolerant or no crops are likely to be spotted in excessively high salinity patches of study area

Table 2.4 SAR classification

SAR (mmol)	Salt concentration level	Interpretation
<10	Non-saline	Low concentration of Sodium (Na) in water. Good yield of crops is likely to exist
10-18	Slightly saline	Acceptable level of Na in irrigation water. Plants sensitive to sodium and fine textured soil is likely to suffer particularly under negligible leaching facility
18-26	Moderate saline	Medium level of Sodium in water. Danger warning for sodium non-tolerant crops.
>26	Highly saline	Unacceptable and worrying level of Na in water.

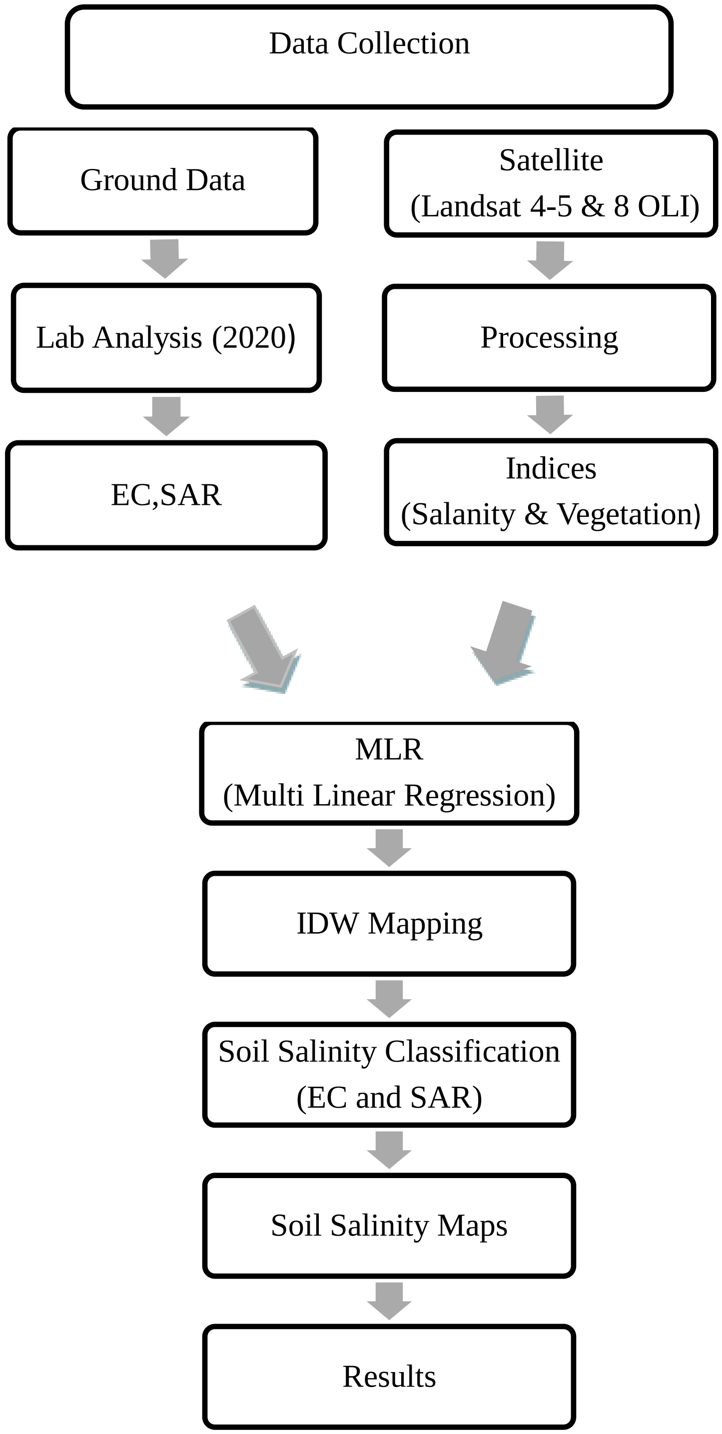

Figure 2.3 Methodology flow-chart

CHAPTER 3

RESULTS AND DISCUSSIONS

3.1 Results of Soil Sampling

The ground data sets as mentioned above in paper were attained via selecting 32 random sampling points in total from the two areas under research and performing laboratory physio-chemical analysis of soil for EC and SAR parameters. EC and SAR have been ascertained to play significant roles in finding out salinity intensity levels and extent in soil in Toba Tek Singh and Shorkot irrespective of their variability due to various external factors. The laboratory analysis showed maximum EC was 17.8 dS/m in Chak No. 408 JB village in Toba Tek Singh while the highest SAR was examined in Chak No. 400 JB, Wariam Road with attached value of 135.10 mmol. Out of 32, 10 sampling locations have EC ranging amidst 7 – 18 dS/m which declares 31.25% of area opted is recognized as excessively high saline according to soil salinity classification given in Table 2B. Simultaneously! 10 out of 32 locales indicting 31.25% area is also cited as highly saline as showed values for SAR >26.

3.2 Model Development

The MLR model was used as there are fewer parameters to assess which reduces the requirement of sample size (Lesch, 1995). It was used in the thesis research to directly assess the average attribute level variations over some time by using dependent ground datasets and independent satellite datasets. Once MLR Model was assembled, various salinity estimates were assessed using this model. Values for NDVI, NDMI, SI_1, SI_3, and NDSI were fitted into the model. The established MLR model for EC and SAR is shown in equations (1) and (2) respectively:

EC= 12.75 + (-2.25) NDMI + (-70.14) *SI1 + (-83.89) *SI3 + 16.26*NDSI (1)

SAR = -207.69 + 16.81 * NDMI + 934.94*SI1 + 2604.53*SI3 + (-140.51) *NDSI (2)

3.3 Correlation Analysis

The correlation is analyzed between ground dataset and satellite derived indices to determine how statistically significant the parameters are i.e., EC and SAR and to evaluate the impact of those parameters on satellite-based indices. For the purpose, a series of OLS regressions were run. This shows the prediction power of the ground dataset parameters (EC and SAR). The overall results of the analysis for EC and SAR are summarized in Table 3.1 and 3.2.

Table 3.1 for EC on the other hand traces the significant relation of EC with indices among which the NDSI and SI3 are positively associated with each other. The SI1 is highly significant at 1%. The results show the overall prediction power of EC is comparatively higher than SAR since the correlation between EC with indices is significant at 5%.

Results of Table 3.2 (SAR) show that salinity index such that SI3 and vegetation index NDSI have correlated positively to the ground data sets. Ground data fluctuates monotonically to the changes in salinity indices and the association is significant at 1%. The monotonic association is consistent across the three components of the index, with little variation in the coefficient value. While the moisture index NDMI, SI1 and NDVI have no significant relation with Ground data sets as associated with negative values as well. It is also described in Table 3.1 below that the correlation amid the indices themselves is highly significant at 1% while the correlation between the indices and SAR parameters is not significant.

Table 3.1 Correlations among EC and Salinity Indices

Parameter		EC	NDVI	NDMI	SI1	SI3	NDSI
EC	Pearson Correlation	1	-.143**	-.382*	-.624**	.627**	.143**
	Sig. (2-tailed)		.000	.031	.000	.000	.000
NDVI	Pearson Correlation	-.143**	1	-.929**	-.847**	.791**	-1.000**
	Sig. (2-tailed)	.000		.000	.000	.000	.000
NDMI	Pearson Correlation	-.382*	-.929**	1	.903**	-.849**	.929**
	Sig. (2-tailed)	.031	.000		.000	.000	.000
SI1	Pearson Correlation	-.624**	-.847**	.903**	1	-.983**	.847**
	Sig. (2-tailed)	.000	.000	.000		.000	.000
SI3	Pearson Correlation	.627**	.791**	-.849**	-.983**	1	-.791**
	Sig. (2-tailed)	.000	.000	.000	.000		.000
NDSI	Pearson Correlation	.143**	-1.000**	.929**	.847**	-.791**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table 3.2 Correlations among SAR and Salinity Indices

Parameter		SAR	NDVI	NDMI	SI1	SI3	NDSI
SAR	Pearson Correlation	1	.832**	-.787**	-.859**	.905**	-.832**
	Sig. (2-tailed)		.000	.000	.000	.000	.000
NDVI	Pearson Correlation	.832**	1	-.929**	-.847**	.791**	-1.000**
	Sig. (2-tailed)	.000		.000	.000	.000	.000
NDMI	Pearson Correlation	-.787**	-.929**	1	.903**	-.849**	.929**
	Sig. (2-tailed)	.000	.000		.000	.000	.000
SI1	Pearson Correlation	-.859**	-.847**	.903**	1	-.983**	.847**
	Sig. (2-tailed)	.000	.000	.000		.000	.000
SI3	Pearson Correlation	.905**	.791**	-.849**	-.983**	1	-.791**
	Sig. (2-tailed)	.000	.000	.000	.000		.000
NDSI	Pearson Correlation	-.832**	-1.000**	.929**	.847**	-.791**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	

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

3.4 Model Prediction Assessment

To predict the previous ground data of soil salinity, the model was fabricated incorporating indices values and observational values 2021.

A. Ground data set predicted 1996

The summarized table of 1996 in table 3.3 indicates that all the area adjacent to sampling points had maximum EC value of 6.39 dS/m and SAR value of 55.77 mmol whereas all the area away from the sampling points had minimum EC value of 3.44 dS/m and SAR value of 7.16 mmol as a result the areas showing maximum EC and SAR values are referred as highly saline and the areas presenting minimum EC and SAR values are referred as Moderate saline. Seven main study variables; EC, SAR, NDVI, NDMI, SI1, SI3 and NDSI were utilized for the conduction of statistical analysis.

Table 3.3 Descriptive Statistics of EC, SAR, and Indices of 1996

	N	Range	Minimum	Maximum	Mean	Std. Deviation
EC	32	2.95	3.44	6.39	4.74	0.69
SAR	32	48.62	7.16	55.77	23.24	12.11
NDVI	32	0.40	-0.36	0.04	-0.12	0.10
NDMI	32	0.25	-0.22	0.04	-0.12	0.06
SI1	32	0.19	0.20	0.39	0.29	0.05
SI3	32	0.02	0.01	0.04	0.02	0.00
NDSI	32	0.40	-0.04	0.36	0.12	0.10

The SAR map (figure 3.1) of 1996 predicts that the maximum study area in orange reveals moderate saline part ranging from (18-26mmol) whereas the red part exhibits highly saline area ranging from (>26mmol). The non-saline part covers very less area ranging from (<10mmol).

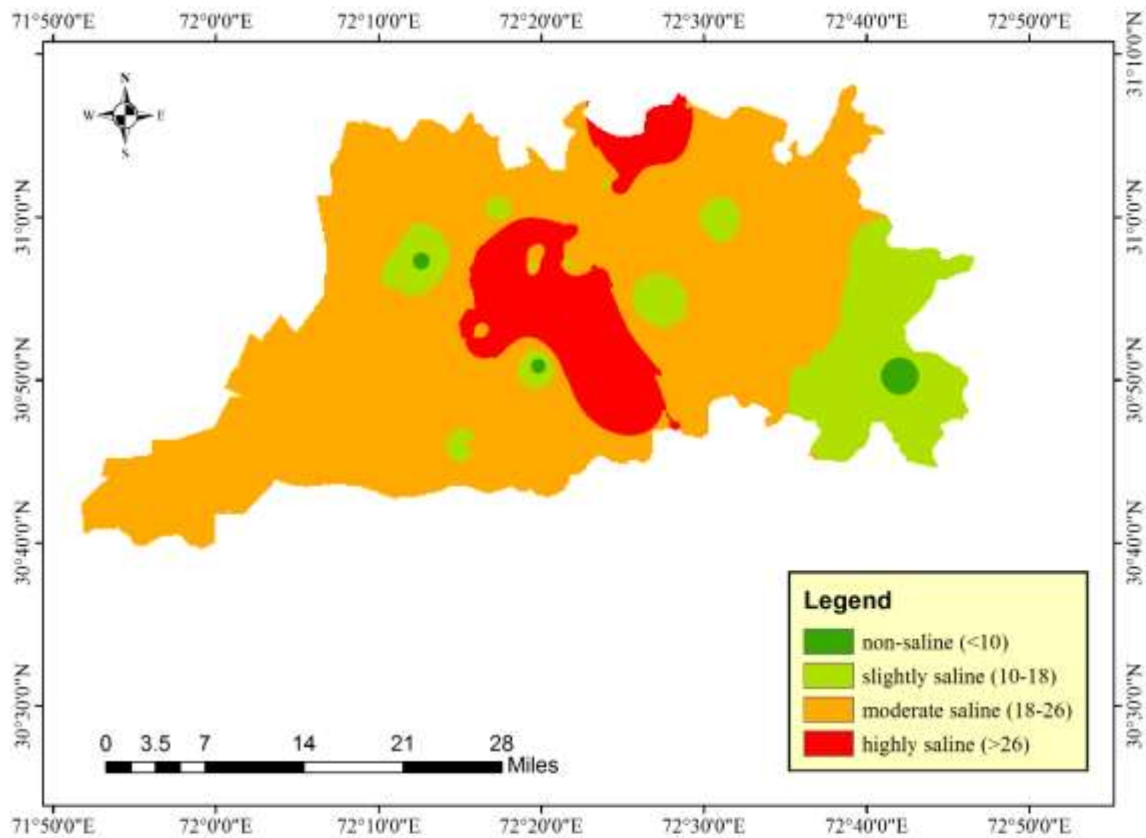

Figure 3.1 SAR Map 1996

According to the EC map (figure 3.2) of 1996 the maximum zone of study area is slightly saline (light green) with the value ranging from (1-2 dS/m) whereas the small region showing yellow color is moderately saline with the value ranging from (2-4 dS/m).

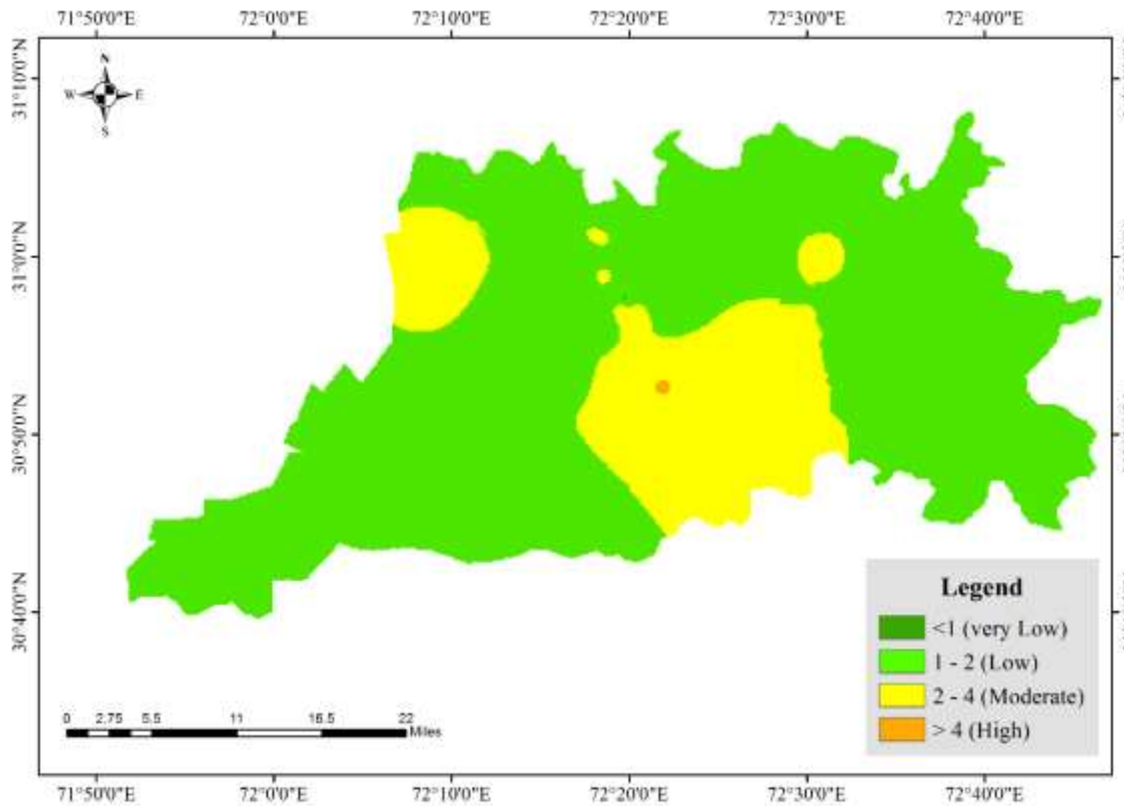

Figure 3.2 EC Map 1996

B. Ground data set predicted 1998

The descriptive statistics shown in table 3.4 of 1998 indicates that all the area adjacent to sampling points had maximum EC value of 6.52 dS/m and SAR value of 55.92 mmol whereas all the area away from the sampling points had minimum EC value of 3.57 dS/m and SAR value of 7.31 mmol as a result the areas showing maximum EC and SAR values are referred as highly saline and the areas presenting minimum EC and SAR values are referred as Moderate saline. Seven main study variables; EC, SAR, NDVI, NDMI, SI1, SI3 and NDSI were utilized for the conduction for statistical analysis.

Table 3.4 Descriptive Statistics of EC, SAR and Indices of 1998						
	N	**Range**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
EC	32	2.95	3.57	6.52	4.87	0.69
SAR	32	48.62	7.31	55.92	23.42	12.11
NDVI	32	0.40	-0.36	0.04	-0.12	0.10
NDMI	32	0.41	-0.27	0.14	-0.10	0.11
SI1	32	0.24	0.18	0.42	0.29	0.07
SI3	32	0.24	0.12	0.36	0.21	0.07
NDSI	32	0.40	-0.04	0.36	0.12	0.10

The SAR map (figure 3.3) of 1998 predicts that the maximum study area in orange reveals moderate saline part ranging from (18-26mmol) whereas the red part exhibits highly saline area ranging from (>26mmol). Comparing with the map of 1996 the area under red has slightly increased thus indicating the growth in highly saline area. The non-saline part covers only three spots ranging from (<10mmol).

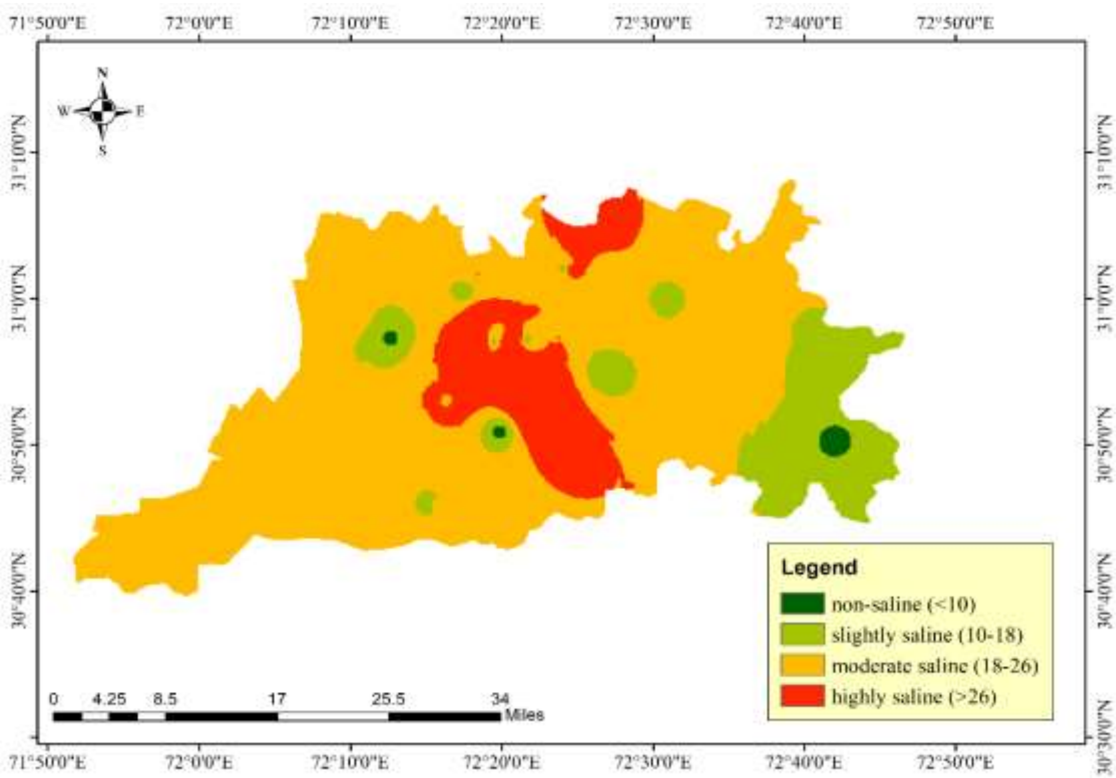

Figure 3.3 SAR Map 1998

According to the EC map (figure 3.4) of 1998 the maximum zone of study area is slightly saline (light green) with the value ranging from (1-2 dS/m) whereas the region showing yellow color is moderately saline with the value ranging from (2-4 dS/m). The yellow part has increased from 1996 to 1998 depicting the rise in moderate saline area.

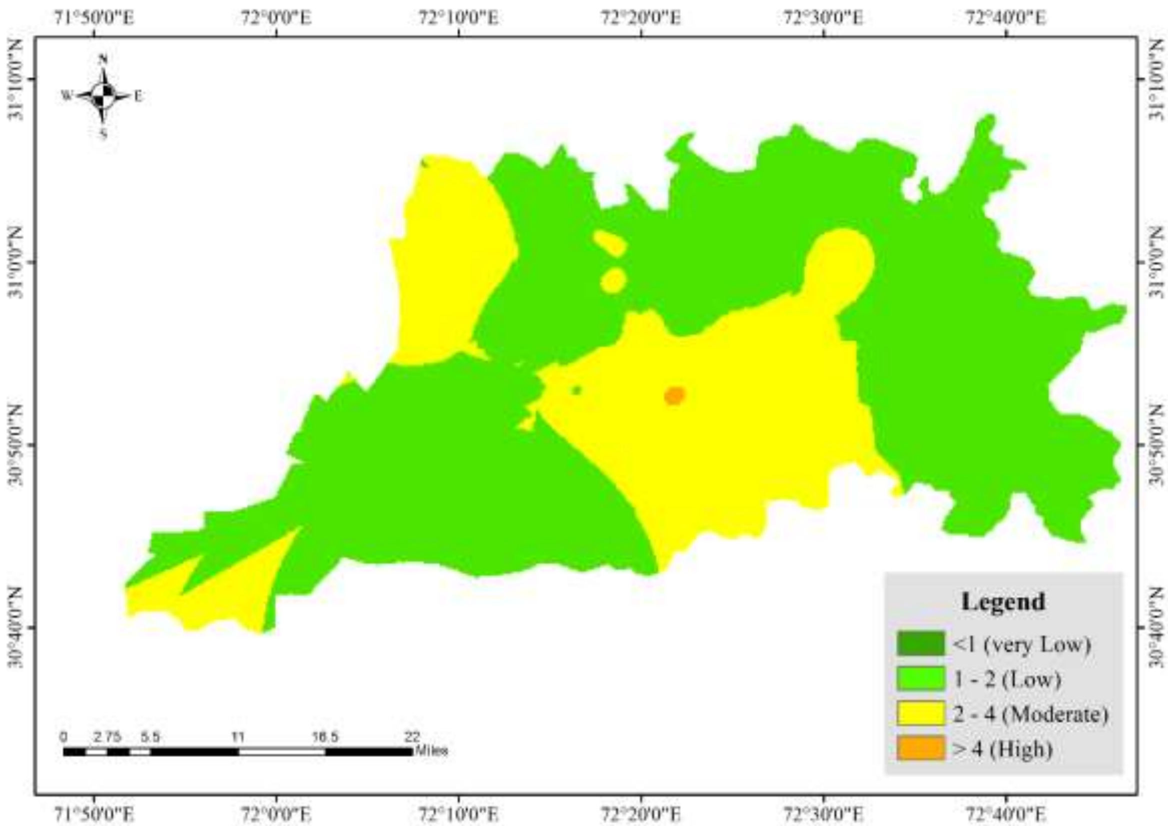

Figure 3.4 EC Map 1998

C. Ground data set predicted 2000

The following table 3.5 defines that all the area adjacent to sampling points had EC mean value of 5.11 dS/m and SAR mean value of 23.52 mmol as a result the areas showing maximum EC and SAR values are referred as highly saline and the areas presenting minimum EC and SAR values are referred as Moderate saline. Seven main study variables; EC, SAR, NDVI, NDMI, SI1, SI3 and NDSI were utilized for the conduction for statistical analysis. The values have been increased in the past 6 years.

Table 3.5 Descriptive Statistics of EC, SAR, and Indices of 2000						
	N	**Range**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
EC	32	2.95	3.81	6.76	5.11	0.69
SAR	32	48.62	7.41	56.02	23.52	12.11
NDVI	32	0.25	-0.17	0.09	-0.05	0.07
NDMI	32	0.25	-0.28	-0.02	-0.16	0.07
SI1	32	0.23	0.16	0.38	0.26	0.06
SI3	32	0.30	0.12	0.42	0.24	0.08
NDSI	32	0.25	-0.09	0.17	0.05	0.07

The SAR map (figure: 3.5) of 2000 predicts that the maximum study area in orange reveals moderate saline part ranging from (18-26mmol) whereas the red part exhibits highly saline area ranging from (>26mmol). Comparing with the map of 1998 the salinity in the area under study has increased nominally thus signifying very little growth in highly saline area. The non-saline part covers only three spots ranging from (<10mmol).

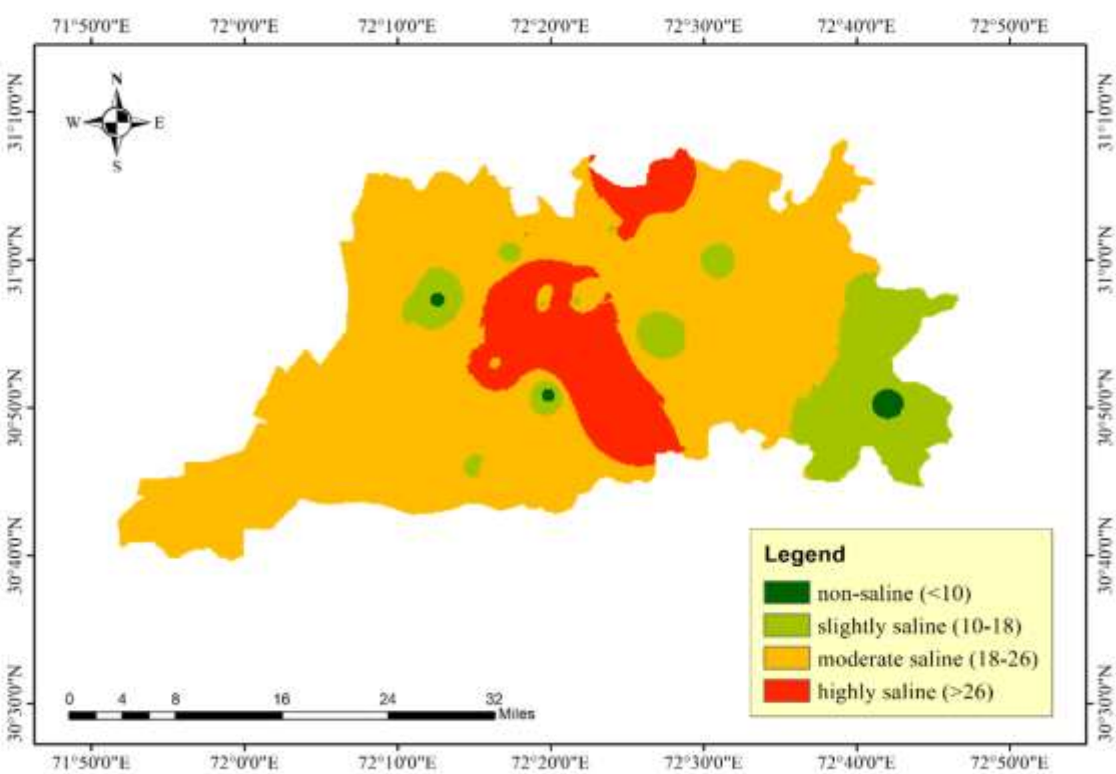

Figure 3.5 SAR Map 2000

According to the EC map (figure 3.6) of 2000 the small-scale zone of study area is slightly saline (light green) with the value ranging from (1-2 dS/m) whereas the region showing yellow color is moderately saline with the value ranging from (2-4 dS/m). The yellow part has highly increased from 1998 to 2000 depicting that the maximum area is moderately saline. Moreover, patches of highly saline have also increased with EC value ranging from (>4 dS/m).

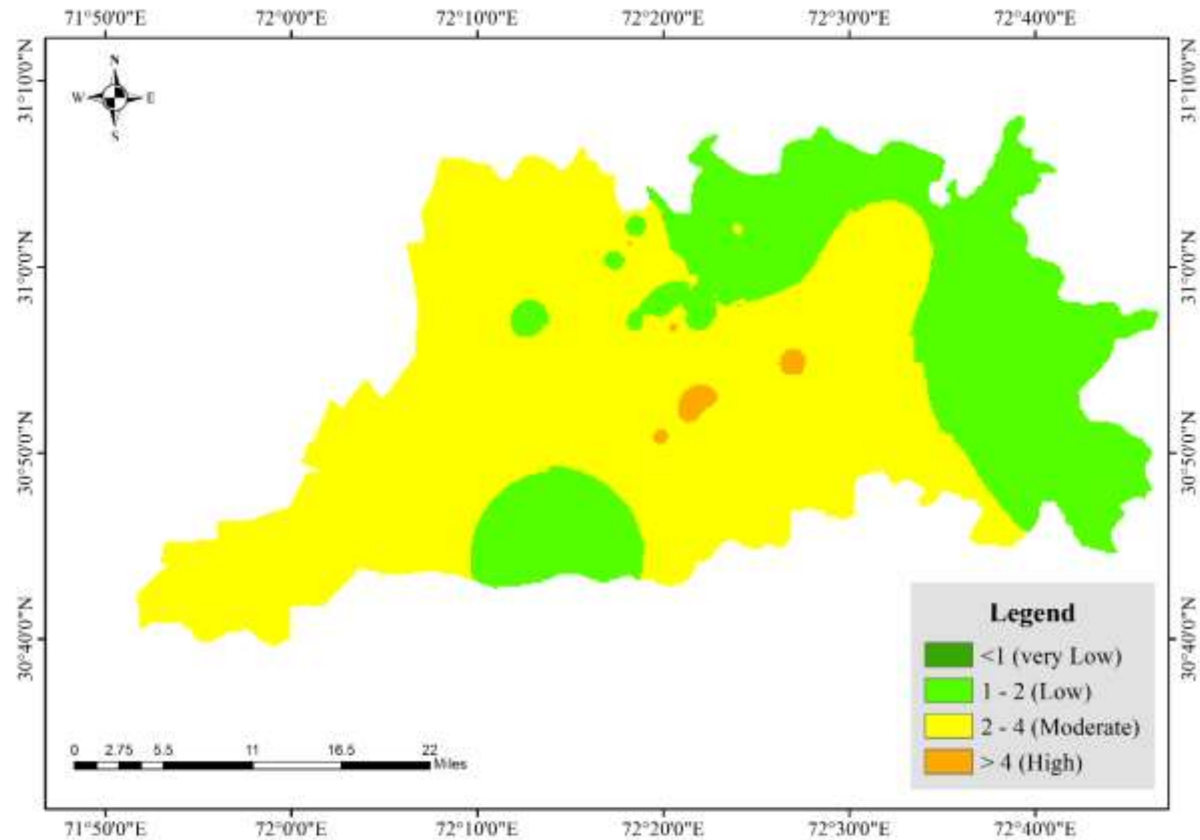

Figure 3.6 EC Map 2000

D. Ground data set predicted 2008

The simplified table attached below (table 3.6) of 2008 specifies that all the area adjacent to sampling points had maximum EC value of 7.76 dS/m and SAR value of 57.42 mmol whereas all the area away from the sampling points had minimum EC value of 4.81 dS/m and SAR value of 8.81 mmol as a result the areas showing maximum EC and SAR values are referred as highly saline and the areas presenting minimum EC and SAR values are referred as Moderate saline. Seven main study variables; EC, SAR, NDVI, NDMI, SI1, SI3 and NDSI were utilized for the conduction of statistical analysis. The values have been increased in the past 8 years (2000-2008).

Table 3.6 Descriptive Statistics of EC, SAR, and Indices of 2008						
	N	**Range**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
EC	32	2.95	4.81	7.76	6.11	0.69
SAR	32	48.61	8.81	57.42	24.92	12.11
NDVI	32	0.40	-0.38	0.02	-0.16	0.12
NDMI	32	0.26	-0.19	0.07	-0.08	0.08
SI1	32	0.18	0.20	0.38	0.29	0.05
SI3	32	0.25	0.16	0.41	0.25	0.06
NDSI	32	0.40	-0.02	0.38	0.16	0.12

The SAR map (figure 3.7) of 2008 predicts that the maximum study area in orange reveals moderate saline part ranging from (18-26mmol) whereas the red part exhibits highly saline area ranging from (>26mmol). Comparing with the map of 2000 the salinity in the area under study has increased hence indicating extensive growth in highly saline area. The non-saline part covers only one spots ranging from (<10mmol) thus indicating scant non-saline area.

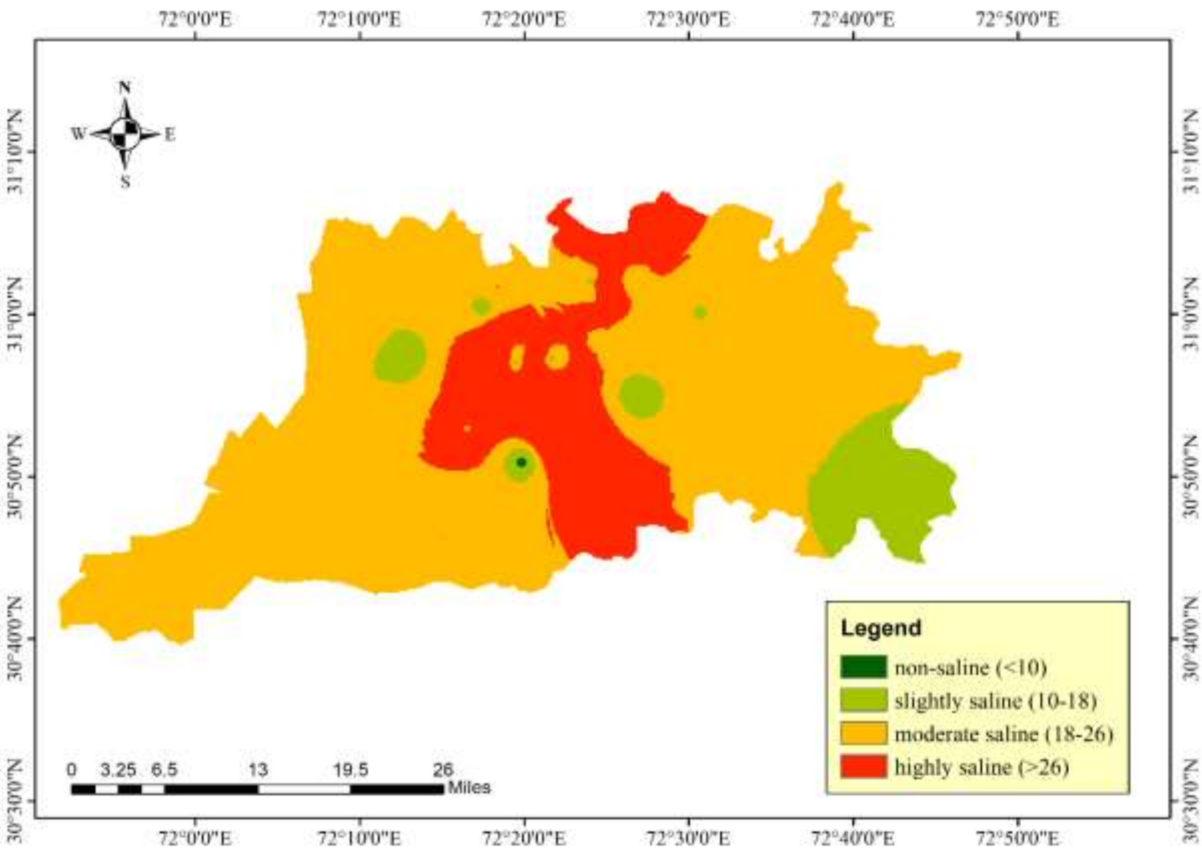

Figure 3.7 SAR Map 2008

According to the EC map (figure 3.8) of 2008 the study area in light green (slightly Saline) has completely wiped out with the value ranging from (1-2 dS/m) whereas the region showing yellow color is moderately saline with the value ranging from (2-4 dS/m). The yellow parts have majorly dropped in the past 8 years depicting those very little areas are moderately saline. Moreover, patches of high salinity have extended over a large area thus depicting high soil salinity with EC value ranging from (>4 dS/m).

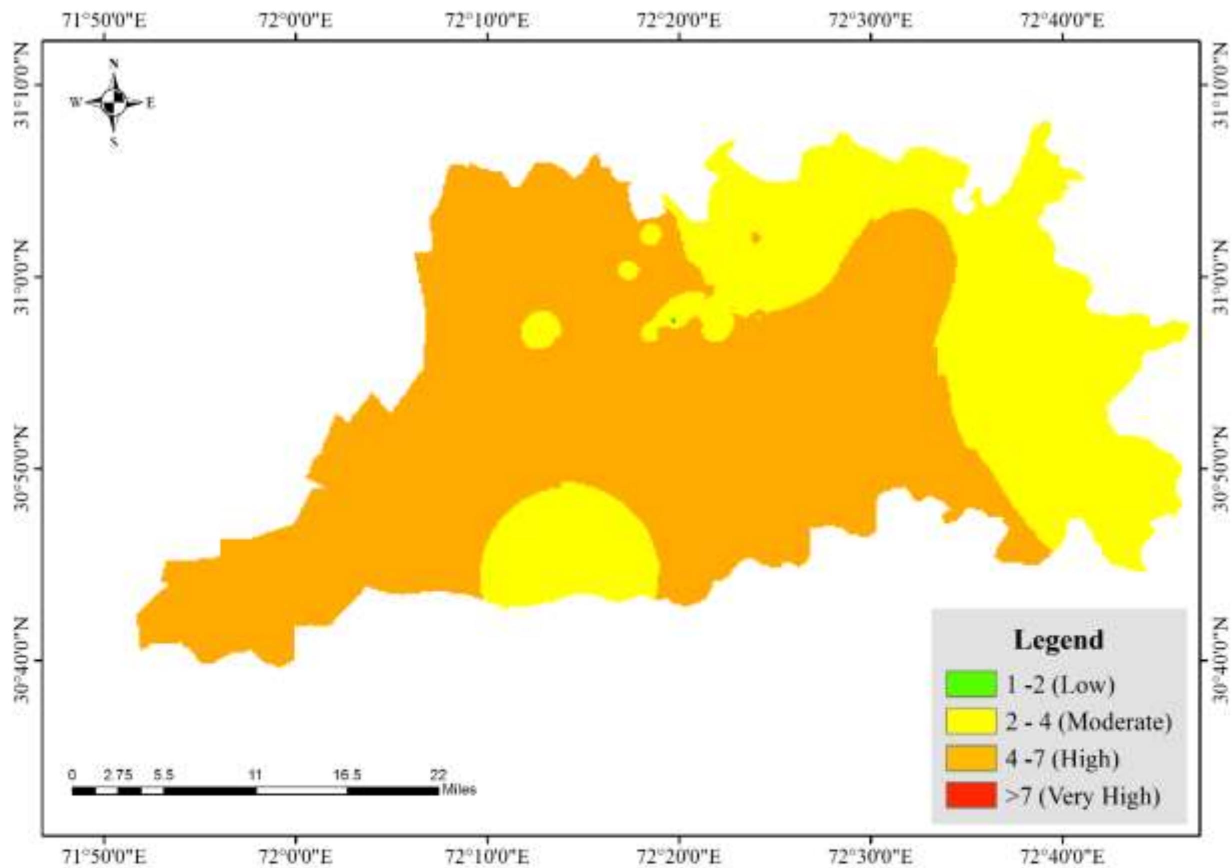

Figure 3.8 EC Map 2008

E. Ground data set predicted 2009

The table 3.7 secured beneath evaluates that the entire area adjacent to sampling points had maximum EC value of 7.77 dS/m and SAR value of 57.52 mmol whereas all the area away from the sampling points had minimum EC value of 4.82 dS/m and SAR value of 8.92 mmol as a result the areas showing maximum EC and SAR values are referred as highly saline and the areas presenting minimum EC and SAR values are referred as Moderate saline. Seven main study variables; EC, SAR, NDVI, NDMI, SI1, SI3 and NDSI were utilized for the conduction of statistical analysis. Slightest increase in values has been observed after one year.

Table 3.7 Descriptive Statistics of EC, SAR, and Indices of 2009						
	N	**Range**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
EC	32	2.95	4.82	7.77	6.12	0.69
SAR	32	48.61	8.91	57.52	25.02	12.11
NDVI	32	0.41	-0.39	0.03	-0.17	0.09
NDMI	32	0.19	-0.15	0.04	-0.07	0.05
SI1	32	0.16	0.25	0.41	0.32	0.04
SI3	32	0.15	0.15	0.30	0.22	0.03
NDSI	32	0.41	-0.03	0.39	0.17	0.09

The SAR map (figure 3.9) of 2009 reveals that the maximum study area in orange is moderate saline ranging from (18-26mmol) whereas the red part exhibits highly saline area ranging from (>26mmol). Comparing with the map of 2008 the salinity in the area under study has a minute increased hence indicating very small growth in highly saline area. The non-saline part covers only one spots ranging from (<10mmol) thus indicating scant non-saline area.

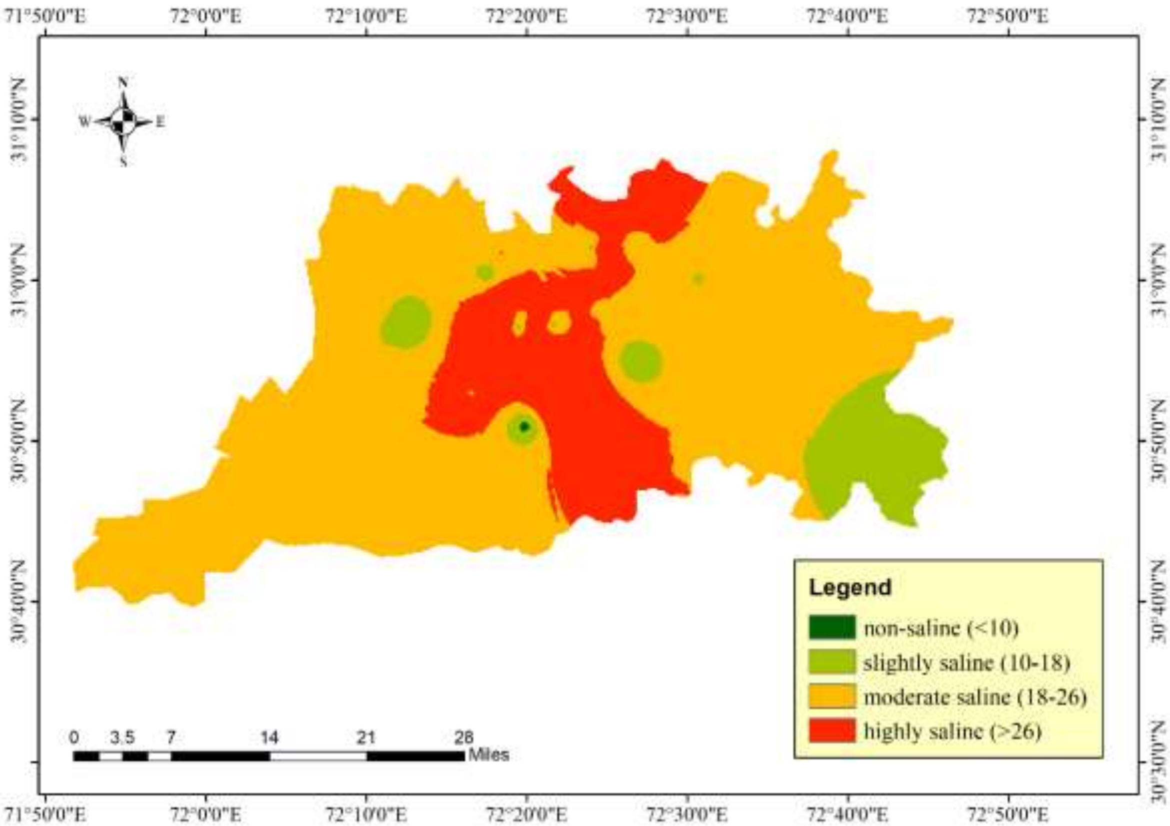

Figure 3.9 SAR Map 2009

According to the EC map (figure 3.10) of 2009 the study area in light green (slightly Saline) has completely wiped out with the value ranging from (1-2 dS/m) whereas the region showing yellow color is moderately saline with the value ranging from (2-4 dS/m). The yellow part has dropped vaguely in last one year. Moreover, the orange depicting high soil salinity with EC value ranging from (4-7 dS/m). The spots in red indicate extremely high saline areas ranging from (>7dS/m) and it has increased from the last year.

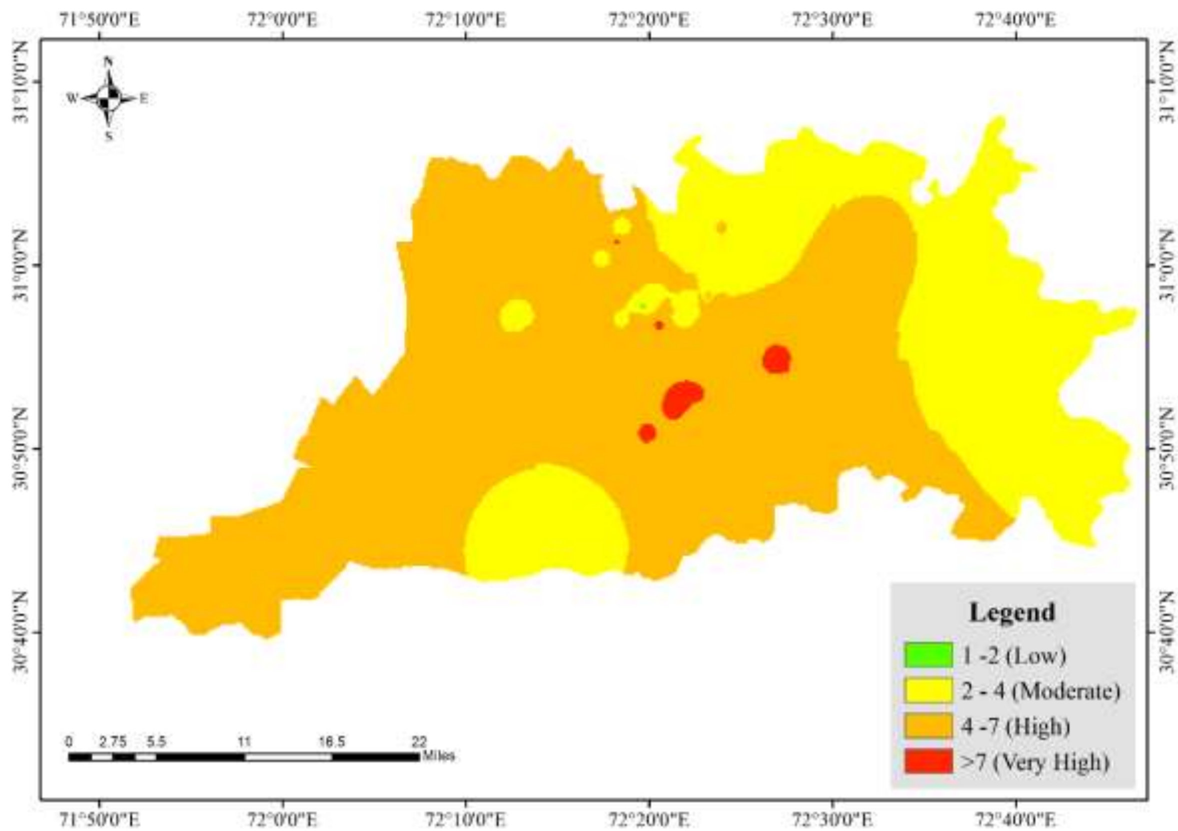

Figure 3.10 EC Map 2009

F. Ground data set predicted 2010

The EC and SAR Standard Deviation is 0.69 dS/m and 12.11 mmol as justified in the table 3.8 as a result the areas showing maximum EC and SAR values are referred as highly saline and the areas presenting minimum EC and SAR values are referred as Moderate saline. Seven main study variables; EC, SAR, NDVI, NDMI, SI1, SI3 and NDSI were utilized for the conduction of statistical analysis. Slightest rise in values have been observed after one year.

Table 3.8 Descriptive Statistics of EC, SAR, and Indices of 2010						
	N	**Range**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
EC	32	2.95	4.83	7.78	6.13	0.69
SAR	32	48.61	9.11	57.72	25.22	12.11
NDVI	32	0.29	-0.28	0.01	-0.10	0.09
NDMI	32	0.21	-0.26	-0.06	-0.18	0.06
SI1	32	0.16	0.20	0.36	0.29	0.04
SI3	32	0.20	0.12	0.32	0.18	0.04
NDSI	32	0.29	-0.01	0.28	0.10	0.09

The SAR map (figure 3.11) of 2010 predicts that the maximum study area in orange reveals moderate saline part ranging from (18-26mmol) whereas the red part exhibits highly saline area ranging from (>26mmol). Comparing with the map of 2009 the salinity in the area under study has increased minutely hence indicating very small growth in highly saline area. The non-saline part covers only one spots ranging from (<10mmol) thus indicating scant non-saline area.

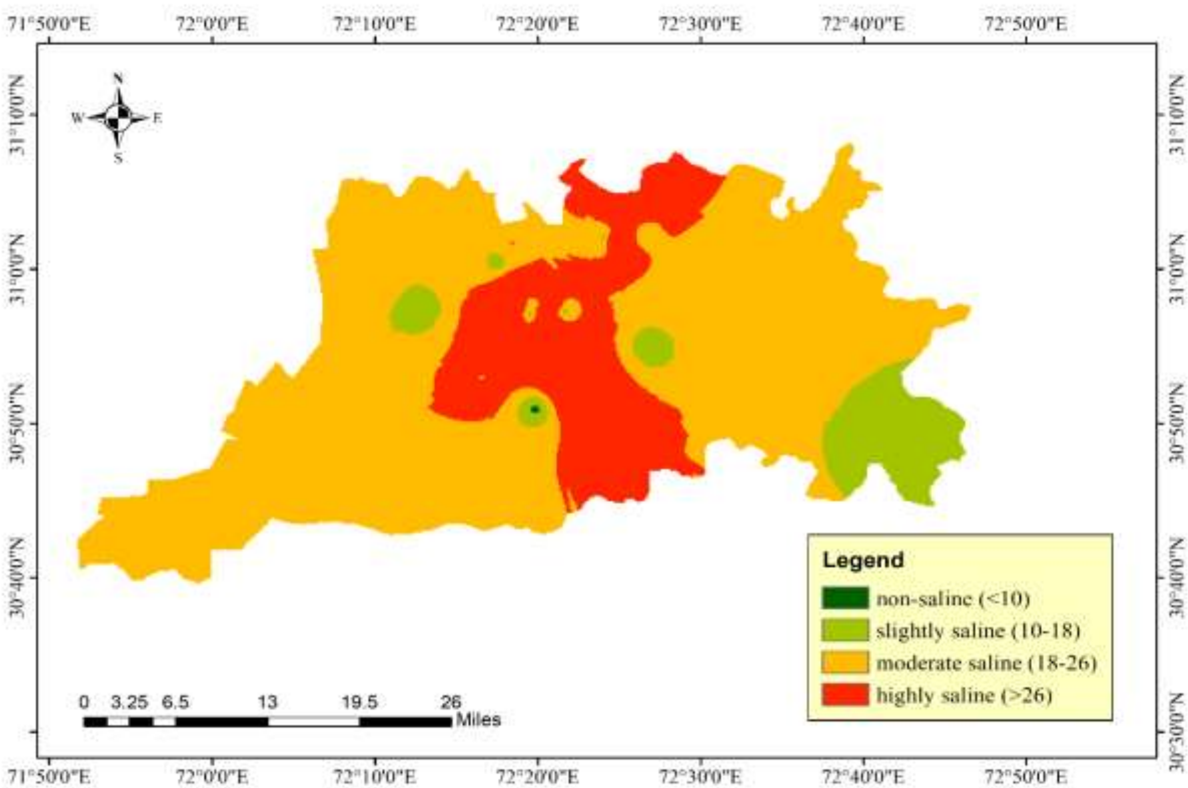

Figure 3.11 SAR Map 2010

According to the EC map (figure 3.12) of 2010 the study area in light green (slightly Saline) has completely wiped out with the value ranging from (1-2 dS/m) whereas the region showing yellow color is moderately saline with the value ranging from (2-4 dS/m). The yellow part has dropped vaguely in last one year. Moreover, the orange depicting high soil salinity with EC value ranging from (4-7 dS/m). The spots in red indicate extremely high saline areas ranging from (>7dS/m) and it has increased in the last year.

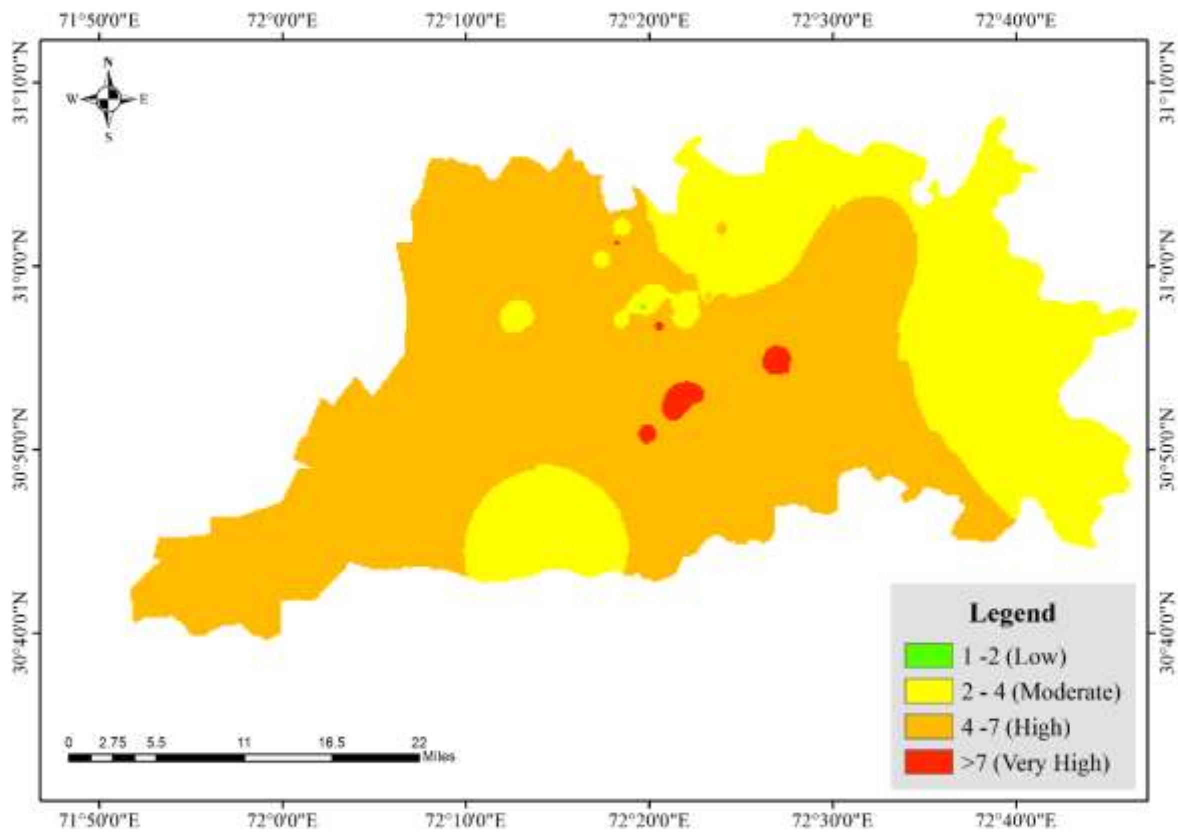

Figure 3.12 EC Map 2010

G. Ground data set predicted 2015

The EC and SAR mean values 6.24 dS/m and 26.12 dS/m are this as stated in table 3.9 which refers all the area adjacent to sampling points. Showing maximum EC and SAR values are referred as highly saline and the areas presenting minimum EC and SAR values are referred as Moderate saline. Seven main study variables; EC, SAR, NDVI, NDMI, SI1, SI3 and NDSI were utilized for the conduction of statistical analysis. Continues rise in values have been observed after five years.

Table 3.9 Descriptive Statistics of EC, SAR, and Indices of 2015

	N	**Range**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
EC	32	2.95	4.94	7.89	6.24	0.69
SAR	32	48.62	10.01	58.62	26.12	12.11
NDVI	32	0.28	-0.38	-0.10	-0.24	0.08
NDMI	32	0.25	0.01	0.26	0.11	0.06
SI1	32	0.12	-0.03	0.09	0.04	0.03
SI3	32	0.04	0.07	0.12	0.09	0.01
NDSI	32	0.28	0.10	0.38	0.24	0.08

The SAR map of 2015 (figure 3.13) predicts that the maximum study area in orange reveals moderate saline part ranging from (18-26mmol) whereas the red part exhibits highly saline area ranging from (>26mmol). Comparing with the map of 2009 the salinity in the area under study has exceptionally increased hence indicating extensive growth in highly saline area in past five years. The non-saline part has completely drawn out ranging from (<10mmol) whereas the slightly saline portion covers only small study area ranging from (10-18mmol).

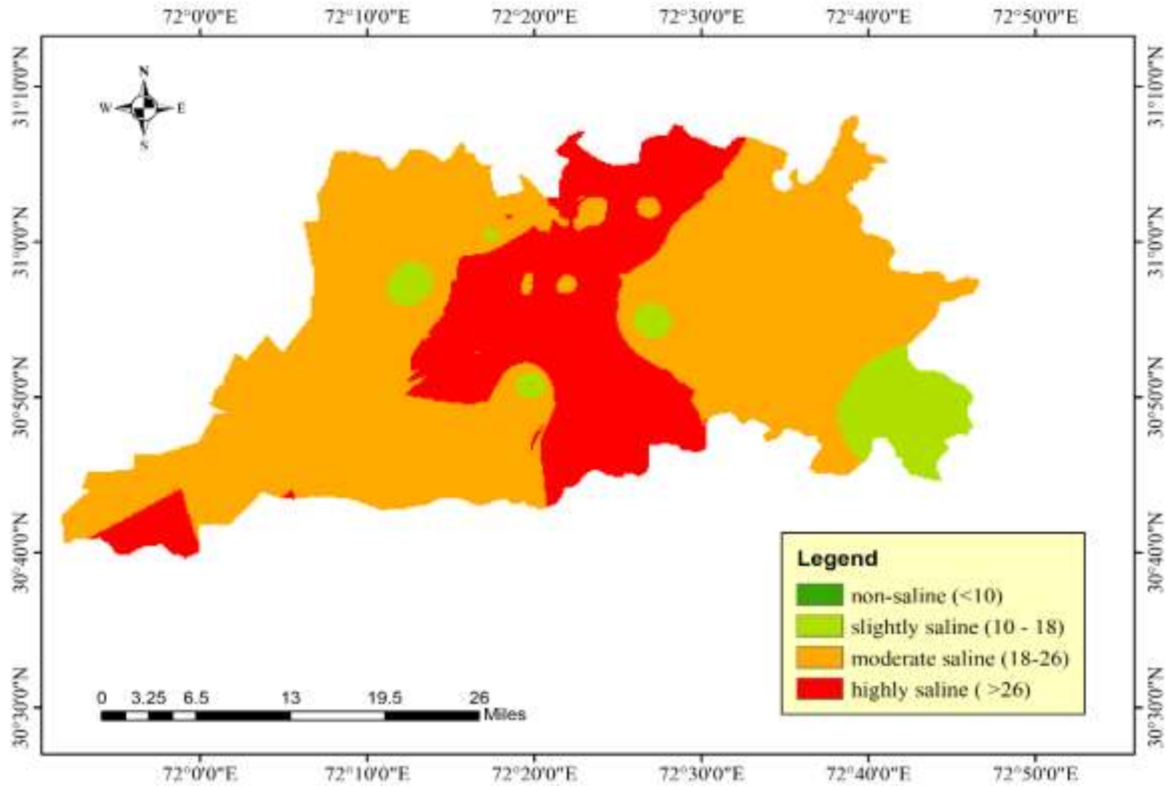

Figure 3.13 SAR Map 2015

According to the EC map (figure 3.14) of 2015 the study area in light green (slightly Saline) has drawn out with the value ranging from (1-2 dS/m) whereas the region showing yellow color is moderately saline with the value ranging from (2-4 dS/m). The yellow part has dropped significantly in the last two years. Moreover, the orange depicting high soil salinity with EC value ranging from (4-7 dS/m). The spots in red indicate extremely high saline areas ranging from (>7dS/m) and it has increased distinctly in the last five years.

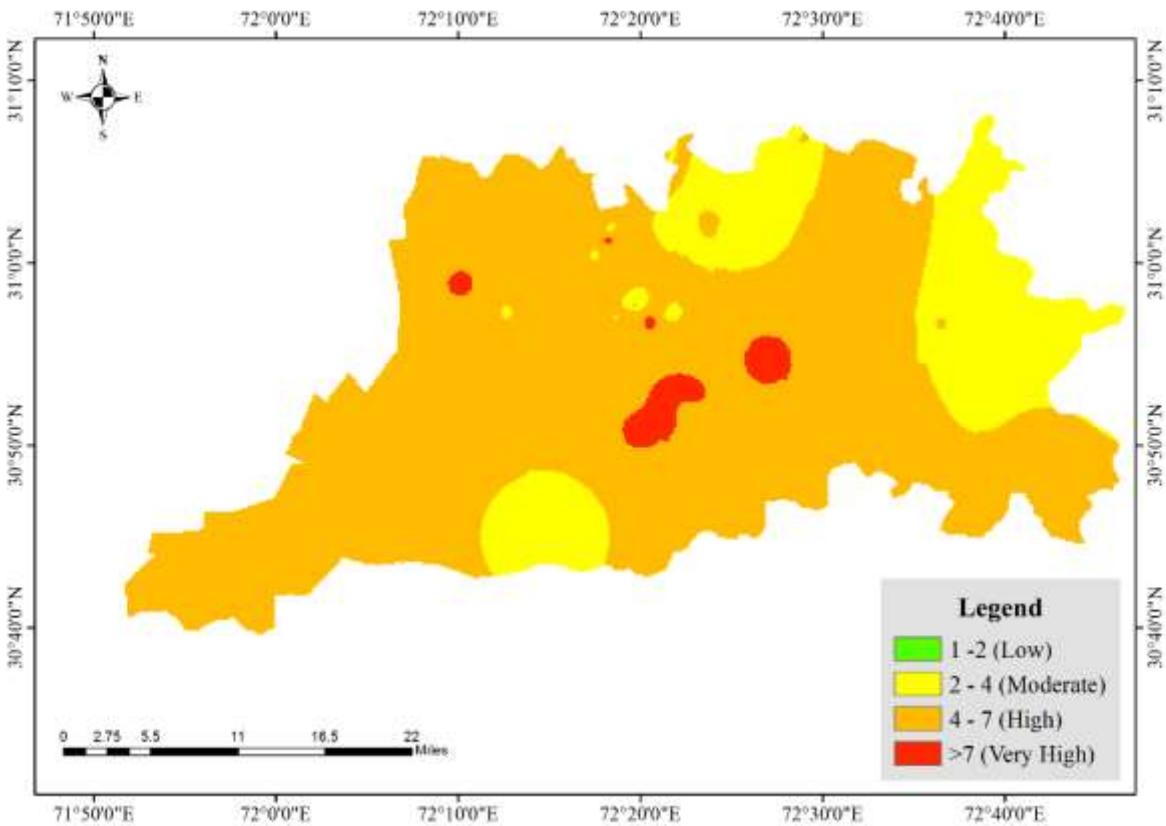

Figure 3.14 EC Map 2015

H. Ground data set predicted 2017

The statistical tabular (table 3.10) calculated states that all the area adjacent to sampling points had maximum EC value of 8.00 dS/m and SAR value of 59.13 mmol whereas all the area away from the sampling points had minimum EC value of 5.05 dS/m and SAR value of 10.59 mmol as a result the areas showing maximum EC and SAR values are referred as highly saline and the areas presenting minimum EC and SAR values are referred as Moderate saline. Seven main study variables; EC, SAR, NDVI, NDMI, SI1, SI3 and NDSI were utilized for the conduction of statistical analysis. Continues rise in values have been observed after two years.

Table 3.10 Descriptive Statistics of EC, SAR, and Indices of 2017

	N	**Range**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
EC	32	2.95	5.05	8.00	6.35	0.69
SAR	32	48.54	10.59	59.13	26.64	12.10
NDVI	32	0.10	-0.17	-0.07	-0.12	0.03
NDMI	32	0.13	-0.01	0.13	0.05	0.03
SI1	32	0.06	0.01	0.07	0.03	0.01
SI3	32	0.02	0.09	0.11	0.10	0.01
NDSI	32	0.10	0.07	0.17	0.12	0.03

The SAR map of 2017 (figure 3.15) predicts that the maximum study area in orange reveals moderate saline part ranging from (18-26mmol) whereas the red part exhibits highly saline area ranging from (>26mmol). Comparing with the map of 2015 the salinity in the area under study has extremely increased hence indicating rapid and massive growth in highly saline area in past two years. The non-saline part has completely drawn out ranging from (<10mmol) whereas the slightly saline portion covers only small study area ranging from (10-18mmol).

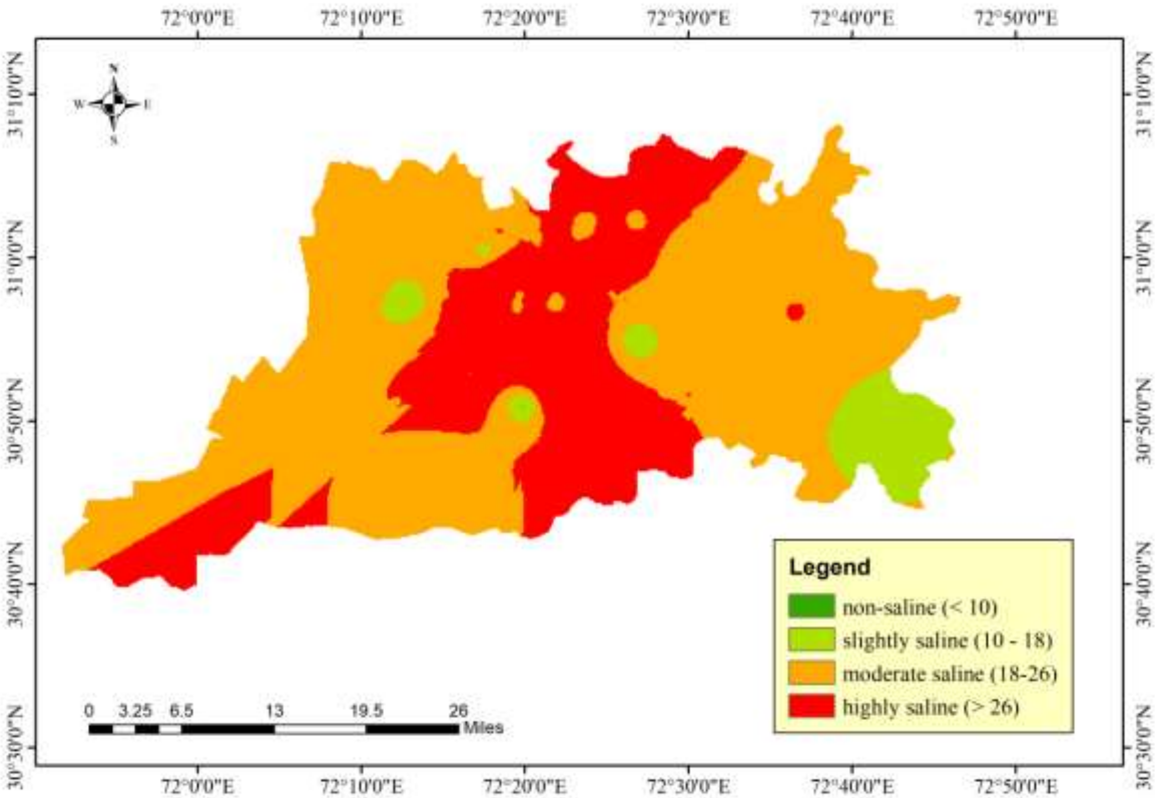

Figure 3.15 SAR Map 2017

According to the EC map (figure 3.16) of 2015 the study area in light green (slightly Saline) has wholly wiped off with the value ranging from (1-2 dS/m) whereas the region showing yellow color is moderately saline with the value ranging from (2-4 dS/m). The yellow part has dropped tremendously in the last five years. Moreover, the orange depicting high soil salinity with EC value ranging from (4-7 dS/m). The spots in red indicate highly saline areas ranging from (>7dS/m) and it has greatly increased in the last two years.

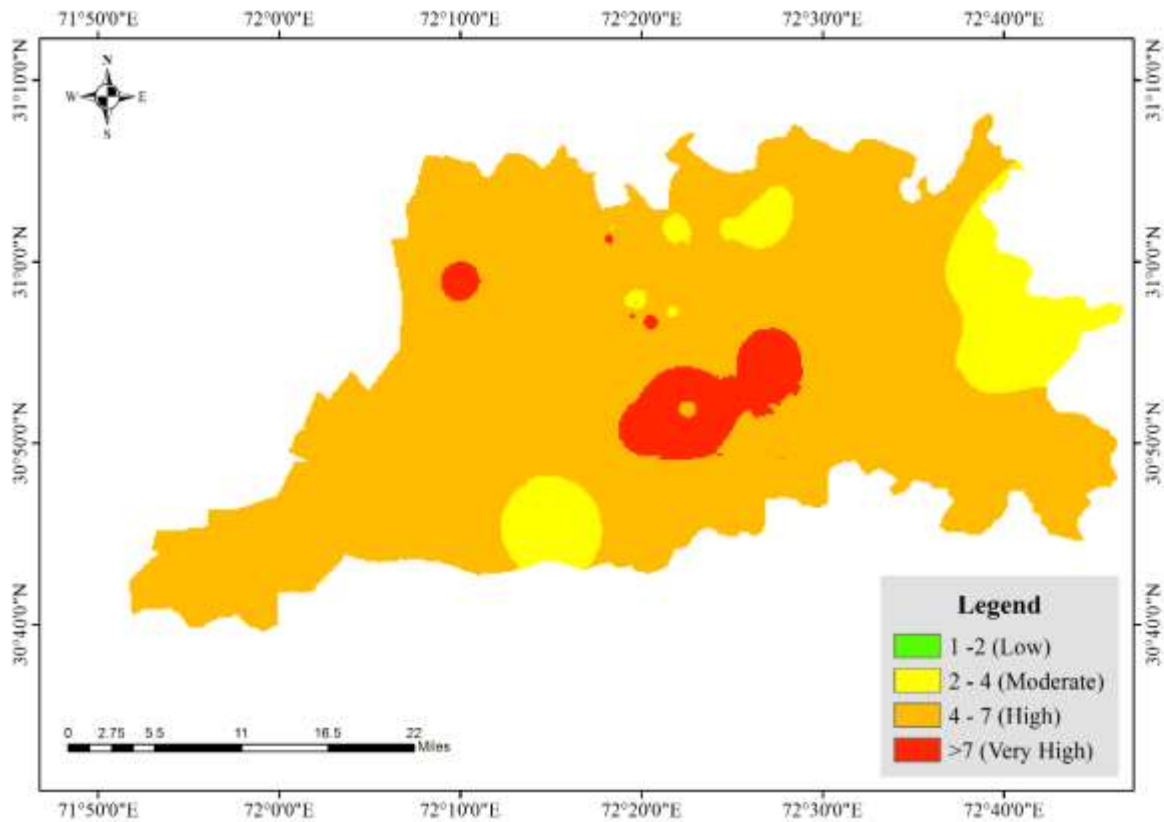

Figure 3.16 EC Map 2017

I. Ground data set predicted 2020

It is predicted that maximum values for EC and SAR in 2020 were 8.23 dS/m and 59.73 mmol as evident in table 3.11 below whereas all the area away from the sampling points had minimum EC value of 5.28 dS/m and SAR value of 11.11 mmol as a result the areas showing maximum EC and SAR values are referred as highly saline and the areas presenting minimum EC and SAR values are referred as Moderate saline. Seven main study variables; EC, SAR, NDVI, NDMI, SI1, SI3 and NDSI were utilized for the conduction of statistical analysis. Continues rise in values have been observed after three years.

Table 3.11 Descriptive Statistics of EC, SAR, and Indices of 2020

	N	Range	Minimum	Maximum	Mean	Std. Deviation
EC	32	2.95	5.28	8.23	6.58	0.69
SAR	32	48.62	11.11	59.73	27.22	12.11
NDVI	32	0.26	-0.33	-0.07	-0.19	0.07
NDMI	32	0.25	-0.03	0.22	0.08	0.06
SI1	32	0.13	-0.06	0.07	0.02	0.03
SI3	32	0.05	0.08	0.13	0.09	0.01
NDSI	32	0.26	0.07	0.33	0.19	0.07

The SAR map of 2020 (figure 3.17) predicts that the maximum study area in orange reveals moderate saline part ranging from (18-26mmol) whereas the maximum study area showing red part exhibits highly saline area ranging from (>26mmol). Comparing with the map of 2017 the salinity in the area under study has increased hence indicating rapid and massive growth in highly saline area in past three years. The non-saline part has completely drawn out ranging from (<10mmol) whereas the slightly saline portion covers only small patches ranging from (10-18mmol).

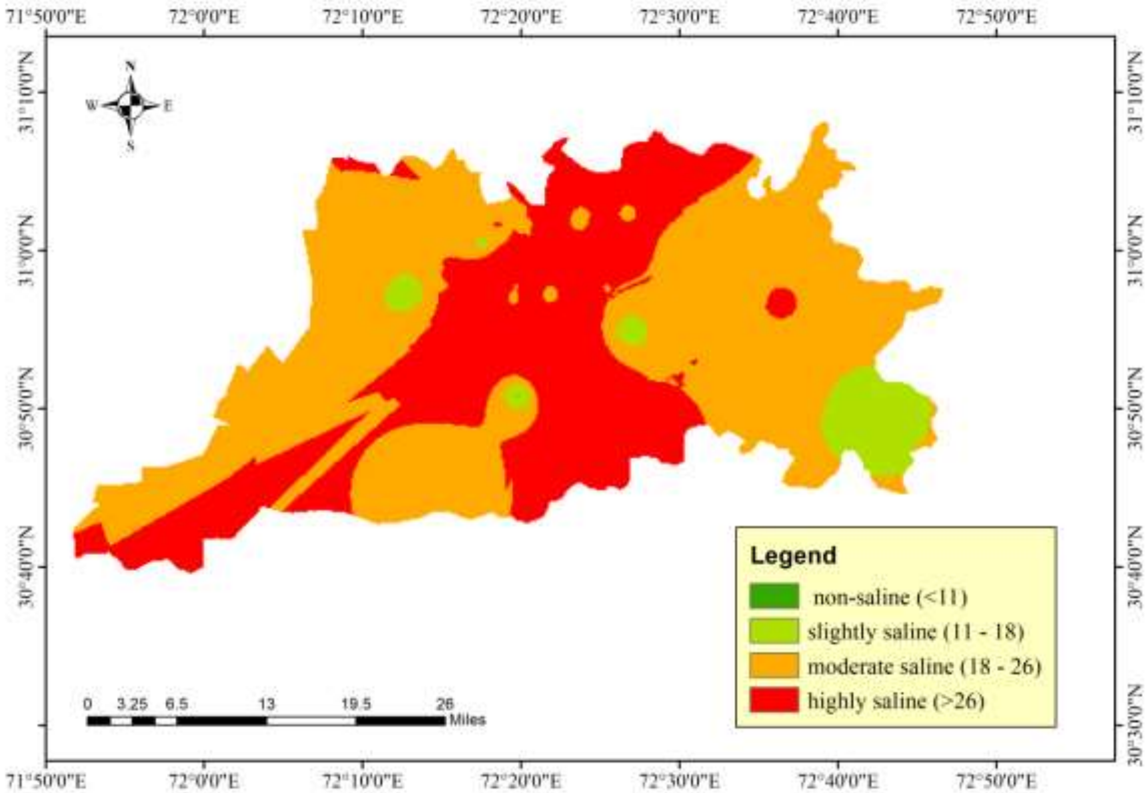

Figure 3.17 SAR Map 2020

According to the EC map (figure 3.18) of 2020 the study area in light green (slightly Saline) has wholly wiped off with the value ranging from (1-2 dS/m) whereas the region showing yellow color is moderately saline with the value ranging from (2-4 dS/m). The yellow part has dropped tremendously in the last five years left with small patches. Moreover, the orange depicting high soil salinity with EC value ranging from (4-7 dS/m). The spots in red indicate highly saline areas ranging from (>7dS/m) and it has significantly increased in the last three years. Evaluating the SAR and EC maps of 2020 with other years there is a continual increase in salinity from non-saline to extremely saline area this proves that there is constant change in the salinity from very low to very high salinity.

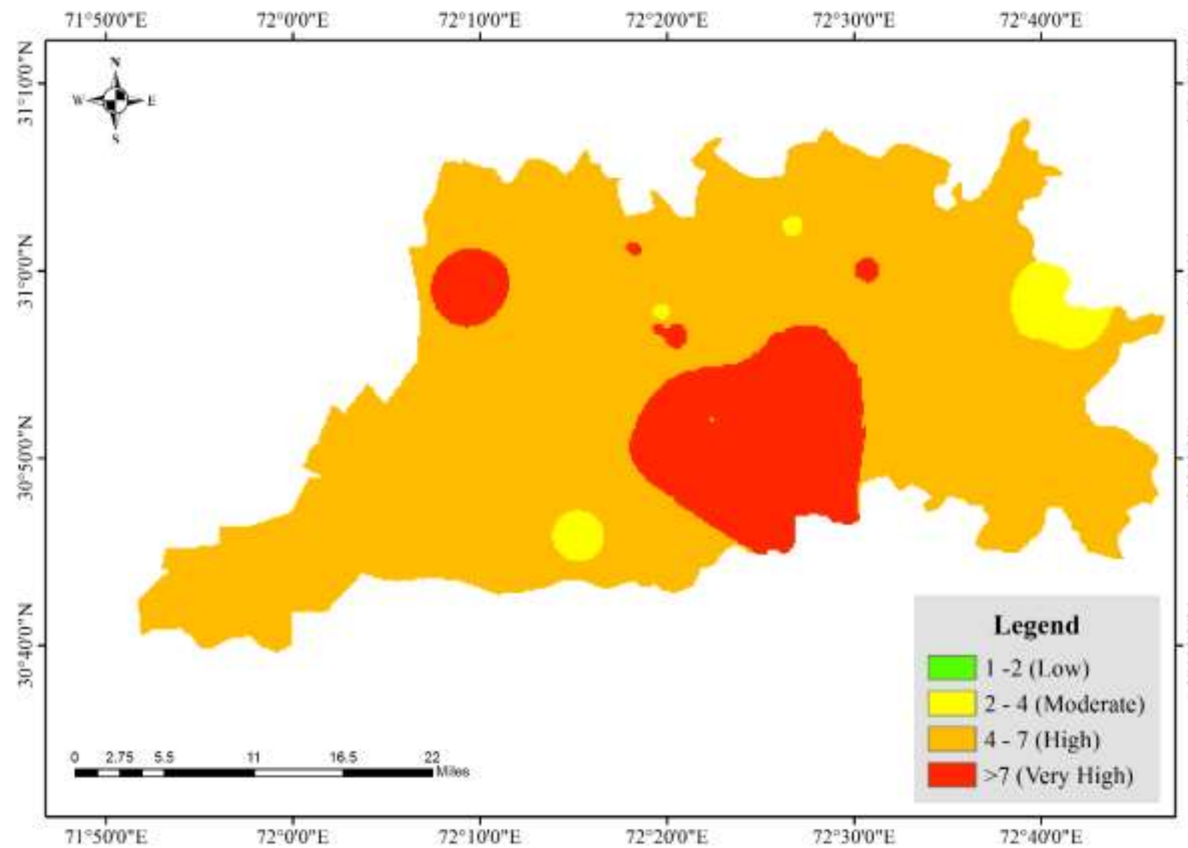

Figure 3.18 EC Map 2020

CONCLUSIONS

The study concludes with attention seeking and well-defined lessons proved with evidence relevant to Soil Salinity status in Toba Tek Singh and Shorkot precincts of populous province of Pakistan, Central Punjab. The lack of study on the topic led to the conduction of research on crucial soil salinity by acquiring data via soil sampling for Ground dataset collection and Remote Sensing for Landsat satellite imagery from 1996 to 2021.

Soil sampling conducted in 2021 therefore displayed maximum EC analyzed was 17.8 dS/m and SAR was 135.10 mmol depicting the ratios have reached far beyond the acceptable levels of salinity in vegetated inherit regions of areas under study. Multiple Linear Regression model established on ArcGIS 10.4.1 software keeping ground dataset as dependent variable and satellite derived salinity and vegetation indices as independent variables exhibited the principle positively influenced relationship between field dataset and salinity indices specifically. This correlation again concludes and proves the constant growth in soil salinity.

Following the model, predicted soil salinity maps generated for Toba Tek Singh and Shorkot by efficient, precise, and relatively accurate IDW technology based on EC and SAR classified into four types has clearly indicated a gradual and consecutive overall rise in soil salinity with both significant EC and SAR soil parameters exacerbating the values allocated for highly saline area since past 20 years regardless of their rate. The difference calculated amid EC values from 1996 to 2020 refers to an increase of 3.39 dS/m while SAR presented an increase of 49.74 mmol during the mentioned years.

Inclusive of all the above-mentioned outcomes it is comprehensively declared the issue of soil salinity in Toba Tek Singh and Shorkot is currently on urge and needs to be considered immediately to restrict its further spread, prohibit its intensity, and mitigate its consequences to protect the crop associated regions of study area, habitat and prevent them from further getting degraded.

RECOMMENDATIONS

Soil sampling is an expensive, time-consuming, and requires intensive labor task, one soil specialist and two laborers must be available to conduct soil sampling. Landsat satellite imagery is now publicly accessible over the website USGS. As a result, integrating GIS and remote sensing to map soil salinity is very cost-effective and provides a better level of spatial reliability.

The recommendations are given as follows.

1. A comprehensive study must be conducted in Central Punjab to find the anthropogenic source of salinity in the soil.

2. Soil salinity of the study area must be monitored periodically to check whether the contributing factors are being controlled or not.

3. To bring back the original potential of land source and for reclaiming the soil problems, new technological options should be made available to the farmer working on fields.

4. Government must take an initiative and provide funds for the installation of skimming wells or fractional wells to exploit fresh water for irrigation in the region of Toba Tek Singh and Shorkot.

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APPENDIX I

Detail analysis of 1996

Sr. #	Village	EC	SAR	NDVI	NDMI	SI1	SI3	NDSI
1.	297/GB	5.7109	10.6801	-0.1351	-0.1310	0.2782	0.0230	0.1351
2.	182/GB	3.7373	17.2549	-0.3592	0.0370	0.3945	0.0150	0.3592
3.	344/GB	6.3914	47.1234	-0.1321	-0.1608	0.2977	0.0220	0.1321
4.	315/GB	5.6652	7.1576	-0.2523	-0.0629	0.3388	0.0180	0.2523
5.	194/GB	4.5704	8.8357	-0.1646	-0.0417	0.3774	0.0140	0.1646
6.	183/GB	4.5041	22.1371	-0.2952	-0.0286	0.3393	0.0170	0.2952
7.	700/42/GB	4.0038	19.7966	-0.1042	-0.1017	0.3120	0.0190	0.1042
8.	700/42/GB	4.0935	15.2070	-0.1868	-0.0609	0.3621	0.0160	0.1868
9.	344/GB	5.0987	34.8466	-0.2110	-0.0959	0.3228	0.0200	0.2110
10.	408/JB	4.7970	21.8779	-0.0080	-0.1871	0.2393	0.0300	0.0080
11.	252/GB	4.2587	16.9201	-0.2115	-0.0735	0.3051	0.0190	0.2115
12.	323/JB	5.2280	16.0675	-0.2353	-0.0597	0.3333	0.0180	0.2353
13.	Chak 407, JB	4.1894	12.3522	-0.2079	-0.0827	0.3443	0.0180	0.2079
14.	Boti wala	4.4804	8.6582	-0.0909	-0.1892	0.2806	0.0240	0.0909
15.	Toba Wariam Road	3.4445	21.4332	-0.0816	-0.1520	0.3023	0.0200	0.0816
16.	Toba Wariam Road	5.4815	13.4917	-0.2039	-0.0313	0.3333	0.0190	0.2039
17.	Toba Wariam Road	4.6473	29.5176	-0.1961	-0.0827	0.3279	0.0190	0.1961
18.	Chak No. 400 JB, Link Road	5.8442	55.7746	-0.0577	-0.1406	0.2687	0.0230	0.0577
19.	Chak No. 400 JB, Wariam Road	4.4792	40.9748	-0.0400	-0.1667	0.2405	0.0300	0.0400
20.	Chak No. 400 JB, Wariam Road	5.0029	32.0126	0.0084	-0.1973	0.2208	0.0300	-0.0084
21.	Chak No. 399, JB	5.5992	20.7167	0.0376	-0.1847	0.2023	0.0350	-0.0376
22.	Chak No. 399, JB	5.1380	39.9125	-0.0286	-0.1429	0.2609	0.0250	0.0286
23.	Chak No. 324 JB	4.4263	11.4068	-0.0339	-0.1286	0.2245	0.0280	0.0339
24.	Chak No. 469 JB	4.1925	15.0461	-0.0566	-0.1942	0.2806	0.0240	0.0566
25.	Chak No. 469 JB	4.2833	23.2594	-0.1321	-0.1608	0.3083	0.0220	0.1321
26.	Chak No. 469 JB	4.6777	29.0011	-0.0084	-0.2157	0.2338	0.0290	0.0084
27.	Chak No. 469 JB	5.8154	17.4974	-0.1589	-0.1389	0.2969	0.0220	0.1589
28.	Chak No. 383JB	4.1640	31.5932	0.0192	-0.2154	0.2429	0.0260	-0.0192
29.	Chak No. 383JB	4.7959	13.2553	-0.0450	-0.1714	0.2587	0.0250	0.0450
30.	Chak No.383JB	4.0213	19.1181	-0.1048	-0.1212	0.2932	0.0210	0.1048
31.	Chak No. 388JB	4.4292	30.3757	-0.0442	-0.1806	0.2394	0.0270	0.0442
32.	Chak No. 388JB	4.4839	40.4781	-0.1712	-0.0780	0.2923	0.0220	0.1712

APPENDIX II

Detail analysis of 1998

Sr #	Village	EC	SAR	NDVI	NDMI	SI1	SI3	NDSI
1.	297/GB	5.8409	10.8401	-0.1351	-0.0959	0.3211	0.1700	0.1351
2.	182/GB	3.8673	17.4049	-0.3592	0.1408	0.4222	0.1200	0.3592
3.	344/GB	6.5214	47.2234	-0.1321	-0.1618	0.2742	0.2200	0.1321
4.	315/GB	5.7952	7.3076	-0.2523	-0.2113	0.2263	0.2700	0.2523
5.	194/GB	4.7004	8.9557	-0.1646	-0.0213	0.3895	0.1300	0.1646
6.	183/GB	4.6341	23.1471	-0.2952	0.1278	0.3763	0.1300	0.2952
7.	700/42/GB	4.1338	19.9466	-0.1042	-0.1348	0.2667	0.2100	0.1042
8.	700/42/GB	4.2235	15.3570	-0.1868	-0.1908	0.2615	0.2200	0.1868
9.	344/GB	5.2287	34.9966	-0.2110	-0.1679	0.2199	0.2700	0.2110
10.	408/JB	4.9270	22.0279	-0.0080	0.0483	0.3800	0.1400	0.0080
11.	252/GB	4.3887	17.0701	-0.2115	-0.1259	0.3084	0.1600	0.2115
12.	323/JB	5.3580	16.2175	-0.2353	-0.0229	0.3148	0.1700	0.2353
13.	Chak 407, JB	4.3194	12.5022	-0.2079	-0.0365	0.3208	0.1600	0.2079
14.	Boti wala	4.6104	8.8082	-0.0909	-0.2129	0.2129	0.3100	0.0909
15.	Toba Wariam Road	3.5745	21.5832	-0.0816	-0.0333	0.3673	0.1300	0.0816
16.	Toba Wariam Road	5.6115	13.6417	-0.2039	0.0345	0.3269	0.1600	0.2039
17.	Toba Wariam Road	4.7773	29.6676	-0.1961	-0.1579	0.3274	0.1700	0.1961
18.	Chak No. 400 JB, Link Road	5.9742	55.9246	-0.0577	-0.1385	0.2742	0.2200	0.0577
19.	Chak No. 400 JB, Wariam Road	4.6092	41.1248	-0.0400	-0.1729	0.2409	0.2500	0.0400
20.	Chak No. 400 JB, Wariam Road	5.1329	32.1626	0.0084	-0.0405	0.2821	0.2100	-0.0084
21.	Chak No. 399, JB	5.7292	20.8667	0.0376	-0.1667	0.2125	0.3200	-0.0376
22.	Chak No. 399, JB	5.2680	40.0625	-0.0286	-0.1484	0.1918	0.3100	0.0286
23.	Chak No. 324 JB	4.5563	11.5568	-0.0339	-0.1079	0.3109	0.1900	0.0339
24.	Chak No. 469 JB	4.3225	15.1961	-0.0566	-0.0963	0.2920	0.1900	0.0566
25.	Chak No. 469 JB	4.4133	23.4094	-0.1321	0.0780	0.3878	0.1400	0.1321
26.	Chak No. 469 JB	4.8077	29.1511	-0.0084	-0.2674	0.1829	0.3600	0.0084
27.	Chak No. 469 JB	5.9454	17.6474	-0.1589	-0.1818	0.2319	0.2600	0.1589
28.	Chak No. 383JB	4.2940	31.7432	0.0192	-0.2245	0.1892	0.3100	-0.0192
29.	Chak No. 383JB	4.9259	13.4053	-0.0450	-0.2208	0.2113	0.2900	0.0450
30.	Chak No.383JB	4.1513	19.2681	-0.1048	-0.0159	0.3592	0.1500	0.1048
31.	Chak No. 388JB	4.5592	30.5257	-0.0442	-0.1642	0.2615	0.2400	0.0442
32.	Chak No. 388JB	4.6139	40.6281	-0.1712	-0.0429	0.2581	0.2200	0.1712

APPENDIX III

Detail analysis of 2000

Sr #	Village	EC	SAR	NDVI	NDMI	SI1	SI3	NDSI
1.	297/GB	6.0809	10.9401	-0.1025	-0.2125	0.2168	0.2800	0.1025
2.	182/GB	4.1073	17.5049	0.0860	-0.0240	0.3830	0.1200	-0.0860
3.	344/GB	6.7614	47.3734	-0.0656	-0.1756	0.2696	0.2000	0.0656
4.	315/GB	6.0352	7.4076	-0.0874	-0.1974	0.2248	0.2600	0.0874
5.	194/GB	4.9404	9.0557	-0.0438	-0.1538	0.3814	0.1200	0.0438
6.	183/GB	4.8741	23.2471	0.0503	-0.0597	0.3137	0.1600	-0.0503
7.	700/42/GB	4.3738	20.0466	-0.0415	-0.1515	0.2500	0.2300	0.0415
8.	700/42/GB	4.4635	15.4570	-0.0969	-0.2069	0.2437	0.2200	0.0969
9.	344/GB	5.4687	35.0966	-0.1116	-0.2216	0.1572	0.3700	0.1116
10.	408/JB	5.1670	22.1279	-0.1057	-0.2157	0.1918	0.2900	0.1057
11.	252/GB	4.6287	17.1701	0.0076	-0.1024	0.3469	0.1500	-0.0076
12.	323/JB	5.5980	16.3175	0.0273	-0.0827	0.3600	0.1400	-0.0273
13.	Chak 407, JB	4.5594	12.6022	-0.0742	-0.1842	0.2381	0.2400	0.0742
14.	Boti wala	4.8504	8.9082	-0.1650	-0.2750	0.2083	0.3000	0.1650
15.	Toba Wariam Road	3.8145	21.6832	0.0645	-0.0455	0.3267	0.1500	-0.0645
16.	Toba Wariam Road	5.8515	13.7417	0.0238	-0.0862	0.3084	0.1700	-0.0238
17.	Toba Wariam Road	5.0173	29.7676	-0.1229	-0.2329	0.2059	0.2700	0.1229
18.	Chak No. 400 JB, Link Road	6.2142	56.0246	-0.1052	-0.2152	0.1948	0.3200	0.1052
19.	Chak No. 400 JB, Wariam Road	4.8492	41.2248	-0.0775	-0.1875	0.2174	0.2700	0.0775
20.	Chak No. 400 JB, Wariam Road	5.3729	32.2626	-0.1033	-0.2133	0.2214	0.2600	0.1033
21.	Chak No. 399, JB	5.9692	20.9667	-0.0835	-0.1935	0.1630	0.4200	0.0835
22.	Chak No. 399, JB	5.5080	40.1625	-0.0792	-0.1892	0.1942	0.2900	0.0792
23.	Chak No. 324 JB	4.7963	11.6568	-0.0590	-0.1690	0.2086	0.2800	0.0590
24.	Chak No. 469 JB	4.5625	15.2961	0.0645	-0.0455	0.3398	0.1500	-0.0645
25.	Chak No. 469 JB	4.6533	23.5094	-0.0210	-0.1310	0.2403	0.2500	0.0210
26.	Chak No. 469 JB	5.0477	29.2511	-0.1532	-0.2632	0.1975	0.3300	0.1532
27.	Chak No. 469 JB	6.1854	17.7474	-0.0438	-0.1538	0.2773	0.2000	0.0438
28.	Chak No. 383JB	4.5340	31.8432	-0.0780	-0.1880	0.2683	0.2100	0.0780
29.	Chak No. 383JB	5.1659	13.5053	-0.1047	-0.2147	0.1847	0.3400	0.1047
30.	Chak No.383JB	4.3913	19.3681	-0.0567	-0.1667	0.2931	0.1900	0.0567
31.	Chak No. 388JB	4.7992	30.6257	0.0294	-0.0806	0.3036	0.1800	-0.0294
32.	Chak No. 388JB	4.8539	40.7281	0.0026	-0.1074	0.3036	0.1800	-0.0026

APPENDIX IV

Detail analysis of 2008

Sr. #	Village	EC	SAR	NDSI	NDMI	SI	SI3	NDVI
1.	297/GB	7.0810	12.3400	-0.1833	-0.1069	0.3050	0.2300	0.1833
2.	182/GB	5.1070	18.9000	-0.3782	0.0581	0.3729	0.1600	0.3782
3.	344/GB	7.7610	48.7300	-0.2320	-0.0435	0.3143	0.2200	0.2320
4.	315/GB	7.0350	8.8100	-0.1270	-0.1069	0.2715	0.2600	0.1270
5.	194/GB	5.9400	10.4600	-0.3739	0.0676	0.3793	0.1600	0.3739
6.	183/GB	5.8740	24.6500	-0.3554	-0.0120	0.3607	0.1700	0.3554
7.	700/42/GB	5.3740	21.4500	-0.0880	-0.1338	0.2597	0.2800	0.0880
8.	700/42/GB	5.4640	16.8600	-0.0690	-0.1014	0.2752	0.2700	0.0690
9.	344/GB	6.4690	36.5000	-0.1852	-0.0643	0.2715	0.2700	0.1852
10.	408/JB	6.1670	23.5300	-0.0222	-0.1266	0.2370	0.3300	0.0222
11.	252/GB	5.6290	18.5700	-0.1864	-0.0541	0.2993	0.2300	0.1864
12.	323/JB	6.5980	17.7200	-0.2397	-0.0323	0.3134	0.2200	0.2397
13.	Chak 407, JB	5.5590	14.0000	-0.0079	-0.1688	0.2364	0.3100	0.0079
14.	Boti wala	5.8500	10.3100	-0.3279	-0.0061	0.3692	0.1900	0.3279
15.	Toba Wariam Road	4.8140	23.0800	-0.2522	-0.0464	0.3534	0.1900	0.2522
16.	Toba Wariam Road	6.8510	15.1400	-0.0698	-0.1210	0.2593	0.2800	0.0698
17.	Toba Wariam Road	6.0170	31.1700	0.0000	-0.1389	0.2346	0.3100	0.0000
18.	Chak No. 400 JB, Link Road	7.2140	57.4200	-0.0606	-0.1908	0.2393	0.3100	0.0606
19.	Chak No. 400 JB, Wariam Road	5.8490	42.6200	0.0191	-0.1809	0.2040	0.4100	-0.0191
20.	Chak No. 400 JB, Wariam Road	6.3730	33.6600	-0.1163	-0.0588	0.2875	0.2700	0.1163
21.	Chak No. 399, JB	6.9690	22.3700	-0.0490	-0.1803	0.2273	0.3500	0.0490
22.	Chak No. 399, JB	6.5080	41.5600	-0.0882	-0.1494	0.2530	0.3000	0.0882
23.	Chak No. 324 JB	5.7960	13.0600	-0.2727	-0.0191	0.3383	0.2000	0.2727
24.	Chak No. 469 JB	5.5620	16.7000	-0.2480	-0.0064	0.3188	0.2200	0.2480
25.	Chak No. 469 JB	5.6530	24.9100	-0.2520	0.0132	0.3285	0.2100	0.2520
26.	Chak No. 469 JB	6.0480	30.6500	-0.0615	-0.1687	0.2515	0.2900	0.0615
27.	Chak No. 469 JB	7.1850	19.1500	-0.3153	0.0429	0.3770	0.1700	0.3153
28.	Chak No. 383JB	5.5340	33.2400	-0.3000	0.0263	0.3488	0.1900	0.3000
29.	Chak No. 383JB	6.1660	14.9100	0.0159	-0.1842	0.2381	0.3200	-0.0159
30.	Chak No.383JB	5.3910	20.7700	-0.1327	-0.0791	0.3050	0.2200	0.1327
31.	Chak No. 388JB	5.7990	32.0300	-0.0877	-0.1206	0.2828	0.2500	0.0877
32.	Chak No. 388JB	5.8540	42.1300	-0.1385	-0.1243	0.2727	0.2700	0.1385

APPENDIX V

Detail analysis of 2009

Sr. #	Village	EC	SAR	NDVI	NDMI	SI1	SI3	NDSI
1.	297/GB	7.091	12.440	-0.231	-0.038	0.350	0.170	0.231
2.	182/GB	5.117	19.000	-0.387	0.041	0.409	0.150	0.387
3.	344/GB	7.771	48.870	-0.145	-0.113	0.309	0.220	0.145
4.	315/GB	7.045	8.910	-0.200	-0.090	0.328	0.200	0.200
5.	194/GB	5.950	10.560	-0.215	-0.044	0.323	0.200	0.215
6.	183/GB	5.884	24.750	-0.302	-0.021	0.378	0.160	0.302
7.	700/42/GB	5.384	21.550	-0.135	-0.071	0.333	0.200	0.135
8.	700/42/GB	5.474	16.960	-0.173	-0.032	0.338	0.200	0.173
9.	344/GB	6.479	36.600	-0.164	-0.092	0.319	0.210	0.164
10.	408/JB	6.177	23.630	-0.229	-0.015	0.364	0.190	0.229
11.	252/GB	5.639	18.670	-0.164	-0.112	0.261	0.250	0.164
12.	323/JB	6.608	17.820	-0.292	-0.082	0.350	0.180	0.292
13.	Chak 407, JB	5.569	14.100	-0.327	0.027	0.372	0.180	0.327
14.	Boti wala	5.860	10.410	-0.183	-0.111	0.319	0.220	0.183
15.	Toba Wariam Road	4.824	23.180	-0.170	-0.095	0.338	0.200	0.170
16.	Toba Wariam Road	6.861	15.240	-0.145	-0.087	0.319	0.220	0.145
17.	Toba Wariam Road	6.027	31.270	-0.178	-0.060	0.348	0.190	0.178
18.	Chak No. 400 JB, Link Road	7.224	57.520	-0.071	-0.143	0.293	0.240	0.071
19.	Chak No. 400 JB, Wariam Road	5.859	42.720	0.025	-0.151	0.248	0.300	-0.025
20.	Chak No. 400 JB, Wariam Road	6.383	33.760	-0.183	-0.041	0.319	0.230	0.183
21.	Chak No. 399, JB	6.979	22.470	-0.008	-0.098	0.267	0.280	0.008
22.	Chak No. 399, JB	6.518	41.660	-0.094	-0.111	0.279	0.250	0.094
23.	Chak No. 324 JB	5.806	13.160	-0.069	-0.068	0.265	0.270	0.069
24.	Chak No. 469 JB	5.572	16.800	-0.091	-0.149	0.296	0.230	0.091
25.	Chak No. 469 JB	5.663	25.010	-0.261	0.007	0.343	0.210	0.261
26.	Chak No. 469 JB	6.058	30.750	-0.081	-0.143	0.292	0.240	0.081
27.	Chak No. 469 JB	7.195	19.250	-0.287	0.000	0.349	0.190	0.287
28.	Chak No. 383JB	5.544	33.340	-0.078	-0.133	0.269	0.250	0.078
29.	Chak No. 383JB	6.176	15.010	-0.054	-0.132	0.289	0.250	0.054
30.	Chak No.383JB	5.401	20.870	-0.216	-0.008	0.355	0.180	0.216
31.	Chak No. 388JB	5.809	32.130	-0.159	-0.088	0.323	0.210	0.159
32.	Chak No. 388JB	5.864	42.230	-0.123	-0.099	0.291	0.240	0.123

APPENDIX VI

Detail analysis of 2010

Sr. #	Village	EC	SAR	NDVI	NDSI	SI1	SI3	NDVI
1.	297/GB	7.1010	12.6400	-0.1190	-0.2101	0.2952	0.1800	0.1190
2.	182/GB	5.1270	19.2000	-0.1688	-0.2308	0.3191	0.1400	0.1688
3.	344/GB	7.7810	49.0700	-0.0602	-0.2143	0.2642	0.1900	0.0602
4.	315/GB	7.0550	9.1100	-0.0500	-0.2364	0.2897	0.1700	0.0500
5.	194/GB	5.9600	10.7600	-0.1351	-0.2222	0.3333	0.1400	0.1351
6.	183/GB	5.8940	24.9500	-0.2750	-0.0973	0.3556	0.1200	0.2750
7.	700/42/GB	5.3940	21.7500	-0.1724	-0.0973	0.3143	0.1700	0.1724
8.	700/42/GB	5.4840	17.1600	-0.0278	-0.1591	0.3069	0.1500	0.0278
9.	344/GB	6.4890	36.8000	-0.0444	-0.2419	0.2389	0.2100	0.0444
10.	408/JB	6.1870	23.8300	0.0115	-0.1963	0.2414	0.2100	-0.0115
11.	252/GB	5.6490	18.8700	-0.2632	-0.0840	0.3204	0.1700	0.2632
12.	323/JB	6.6180	18.0200	-0.2727	-0.0588	0.3333	0.1400	0.2727
13.	Chak 407, JB	5.5790	14.3000	-0.2152	-0.1351	0.3404	0.1400	0.2152
14.	Boti wala	5.8700	10.6100	-0.0390	-0.2157	0.2952	0.1700	0.0390
15.	Toba Wariam Road	4.8340	23.3800	-0.0556	-0.1915	0.3200	0.1500	0.0556
16.	Toba Wariam Road	6.8710	15.4400	-0.0732	-0.2072	0.2963	0.1700	0.0732
17.	Toba Wariam Road	6.0370	31.4700	-0.0256	-0.2157	0.2692	0.1900	0.0256
18.	Chak No. 400 JB, Link Road	7.2340	57.7200	-0.0297	-0.2061	0.2033	0.2500	0.0297
19.	Chak No. 400 JB, Wariam Road	5.8690	42.9200	0.0127	-0.1429	0.2727	0.2000	-0.0127
20.	Chak No. 400 JB, Wariam Road	6.3930	33.9600	-0.1364	-0.1304	0.3091	0.1800	0.1364
21.	Chak No. 399, JB	6.9890	22.6700	-0.0244	-0.2410	0.2000	0.3200	0.0244
22.	Chak No. 399, JB	6.5280	41.8600	0.0000	-0.2079	0.2661	0.1900	0.0000
23.	Chak No. 324 JB	5.8160	13.3600	-0.1059	-0.1826	0.2963	0.1800	0.1059
24.	Chak No. 469 JB	5.5820	17.0000	-0.0612	-0.2239	0.2459	0.2300	0.0612
25.	Chak No. 469 JB	5.6730	25.2100	-0.2439	-0.1429	0.3474	0.1300	0.2439
26.	Chak No. 469 JB	6.0680	30.9500	-0.0238	-0.2389	0.2613	0.1900	0.0238
27.	Chak No. 469 JB	7.2050	19.4500	-0.1899	-0.1754	0.3263	0.1400	0.1899
28.	Chak No. 383JB	5.5540	33.5400	-0.2771	-0.1167	0.3478	0.1300	0.2771
29.	Chak No. 383JB	6.1860	15.2100	0.0000	-0.2642	0.2909	0.1900	0.0000
30.	Chak No.383JB	5.4110	21.0700	-0.1389	-0.0787	0.3333	0.1300	0.1389
31.	Chak No. 388JB	5.8190	32.3300	-0.0909	-0.1845	0.3204	0.1500	0.0909
32.	Chak No. 388JB	5.8740	42.4300	-0.0467	-0.2329	0.2154	0.2600	0.0467

APPENDIX VII

Detail analysis of 2015

Sr. #	Village	EC	SAR	NDVI	NDMI	SI1	SI3	NDSI
1.	297/GB	7.2109	13.5401	-0.3434	0.1632	0.0683	0.0809	0.3434
2.	182/GB	5.2373	20.1049	-0.3809	0.2626	0.0890	0.0749	0.3809
3.	344/GB	7.8914	49.9734	-0.2807	0.1131	0.0447	0.0880	0.2807
4.	315/GB	7.1652	10.0076	-0.2841	0.1185	0.0428	0.0886	0.2841
5.	194/GB	6.0704	11.6557	-0.3185	0.1822	0.0760	0.0785	0.3185
6.	183/GB	6.0041	25.8471	-0.3620	0.1870	0.0692	0.0807	0.3620
7.	700/42/GB	5.5038	22.6466	-0.1694	0.0960	0.0353	0.0901	0.1694
8.	700/42/GB	5.5935	18.0570	-0.3087	0.1513	0.0568	0.0841	0.3087
9.	344/GB	6.5987	37.6966	-0.3302	0.1708	0.0617	0.0830	0.3302
10.	408/JB	6.2970	24.7279	-0.1873	0.0794	0.0076	0.1032	0.1873
11.	252/GB	5.7587	19.7701	-0.3048	0.1801	0.0748	0.0792	0.3048
12.	323/JB	6.7280	18.9175	-0.2826	0.1337	0.0458	0.0883	0.2826
13.	Chak 407, JB	5.6894	15.2022	-0.3574	0.2287	0.0755	0.0805	0.3574
14.	Boti wala	5.9804	11.5082	-0.1327	0.0135	-0.0008	0.1036	0.1327
15.	Toba Wariam Road	4.9445	24.2832	-0.2822	0.1393	0.0603	0.0830	0.2822
16.	Toba Wariam Road	6.9815	16.3417	-0.2617	0.1014	0.0511	0.0871	0.2617
17.	Toba Wariam Road	6.1473	32.3676	-0.1723	0.0783	0.0049	0.1026	0.1723
18.	Chak No. 400 JB, Link Road	7.3442	58.6246	-0.1771	0.0507	0.0254	0.0973	0.1771
19.	Chak No. 400 JB, Wariam Road	5.9792	43.8248	-0.1501	0.0398	-0.0103	0.1079	0.1501
20.	Chak No. 400 JB, Wariam Road	6.5029	34.8626	-0.1940	0.0726	0.0240	0.0968	0.1940
21.	Chak No. 399, JB	7.0992	23.5667	-0.1883	0.0412	-0.0048	0.1083	0.1883
22.	Chak No. 399, JB	6.6380	42.7625	-0.1415	0.0127	-0.0187	0.1139	0.1415
23.	Chak No. 324 JB	5.9263	14.2568	-0.1426	0.0469	0.0104	0.0983	0.1426
24.	Chak No. 469 JB	5.6925	17.8961	-0.3082	0.1394	0.0551	0.0856	0.3082
25.	Chak No. 469 JB	5.7833	26.1094	-0.3193	0.1622	0.0503	0.0878	0.3193
26.	Chak No. 469 JB	6.1777	31.8511	-0.2391	0.0749	0.0355	0.0919	0.2391
27.	Chak No. 469 JB	7.3154	20.3474	-0.2183	0.0723	0.0232	0.0954	0.2183
28.	Chak No. 383JB	5.6640	34.4432	-0.1014	0.0207	0.0035	0.1016	0.1014
29.	Chak No. 383JB	6.2959	16.1053	-0.2849	0.1210	0.0532	0.0866	0.2849
30.	Chak No.383JB	5.5213	21.9681	-0.1992	0.0770	0.0286	0.0928	0.1992
31.	Chak No. 388JB	5.9292	33.2257	-0.2839	0.1558	0.0685	0.0792	0.2839
32.	Chak No. 388JB	5.9839	43.3281	-0.1327	0.0202	-0.0277	0.1177	0.1327

APPENDIX VIII

Detail analysis of 2017

Sr. #	Village	EC	SAR	NDVI	NDMI	SI1	SI3	NDSI
1.	297/GB	7.321	14.060	-0.142	0.058	0.034	0.100	0.142
2.	182/GB	5.347	20.615	-0.127	0.062	0.049	0.095	0.127
3.	344/GB	8.001	50.473	-0.096	0.012	0.016	0.104	0.096
4.	315/GB	7.275	10.588	-0.107	0.012	0.016	0.104	0.107
5.	194/GB	6.180	12.176	-0.171	0.125	0.065	0.088	0.171
6.	183/GB	6.114	26.347	-0.144	0.045	0.041	0.096	0.144
7.	700/42/GB	5.614	23.547	-0.126	0.071	0.045	0.093	0.126
8.	700/42/GB	5.704	18.557	-0.145	0.091	0.041	0.094	0.145
9.	344/GB	6.709	38.197	-0.128	0.035	0.033	0.099	0.128
10.	408/JB	6.407	25.228	-0.075	0.035	0.022	0.103	0.075
11.	252/GB	5.869	20.270	-0.126	0.071	0.051	0.094	0.126
12.	323/JB	6.838	19.418	-0.130	0.040	0.038	0.099	0.130
13.	Chak 407, JB	5.799	15.702	-0.169	0.121	0.051	0.094	0.169
14.	Boti wala	6.090	12.008	-0.162	0.066	0.046	0.095	0.162
15.	Toba Wariam Road	5.054	24.783	-0.091	0.080	0.049	0.095	0.091
16.	Toba Wariam Road	7.091	16.842	-0.163	0.084	0.036	0.100	0.163
17.	Toba Wariam Road	6.257	32.868	-0.133	0.059	0.042	0.097	0.133
18.	Chak No. 400 JB, Link Road	7.454	59.125	-0.100	-0.007	0.015	0.107	0.100
19.	Chak No. 400 JB, Wariam Road	6.089	44.325	-0.068	0.045	0.014	0.108	0.068
20.	Chak No. 400 JB, Wariam Road	6.613	35.363	-0.068	0.009	0.012	0.106	0.068
21.	Chak No. 399, JB	7.209	24.067	-0.119	0.010	0.016	0.107	0.119
22.	Chak No. 399, JB	6.748	43.262	-0.078	0.004	0.010	0.110	0.078
23.	Chak No. 324 JB	6.036	14.757	-0.138	0.066	0.052	0.094	0.138
24.	Chak No. 469 JB	5.802	18.396	-0.166	0.097	0.043	0.099	0.166
25.	Chak No. 469 JB	5.893	26.609	-0.110	0.073	0.038	0.099	0.110
26.	Chak No. 469 JB	6.288	32.351	-0.092	-0.009	0.020	0.106	0.092
27.	Chak No. 469 JB	7.425	20.847	-0.120	0.037	0.041	0.098	0.120
28.	Chak No. 383JB	5.774	34.943	-0.128	0.040	0.040	0.099	0.128
29.	Chak No. 383JB	6.406	16.605	-0.104	0.004	0.028	0.103	0.104
30.	Chak No.383JB	5.631	22.468	-0.088	0.048	0.038	0.099	0.088
31.	Chak No. 388JB	6.039	33.726	-0.091	0.020	0.023	0.105	0.091
32.	Chak No. 388JB	6.094	43.828	-0.090	0.038	0.023	0.106	0.090

APPENDIX IX

Detail analysis of 2020

Sr. #	Village	EC	SAR	NDVI	NDMI	SI1	SI3	NDSI
1.	297/GB	7.551	14.640	-0.223	0.045	0.014	0.092	0.223
2.	182/GB	5.577	21.205	-0.266	0.157	0.066	0.077	0.266
3.	344/GB	8.231	51.073	-0.111	-0.026	-0.062	0.128	0.111
4.	315/GB	7.505	11.108	-0.239	0.109	0.020	0.089	0.239
5.	194/GB	6.410	12.756	-0.317	0.175	0.066	0.077	0.317
6.	183/GB	6.344	26.947	-0.124	0.002	0.008	0.094	0.124
7.	700/42/GB	5.844	23.747	-0.186	0.095	0.037	0.085	0.186
8.	700/42/GB	5.934	19.157	-0.183	0.120	0.036	0.083	0.183
9.	344/GB	6.939	38.797	-0.084	0.007	-0.029	0.109	0.084
10.	408/JB	6.637	25.828	-0.199	0.099	0.019	0.093	0.199
11.	252/GB	6.099	20.870	-0.266	0.134	0.054	0.082	0.266
12.	323/JB	7.068	20.018	-0.208	0.052	0.018	0.092	0.208
13.	Chak 407, JB	6.029	16.302	-0.272	0.139	0.061	0.078	0.272
14.	Boti wala	6.320	12.608	-0.331	0.223	0.071	0.076	0.331
15.	Toba Wariam Road	5.284	25.383	-0.184	0.103	0.048	0.081	0.184
16.	Toba Wariam Road	7.321	17.442	-0.243	0.118	0.021	0.091	0.243
17.	Toba Wariam Road	6.487	33.468	-0.113	0.029	-0.006	0.101	0.113
18.	Chak No. 400 JB, Link Road	7.684	59.725	-0.131	0.030	-0.051	0.128	0.131
19.	Chak No. 400 JB, Wariam Road	6.319	44.925	-0.074	-0.006	-0.021	0.108	0.074
20.	Chak No. 400 JB, Wariam Road	6.843	35.963	-0.116	0.014	-0.015	0.105	0.116
21.	Chak No. 399, JB	7.439	24.667	-0.198	0.059	0.001	0.099	0.198
22.	Chak No. 399, JB	6.978	43.862	-0.098	0.015	-0.030	0.113	0.098
23.	Chak No. 324 JB	6.266	15.357	-0.293	0.193	0.060	0.079	0.293
24.	Chak No. 469 JB	6.032	18.996	-0.269	0.146	0.058	0.080	0.269
25.	Chak No. 469 JB	6.123	27.209	-0.145	0.074	0.016	0.092	0.145
26.	Chak No. 469 JB	6.518	32.951	-0.137	0.027	0.001	0.099	0.137
27.	Chak No. 469 JB	7.655	21.447	-0.213	0.088	0.002	0.098	0.213
28.	Chak No. 383JB	6.004	35.543	-0.090	0.030	-0.002	0.099	0.090
29.	Chak No. 383JB	6.636	17.205	-0.259	0.132	0.042	0.084	0.259
30.	Chak No.383JB	5.861	23.068	-0.188	0.097	0.037	0.085	0.188
31.	Chak No. 388JB	6.269	34.326	-0.119	0.032	0.001	0.099	0.119
32.	Chak No. 388JB	6.324	44.428	-0.107	0.004	-0.011	0.107	0.107