



An overview of land degradation, desertification and sustainable land management using GIS and remote sensing applications

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Abstract

Land degradation (LD) poses a major threat to food security, livelihoods sustainability, ecosystem services and biodiversity conservation. The total area of arable land in the world is estimated at 7616 million acres or only 24% of the total area of the land surface, and currently about half of this area is cultivated. The productivity of arable land depends mainly on soil formation and management. Soil contains mineral components, organic matter and microorganism in a natural dynamic balance whose components have been formed in thousands and millions of years (geologic ages). Disruption of this balance due to human pressures and poor land use leads to soil degradation in few years. Scientists differed in setting a precise definition of the concept and dimensions of land degradation, but many agreed on the general concept of land degradation: ‘quantitative or qualitative change in the properties of soil that reduces the land’s potential for production’ and the more comprehensive definition that land degradation is Change in the characteristics of the Earth. Leading to the creation of more desert or drier conditions, due to the decline or deterioration of the load of biological energy for a period of time does not have to be continuous, but temporary. Additionally, organic farming might be a substitute to prevent the deterioration of our soil. The emphasis of the current review is on how land degradation affects agriculture and the environment, as well as how we can manage our lands to prevent further degradation. Therefore, this review will focus in explain the land degradation definition and concept, and presenting two case studies from Egypt and India.

Keywords Land degradation · Desertification · Arid region · Egypt · India

1 Introduction

Land degradation has several causes, including severe weather, especially drought; human activities (AbdelRahman and Arafat 2020; AbdelRahman et al. 2022a,b,c,) that lead to soil pollution (El-Rawy et al 2020) or degradation (AbdelRahman et al. 2019a, b); land use (AbdelRahman et al. 2022d), which adversely affects food and livelihood production, fabrication and delivery of other ecosystem goods and services. Land degradation accelerated during the twentieth century due to increasing and combined pressures for agricultural production and livestock production (overgrazing, overgrazing and forest conversion), urbanization,

deforestation and extreme weather events, such as drought and coastal erosion that cause soil salinity (Delang 2018; Janečková et al. 2023). UNCCD (2012) stated that land deterioration is a decrease or damage of the biological or economic efficiency and involvedness of rainfed cultivation, irrigated cultivation, or range, pasture, forest and woodlands subsequent from land uses or from a progression or amalgamation of progressions, counting processes stand up from human actions and habitation shapes, such as: (i) soil erosion triggered by wind and/or water; (ii) decline of the physical, chemical and biological or economic assets of soil; and (iii) lasting loss of natural vegetation. ADB (2008) reported that land degradation severity in the irrigated agricultural areas, can be mapped by analyzing crop conditions and soil conditions. Information on both crop and soil conditions can be obtained from satellite imageries. Remote sensing data are being regularly employed in the survey of degraded soils, because of the development of operational methodologies (Sreenivas et al. 2021; Ali 2012; Ali et al. 2019). Several attempts have been made by various organizations to map/

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derive the spatial distribution of LD status (AbdelRahman et al. 2017; Hossini et al. 2022).

Desertification is a phenomenon of land degradation that makes the fertile land arid desert. Land degradation and desertification can affect human health through complex paths. Land is deteriorating and deserts are expanding in some areas, food production is low, water sources are drying up and people are forced to move to areas that are more likely to be destroyed. Potential health impacts of desertification include:

- Increased risk of malnutrition due to reduced food and water supplies;
- Increased incidence of water-borne diseases due to poor sanitation and lack of clean water;
- The incidence of respiratory diseases as a result of dust diffused in the atmosphere by wind erosion and other air pollutants;
- The spread of infectious diseases due to population migration.

So, a global initiative should be undertaken to raise awareness of the economic consequences of land degradation and promote sustainable land management. This initiative should aim at a global study on the economic benefits of land and terrestrial ecosystems. It also should provide a global approach to analyzing the economics of land degradation. It also should aim to make the land degradation economy an integral part of policy and decision-making strategies by increasing political and public awareness of the costs and benefits of land and land ecosystems.

The degradation and desertification of the earth threatens people's livelihood at the global level. 20 million hectares of fertile land are deteriorating each year. About one-third of all agricultural land on the planet became Bora through the degradation process of the previous 40 years. Developing countries are more vulnerable to desertification and land degradation because they lack the infrastructure and capital to deal with these threats and implement land management in a sustainable manner. Degraded soil is less resilient and crops that grow on it produce less productivity. Land degradation also affects global food security: global food production could fall by 12% in the next 25 years. This will result in an average increase in food prices by as much as 30%. It is estimated that the annual cost of land degradation amounts to 3.4 trillion Euros (ELD Initiative 2013a) Land degradation, coupled with population growth and the excessive demand for alternative land management products such as biofuels, poverty, food instability, low availability of clean water and increased sensitivity to climate change and extreme weather conditions (ELD Initiative 2013b).

Man first placed his imprint on the landscapes of Asia thousands of year's age. Historical records make it clear

that the destructive impact of man was already apparent two or three thousand years age in China and the Middle East. It was then that the first period of accelerated man made erosion began. Wood cutting and cultivation of sloping lands were responsible for most of the land degradation that occurred in the upland China and around the Fertile Crescent. Sedimentation of canals, water logging and salinization combined to raise havoc in the Tigris and Euphrates Valley of Mesopotamia (Jacobsen and Adams 1958).

Salinization and water logging affect about 240.000 hectares of irrigated land to various degrees in Spain (Ayers et al. 1960). About 85.000 hectares of irrigated land in Australia are salt-affected, most of it in the Murray Basin and at least 197.000 hectares of dry land are affected by secondary salinization (Northcote and Skene 1972; Conacher and Conacher 1995). All of usual forms of land degradation are present in the arid regions of the African continent (Rapp 1974). Salinization and water logging are as bad and as difficult to control in the irrigated region of southern Iraq as they are anywhere in the world. Deep fine texture soils and almost flat topography make it hard to provide drainage that is an adequate to maintain a deep water table and prevent salt accumulation (Dogrameji and Clor 1977). The present rate of land degradation is estimated at 5 to 7 million hectares per year implying that 0.3to 0.5% of the world's arable land is lost every year because of soil degradation (Dudal 1982). About 18% of arid region of Africa is severely desertified, and most of that represented by grazing lands and rain fed cropping lands on the south side of the Saharan the other large area that is severely affected is the mountain slopes and the plains of North Africa (Dregene 1986; Tesfa and Mekuriaw 2014).

There are around 25 million hectare worldwide are unusable for agriculture because of salinization (Kayasseh and Schenck 1989). The problem of soil degradation has been drastically accentuated by changes in land use since the 18th Century (Richard 1991; Williams 1991). Data show that the total land area of the world is 13.4×10^9 ha, of which 2×10^9 ha is degraded to some degree. Asia and Africa combined account for a total 1.24×10^9 ha of degraded lands. Human-induced soil degradation has affected 1965 million hectares worldwide. Water erosion followed by wind erosion is the most important type of soil degradation, Oldeman et al. (1991).

According to the World Resources Institute (1992–1993), an area equivalent the size of China and India has suffered from moderate to extreme soil degradation in the past 45 years. By year 2000, desert could occupy more than three times 7,992,000 square kilometers they occupied in 1977. It is estimated that about 3.6 billion hectares or 70% of potentially productive dry lands, are currently threatened by the various form of land degradation known as desertification.

Degradation by water logging, salinization, and/or alkalization of 43 million hectares of irrigated croplands, amounting to nearly 30% of total area in the dry lands (Rozanov 1994). About 50% of sub-Saharan agriculture land has lost its productivity due to degradation and about 80% of rangeland shows signs of degradation (Cleaver and Schreiber 1994). The degraded area on the world scale due to water erosion represents 56%, wind erosion 28%, chemical degradation 12% and physical degradation represents only 4% from the total degraded lands (Lal and Eliot 1994). About 3.6 million ha or 70% of potentially productive dry lands, are currently threatened by the various forms of land degradation. Degradation by water logging, salinization, and alkalization of 43 million ha of irrigated croplands amount to nearly 30% of the total area in the dry lands (Rozanov 1994).

Vilanculos (1994) reported that except for some environmental processes as leaching and erosion which can occur with or without human interference soil degradation is resulted when soils are not properly managed or not used in the right way. Worldwide, it is estimated that nearly two billion hectares of biologically productive land have been rendered unproductive due to irreversible degradation. Ludwig and Tongway (1995) estimated that land degradation in some forms is estimated to have occurred over about 42% of the 5 million km² of arid and semi-arid lands in Australia. Barber et al. (1996) reported that the mechanized annual cropping in the central zone Santa Cruz Bolivia, has caused serious degradation, manifested by problems of compaction, accelerated soil organic matter losses, nitrogen deficiencies and wind erosion.

Eswaran and Reich (1997) showed that 55% of the land area in Africa is unsuitable for agriculture and 11% has high quality soils that can effectively be managed to sustain more than double its current population. Eswaran et al. (2001a) Stated that there are about 7.1 million km² of land under low risk of human-induced desertification 8.6 million km² at moderate risk, 15.6 million km² at high risk and 11.9 million km² under very high risk. Each of these classes represents a desertification tension zone; the major critical tension zone that requires immediate attention is the very high risk class.

In Africa, two-thirds of the region's people depend on agriculture for their livelihoods. Despite the large potential for irrigation, estimated by FAO about 27 million hectares, but only one sixth of the area is available for development. Thus, 97 percent of land remains rainfed agriculture, where water scarcity and land degradation caused by depletion of soil nutrients are major challenges for smallholder farmers, particularly in drylands.

Globally, more than 24 billion tons of fertile soils are lost in crop-prone land each year (mostly in Africa). Global data show that 33 per cent of the soil is degraded by various disturbances, while 20 percent of irrigated land is subject to

salinization to varying degrees. In addition, the impact of climate change is another major concern.

Farmers in dry areas face a number of challenges associated with natural resources and soil, which hinder their agricultural productivity. One of the challenges faced by smallholder farmers is the lack of information on soil fertility and the adoption of land management practices. In rainfed agriculture, water erosion has caused soil degradation and nutrient depletion, leading to increased costs of agricultural production; irrigated agriculture has increased secondary salinization. The question remains what small farmers can do in terms of long-term soil recovery, bearing in mind that soil is the basis of food production. Therefore, the pressing issue is to promote the restoration of degraded agricultural soils and to stimulate 'sustainable production intensification' through increased soil fertility, water use efficiency, reclamation of saline-prone and degraded soils, ensuring sustainable use of inputs and recycling of secondary agricultural products.

So, training should be designed to address land degradation and soil management issues in Africa as well as to present a variety of options to either reverse or reduce the deterioration of the situation in order to intensify agriculture. In this such type of training, participants should be guided to the importance of sound soil in the provision of ecosystem services and identification of soil safety constraints based on diagnosis. This will help to improve knowledge of best practices at the farm level to combat soil desertification and degradation, which will also raise awareness information on protected agriculture, integrated soil fertility management and integrated soil reclamation. In addition, this will help to increase spread of through topics specifically designed to deliver science from laboratories to fields and vice versa. In addition, the training will provide an opportunity to exchange ideas on a range of topics and establish a network of communication with other participants.

2 Definition and concept of land degradation and desertification

2.1 Definition of land degradation and desertification

Land degradation can simply be defined as a degradation and impoverishment of the ecosystem that reduces its ability to perform its natural role in life. Land degradation can be simple, in its first phase, so that it can be controlled in easy, low-cost, short-term or severe conditions that are difficult to treat, requiring more effort, time and money. Human practices, such as camping or grazing for a limited period of time, cause the temporary disappearance of vegetation, and a limited breakage of the soil surface. This is a simple

deterioration for a short time which could be disappeared over time. But if the same area is exposed to multiple human activities at the same time and for long periods of time, this causes total disappearance of vegetation and clear soil destruction. This is a severe deterioration that requires some measures to rehabilitate the environment, such as flipping, plowing and planting some plant varieties (Misak et al. 1988).

Land degradation is a complex process in which several features can be recognized as contributing to the loss of production capacity (Várallya 1987). Land degradation is the process which lowers the current and/or the potential capability of soil to produce goods or services. Land degradation is not necessarily continuous; it may take place over just a short period between two states of ecological equilibrium, (FAO/UNEP 1978) and degradation is a reduction in the soil capacity to produce in term of quantity, quality goods and services. UNCOD (1978) added that the desertification is a diminution or destruction of the biological potential of the land which can lead ultimately to desert like condition. Land degradation is the loss of resilience of land to climatic and land use change (Warren and Agnew 1988). Land degradation is the decline in soil quality caused through its misuse by human (Lal and Stewart 1990). Land degradation is a combination of processes causing the removal of land form agricultural productivity and leading to desertification (Mashali 1991). Land degradation can be defined from another perspective (Conacher and Sala 1998), as ‘alterations to all aspects of the natural (or biophysical) environment by human actions, to the detriment of vegetation, soils, landforms, water (surface and subsurface) and ecosystems’. In this definition, the natural conditions of the area are not considered as factors that can threat land degradation and the human activities are the main responsible factors for the development of this phenomenon.

AbdelRahman et al. (2022c) stated that the issue of land degradation is directly linked with sustainability and defined Soil Sustainability (SS) as an account of the resilience of the soil to resist various degradation processes and the extent of its response to fertility processes, and thus a reflection of soil quality to provide the ecosystem and social services through its capabilities to perform its functions and respond to external influences. And from another perspective AbdelRahman et al. (2022a,b,c, d) defined Soil Sustainability (SS) as an account of the resilience of soils to resist various degradation processes and their response to fertility processes, and thus as a reflection of soil quality to provide ecosystem and social services through their abilities to perform their functions and respond to external influences. Thus determines the priorities of soil zone management.

The concept of sustainable land management is a system of technologies that aims to integrate ecological and socioeconomic principles in the management of land for

agriculture and other uses to achieve intergenerational equity (UNEP 1991; Eswaran 1992; Aboelsoud et al. 2022). Land degradation implies reduction of resource potential by one or a combination of processes acting on the land. These processes include water erosion, wind erosion and sedimentation by those agents, long-term reduction in the amount or diversity of natural vegetation, where relevant, and salinization and sodification’ (UNEP 1992). Land degradation is one of the consequences of mismanagement of land and result frequently from mismatch between land qualities and land use (Beinroth et al. 1994).

Soil degradation is a process that describes human induced phenomena, which reduce the current and/ or future soil capability to support human life (Ayoub 1991). Land degradation is defined as removing or exhausting land quality; decreasing lands potential to support life; so life is unable to flourish and ultimately end in desertification resulting mainly from adverse human impact (Oldeman et al. 1991). Soil degradation is a broad term that refers to a diminution of soils current and/or potential capability to produce quantitative or qualitative goods or services as a result of one or more degradation processes (Ivaldi 1997).

The terms land degradation and desertification, have a close relationship and several attempts to define and describe them have been made (UNEP 1991; Conacher and Sala 1998, Oldeman et al. 1990. Desertification was redefined by (UNEP 1991), in the sense of considering it as ‘the land degradation in arid, semiarid and dry-semi-humid areas resulting mainly from adverse human impact’. The term land includes land and local water resources, the land surface and its natural vegetation. It is important to notice that this definition, attributes the causes of land degradation to natural processes and human activities are introduced as another factor.

Le Houerou (2002) reported that desertification is defined as the irreversible extension of desert land forms and landscapes to areas where they did not occur in a recent past. Such extension does not result from a would-be increasing aridity as there is no evidence of any global long-term trends in rainfall in arid lands since the period of instrumental record (ca. 150 years).

The degradation of the land involves the reduction of the renewable resource potential by one or a combination of processes acting upon the land. The resource potential relates to agricultural suitability, primary productivity level and natural biotic functions. Such a reduction leading to an abandonment, or ‘deserting’ of the land can be because of natural processes such as a natural aridification of atmospheric climate, natural processes of erosion, some processes of soil formations such as primary salinization and hardpan formation, a natural change in the base level river catchments, or natural invasion by noxious plants or animals (Wim and El-Hadji 2002).

2.2 Concept of land degradation and desertification

Land degradation is a complex process caused by various natural, chemical and biological factors. Although soil erosion is a natural process, human activity has greatly increased its severity. The global average soil erosion rate per year is estimated to be between 0.5 and 2 tons per acre, depending on the type of soil, the degree of land degradation and the nature of erosion. Soil erosion rates vary from region to region, in the United States of America for example, 44% of agricultural land is affected by erosion to varying degrees, and in India nearly half of the agricultural land is subject to erosion. In some areas—especially in the Middle East—wind is an important factor of erosion affecting about 35% of the land area in the region. The most important problems of soil change and perhaps the most serious of these are irrigation increase. Water saturation, salinity and sodium rise occur if marginal water is used for irrigation, or improper water management methods are used such as poor drainage. The Middle East is one of the most affected areas. In Iraq, saline and waterlogging are problematic in about 50% of irrigated land in the Euphrates valley. In Iran, soil salinity and sodium problems in about 10% of the agricultural lands. These operations also affected 25% of Pakistan's agricultural land. Studies estimate that 10% of the total land area in the world has deteriorated to varying degrees due to human activities. Of this area, about 55% was damaged by water erosion, 48% by wind erosion and 12% by erosion by chemical factors (water saturation and salinity) (World Resources Institute 1992)–1993.

The main causes of this degradation were overgrazing, responsible for degradation of about 34% of degraded area, deforestation 29%, agricultural activities 28%, overuse of land 7% and other irrational activities 1.5%. Land degradation in dry areas (arid, semi-arid and dry sub-humid) is characterized by desertification, which is defined as 'loss of productivity and land biodiversity in arid, semi-arid and dry sub-humid areas due to natural factors or processes resulting from human activities'.

It was estimated that about 30% of irrigated areas in drylands, 47% of cropland, and 73% of rangeland were affected by desertification at least moderately. Africa is at the forefront of areas where land has been affected by desertification.

Under the United Nations Convention to Combat Desertification in 1995, desertification was defined as a form of land degradation, in dry or semi-arid areas, due to the influence of climate factors and inappropriate human activities. In this Convention, the word 'Earth' means the balanced system consisting of two sets of elements, the first of which is the group of organisms. This is meant by vegetative growth and the accompanying growth of animals. The second is the soil which is the outcome of the interactions of these living

organisms, mineral components and organic residues and their impact on climatic conditions.

Land degradation is called desertification when it occurs in arid, semi-arid and sub-humid lands, which account for 47% of the world's land area. Desertification results from multiple interactions between physical, biological, political, social, cultural and economic factors. Desertification does not mean the existence of deserts extended within the territory, but means the destruction of vital productive potential, leading to the emergence of conditions of the desert environment on these lands.

Environmentally, land degradation is an additional element in the degradation of the Earth's environment, because it plays an active role in polluting water and air. Land degradation contributes significantly to the loss of biodiversity in the world, increases the loss of the productive mass and vitality of the land and the loss of global humus stocks, causing disruption of terrestrial biochemical transformation. Land degradation also leads to increased accumulation of atmospheric carbon dioxide, through reduces amount of plants that incorporate it into plant organic matter (biomass).

Soil degradation leads to a deterioration in the natural vegetation cover of the land (AbdelRahman et al. 2017). This means that soil drifts with strong floods, eventually increasing the amount of silt in the streams, thus adversely affecting aquatic life of aquatic plants and animals. This may lead to decrease in the recharge rate of groundwater through the surface of the earth as well as to increased storms and sandstorms.

Land is the solid surface of the Earth that is not permanently covered by water while Soil is a mixture of minerals, organic matter, and other things that can support plant life. Soil is a non-renewable resource. It takes ages for rocks to weather into soil and rich organic matter to build up. The rock is a natural resource on land. Soil is comprised of rocks which had been eroded due to uneven heating or cooling. Soil components and their importance Soil consists of plants, animal materials such as worms, microbes, plant roots, small mammals, insects, water that dissolves nutrients and minerals in them, metals such as quartz, vermiculite, mica, albite, feldspar, kaolin,, Potassium, calcium, air that enters the air in large soil soils and water.

Land degradation is a physically occurred process that can be observed, while soil degradation is a process, that cannot be seen. In another sense, on-site deterioration processes can be recognized as soil degradation, such as soil compaction, while the off-site processes can be recognized as land degradation, such as erosion. The productivity of agricultural land depends on soil composition and management. Soil contains organic, mineral and bio-organic materials in a dynamic natural balance that has been formed for millions and thousands of years during geological times. However, this imbalance may be impaired due to soil

degradation. The causes of soil degradation and desertification, which emerged after the increase in population and expansion of construction led to the destruction and reduction of agricultural soils.

The complex chemical, natural, and biological factors will be discussed in detail in this chapter. For example, but not limited to:

- Drift: the soil drifts from mountainous slopes to lowlands due to collapses and rain torrents.
- Deforestation leads to loss of soil protection and its fertility.
- Heavy metals and radioactive materials that cause soil degradation due to their toxicity.
- Soil fertility losses due to continuous cultivation, and nutrient mining.
- The use of insecticides causes the destruction of soil bacteria.
- Soil pollution from mixed waste dumping making it unsuitable for agricultural use.
- Salinization, which increases the proportion of salts deposited on the soil surface, and this problem is caused by the evaporation of excess irrigation water that exceeds the need for soil and plant.
- Plowing during drought.

Ways to protect the soil from degradation:

- Reduced overgrazing, and avoid ploughing forest and wood areas.
- Reclamation of the lands subject to salinization or deterioration.
- Combating wind erosion by using windbreaks from long trees.
- Protecting the soil from pollution resulting from rapid modern urbanization.
- Use appropriate and modern irrigation methods such as: sprinkler irrigation and drip irrigation, to maintain the moisture content necessary for plant growth, and wash the soil from excess salts, to maintain an acceptable salinity concentration in the plant root area.
- Afforestation in lands threatened by desertification and/or erosion.
- Disposal of contaminated materials in proper ways.

3 Some methods of soil protection from degradation and desertification

3.1 Irrigation

Irrigation is one of the most important methods used to protect the soil, but on the condition that the rainfall does not

increase in the cultivated areas. In this case, the irrigation should be stopped especially if the plants are located next to the slopes, because rain water is sufficient for the growth of different plants (NRCS 7–2002) (NRCS 2002).

3.2 Protection from drifting or stripping

The soil can be protected from drifting or stripping processes as it comes (Peterson 2018):

- Collect rainwater or any type of water in a barrel; direct water into a garden or water tank.
- Plant shrubs and trees near slopes and beaches, as they reduce water flow by 50%. Use mulch (soil cover) if possible.
- Cultivate any type of plants on bare sites in the gardens. Create terraces or walls aimed to book water, and protect the soil from drifting.
- Leave the gardens without plowing.

3.3 The living organisms in the soil

The focus now is on the provision of chemical inputs in the soil. However, the presence of organisms is the best and most beneficial for the soil. Farmers need to know how to best maintain the presence of soil organisms to improve the productivity of agricultural crops (Payton 2018).

3.4 Permanent soil cultivation

In addition, dry beans, such as lima beans, red beans, or black beans, can be added to the soil. Beans supply the soil with a high nutritional value, and their roots are rich in soil microbes. Nitrogen from the atmosphere layers, which is one of the important compounds for the majority of organisms, especially plants (Izlar 2016).

4 Land degradation in Egypt

The phenomenon of land degradation and desertification in Egypt is a geographical phenomenon that means the decrease or deterioration of the biological production capacity of the land, (Mohamed et al. 2019) which may eventually lead to the creation of semi-desert conditions, or in other words the deterioration of the fertility of productive lands, whether they are pastures or farms that depend on rain irrigation or irrigated farms, by becoming substantially less productive, or perhaps losing fertility entirely.

In the seventies, the United Nations declared that Egypt was the first desert country in the world due to the harsh conditions that characterize the desert, as it contains about 86% of the very arid lands and 14% of the arid lands. Egypt constitutes an area of approximately one million square kilometers in the northeastern corner of Africa, which is part of The Sahara belt extending from the Atlantic Ocean eastward across the whole of North Africa to Arabia.

Egypt ranks first in the world in the phenomenon of desertification, according to what was announced in June 2011 by the Executive Secretariat of the United Nations Convention to Combat Desertification, which occurs due to a combination of geological, biological, human and climatic factors that lead to the deterioration of the physical, chemical and biological components of the land in arid and semi-arid regions. Arid regions, which leads to an impact on environmental diversity and human groups, according to the guide of the Food and Agriculture Organization of the United Nations (FAO) issued in June 2010.

The most degraded places threatened by desertification in Egypt are divided into four regions, each of which has its own reasons, and the North Coast region is at the forefront of those areas, and includes both: Al-Hammam area, Burj Al Arab in Alexandria, Marsa Matrouh, Apis region, and Tina Plain. The region suffers from very severe degradation and desertification as a result of land salinization and high ground water levels, followed by the Nile Delta region and the valley and it includes: Kafr El Sheikh, Rashid, Damanhur, Beni Suef, Sohag and Minya.

Because of salinization, the rise in ground water levels, and construction on agricultural lands, the lands of this region have deteriorated and have been subject to desertification. The causes of desertification in the Western Sahara region, which includes: Fayoum, Bahariya Oasis, Farafra Oasis and some limited areas in the New Valley, are due to salinization and the rise in the ground water level, while land degradation in the Eastern Desert and Sinai includes: Hurghada, Arish, East Qantara, Halayeb, Shalateen and Abu Rama, as a result of natural causes. Environmental degradation includes the erosion of water as a result of floods or winds.

As a result of land degradation in those areas and their entry into desertification, Egypt lost 2 million feddans in the north and east of the delta. Urban expansion, salinization of agricultural lands, pollution, depletion of soil fertility, physical degradation of land, erosion of soil and sand dunes, which lead to the annual loss of 30 thousand acres of the best agricultural and arable land.

Irrigated agricultural lands in the valley and delta suffer from side effects of irrigation. Due to the lack of an effective drainage system, this led to the rise of groundwater, and the accumulation of salts, which reduces its productivity. The

lands of the oases and the western regions of “North Sinai, Minya, Assiut, and the western shore of Lake Nasser” suffer from desertification, as a result of the invasion of sand dunes, Pesticides, factory residues, sewage and soil fertility degradation.

The problems of accumulation of water and salts in the lands are exacerbated by other factors, including a decrease in the area's land level in relation to the neighboring lands, a high concentration of salts in irrigation water, or a rise in the level of groundwater to a critical level. On the one hand, the quality of irrigation water is low on the one hand, and this desertification is widespread in the oases of the Western Sahara, especially the Siwa Oasis, due to the severe wastage of irrigation, without the presence of drainage systems.

4.1 The climate of Egypt

The climate of Egypt is affected by several factors, the most important of which are the location, the surface features, the general system of pressure, depressions and water bodies. All this helped split Egypt into quite a few discrete climatic zones. Egypt is situated in the arid tropical zone excluding for the northern fragments that enter the temperate green zone that has a climate similar to a zone the Mediterranean (Fig. 1), which is categorized by heat and drought in the summer months and moderation in the winter, with little rain falling on the coast. The climate of Egypt can be distinguished in two climatic seasons: the hot dry summer that extends between the months of May and October, and the mild winter with little rain and extends between the months of November and April (UNDP 2010).

4.2 Current status of land in Egypt

The current use of agricultural land in Egypt is evident from it being among the most escalating agricultural frameworks on the planet. You may reach three harvest developments each year—this wide use is a situation in which it is subjected to microevolution pressures, and the transition requires additional inputs to form the vegetation, i.e., water system, preparation, pesticides ... etc. This has led to a reasonable imbalance between construction and land maintenance, especially since the vast majority of farm owners as mentioned above are small farm owners who cannot use convincing methods of support to secure their lands.

Despite the developed topography, Egypt has extensive grazing lands estimated at 4 million hectares, or about 9.5 million acres, according to the National Program to Combat Desertification 6, and includes 5.5 million feddans on the northwestern coast, and 2.6 million feddans in separate

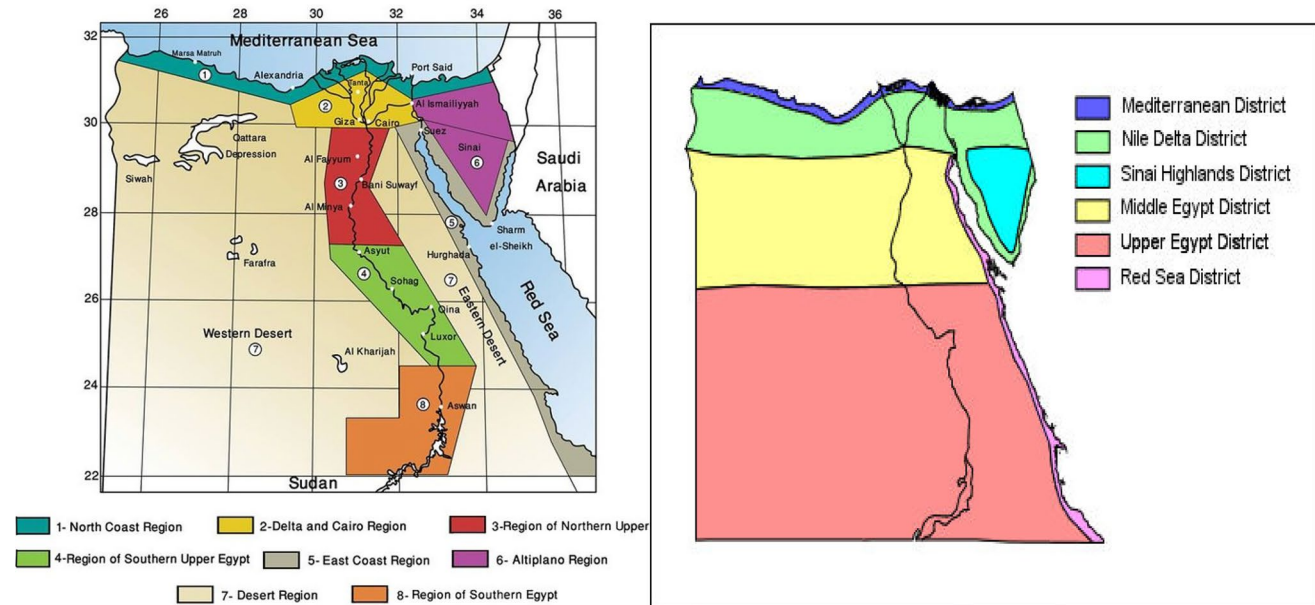


Fig. 1 Classification of climatic zones in Egypt according to HBRC, After (Saleem et al. 2014; Hamed et al.2022; UNDP 2010)

areas of the Sinai. First: The northern fields and valleys in the interior to the north, the “center” and southwestern Sinai, and 1.4 million feddans in the Halayeb—Shalateen triangle.

The current conditions of pasture lands in Egypt tend to restrict all things taken into consideration. Almost half of this terrain is rated poor, about 35% is reasonable and 15% is tolerable.

4.3 Major pressures on land resources in Egypt

Beneficial land assets in Egypt are subject to various weights and factors that lead to soil corruption and hinder economic improvement that ensures a decent quality of human well-being in the climate. Accompanying the basic elements and tasks that stimulate desertification and soil deterioration are explained in Table 1.

4.4 Main challenges to land resources in Egypt

The basic situation in Egypt in light of logging, salinity, pollution of surface and ground water, degradation of the flooded terrain, and soil disintegration demonstrates that agricultural management is not sound.

4.5 State efforts in the area of fighting land degradation

The state applies genuine endeavors to address farming area corruption and moderate weights to which it is uncovered. The overall arrangement received by Egypt of fighting area debasement and desertification depend on two patterns:

First Trend: It targets controlling area corruption factors and diminishing their dangers and suggestions. Essential highlights and exercises are featured in the structure of this pattern as follows in Table 2.

4.6 National program of action of the Arab republic of Egypt designed to fight desertification

In 1994, Arab Republic of Egypt signed the UNCCD (United Nations Convention on Fighting Desertification) and was sanctioned by the Republican announcement No. 155 of 1995. In 2001, the state allotted the usage of the show to the Ministry of Agriculture and Land Reclamation and commanded Desert Research Center to be the public organizer of the show.

The Egyptian National Program on Combating Desertification included five significant projects of which exude various undertakings for battling desertification different farming ecological districts, summed up in the accompanying in Table 3.

Table 1 Major pressures on land re-sources in Egypt

1. Urbanization	2. Water logging and soil salinity	3. Pollution	4. Soil Fertility Depletion	5. Land Physical Degradation	6. Soil Erosion	7. Sand Dunes
<p>The urban encroachment over the fer-tile agricultural lands is considered one of the most serious desertification processes – as it is from an agricultural view—a complete and total impairment of the basic function of the land which is the biomass production, including food, clothing and medicine. This phenomenon has been addressed by new legislations, where the ratio of urban encroachment over the fertile agricultural lands decreased from nearly 30,000 feddans in the year to 5000 fed-dans in 2005</p>	<p>The water logging and soil salinity is one of the most eminent processes of agricultural lands degradation in Egypt due to poor water management in the domain of agriculture which follows the conventional surface irrigation system with an efficiency of no more than 60% in the vast majority of the irri-gated lands of the countries in addition to reusing the agricultural drainage water containing a high ratio of saline in irrigation by mixing it with canals wa-ter used in irrigation. Also, the extreme drawing of underground water in the reclaimed areas, sea water intrusion in coastal areas and lack of adequate agricultural draining system in large areas of the irrigated lands</p>	<p>Pollution is among the most serious factors of lands degradation in Egypt as it threatens large areas of agricultural lands and consequently human beings and animals as a result of poor lands and water management, and human behavior in the rural community. Pollution comes from the fact that the Nile water—the main source of irrigation in the Egyptian lands- contains high con-centrations of pollutant materials and ele-ments in addition to reus-ing agricultural drainage water-containing resi-dues of fertilizers and pesticides as well as using treated sewage water in irri-ga-tion. (Mahmoud 2005)</p>	<p>Intensive agriculture and excess quanti-ties of irrigation water, given the lack of Nile alluvium with what it carries of basic nutrient (alimentary) elements for vegetation after building the High Dam and lowering organic fertilizing ratios, particu-larly in reclaimed lands (estimated to constitute about 40% of the total irri-gated lands in Egypt. All this led to clearly shown degradation of soil fertility and levels of vegetation production from land were in most cases inadequate to the levels of pro-duction inputs and do not respond to be increased. Lack of agricultural production in lands deficient in concen-trations of basic nutrient (alimentary) elements and clear degradation of their fertility reached nearly 15% (Gabber 2002)</p>	<p>Excess exploitation occurred as a result of intensive agriculture in agrarian lands aiming at performing most ser-vice operations i.e., surface plowing, agriculture, pest control and harvesting under unsuitable conditions and mostly with unfit-ting tools. All this led to clear degradation of soil structure and appearance of plow pans limiting the growth, deepening the growing plant roots and reducing the efficiency of ag-ricultural drainage, especially in some areas of north and northeast Delta and production decrease in these sites is estimated as a result to be about 8% (Gomaa 2001)</p>	<p>Given that Egypt is located in the se-vere dry region extended from North Africa to West Asia, the wind erosion is considered one of the important land desertification processes in areas exceeding 90% of the state area in west-ern desert, eastern desert and particularly Sinai. These areas are characterized by a fragile ecosystem, scarcity of vegetation cover and severe drought. Studies indicate that wind erosion ratio in Egypt is about 5.5 ton/hectare a year in oases (880 square kilometers), in western grooves of Minya, Assyout and Beni Swaif governorates (350 square kilo-meters), in El-Kharja oases (400 square kilom-eters) and in northwest High Dam lake (800 square kilo-meters) in addition to other areas in east delta and north Sinai, particularly in some sites around the path of Al Salam canal (UNCCD–NAP 2005)</p>	<p>Sand dunes and piles/heaps are most vulnerable areas to wind erosion and sedimenta-tion. Thus, they severely jeopardize all activities of agricultural development and urban communities both rural and urban. Sand dunes cover an area more than 166,000 square kilometers or 16.6% of the total area of state. Most dangerous are the active dunes which are threatening develop-ment in areas of west delta (255 square kilometers), in Fayoum and Wadi Al Rayan (880 square kilometers), in western grooves of Minya, Assyout and Beni Swaif governorates (350 square kilo-meters), in El-Kharja oases (400 square kilom-eters) and in northwest High Dam lake (800 square kilo-meters) in addition to other areas in east delta and north Sinai, particularly in some sites around the path of Al Salam canal (UNCCD–NAP 2005)</p>

Table 2 State efforts in the area of fighting land degradation**First trend**

It aims at controlling land degradation factors and reducing their risks and implications. Basic features and activities are high-lighted in the framework of this trend as follows

- | | |
|---|---|
| <ol style="list-style-type: none"> 1. Pollution reduction a. Implementation of integrated agricultural pest control program and using hormones for biological resistance of agricultural pests, have led to rationalization of using chemical pesticides in resisting agricultural pests. This resulted in reducing their use with more than 80% b. Implementation of using treated sewage water for afforestation in targeted areas of nearly 400 thousand feddans—to prevent getting rid of it in the Nile or agricultural drains c. Removal of subsidies allocated for commercial fertilizers led to raising their prices, helped in reducing their waste ratios and hence helped in reducing water and land pollution | <ol style="list-style-type: none"> 2. Land improvement and upgrading its productivity: <ol style="list-style-type: none"> a. National program of agricultural drainage in cooperation with the World Bank and other institutions besides private sector contribution in some areas. By the end of current five year plan 2002–2007, the introduction of tiled drainage in about 5.75 million feddans shall be completed (Hassan 2003) b. Agricultural land physical properties improvement program, where the state established the Executive Authority of Projects for Land Improvement to initiate soil laser leveling operations aiming at raising the efficiency of distributing and using the irrigation water, subsoiling to disintegrate plow pans and adding agricultural gypsum to treat the soil alkalinity |
|---|---|

Second Trend

The state strategy which is built on minimizing land degradation would be extended to the desert in order to increase the populated area to 50–60 million feddans or 25% of total area of the state where new urban communities shall be established. The state pays this trend a great heed and dedicates a large part of consultations to this discipline. Apparent examples on this trend are the following:

1. The electoral program of the President of the Republic included reclaiming and cultivating one million new feddans during the present presidency term of office (6 years)
2. The present government has adopted a project for establishing 400 villages in the desert lowland/hinterland areas between Beni Swaif and Aswan governorates
3. Implementation of a number of national mega projects for expansion and comprehensive development in the depth of the desert—on top of them South Egypt Development Program known as Tushki Project (540 thousand feddans in Tushki desert west the High Dam Lake) and East Ouyanat Project (another 500 thousand feddans east Ouyanat and south the oases of the western desert) irrigated by underground water. The other national project is Al Salam Canal project targeting cultivating and developing 600 thousand feddans, about 400 thousand feddans in north Sinai and the rest west Suez Canal. This project is dependent on irrigation by mixed Nile water with agricultural drainage water
4. The state also pays a great heed to developing and upgrading Egyptian agricultural areas with a view to expanding sustainable development, establishing urban communities and development activities in these areas. Most important activities in such rainfed areas, are as follows:
 - a. Matrouh resources development project which contributed in upgrading and developing pastures animal wealth, rain water harvesting and increasing productivity of horticulture and field crops
 - b. Joint projects with German Aid Agency (GTZ) targeting the development of local communities and promoting indigenous knowledge besides identifying the development needs in these areas
 - c. National project for Sinai development involving modernization of fruits cultivation, valleys development and stabilization of sand dunes in the north part of Sinai

5 Land degradation in India

India is bestowed with vast natural resources. However, it suffers from a variety of LD problems affecting the quality and quantity of available land. India homes more than 18% of world's population over an area that is just 2.42% of global spread (Bhattacharyya et al. 2015). According to Sreenivas et al (2021) more than half of the degraded land in India is either rainfed farmland, responsible for the food security of the country or forest land that offers the best defense against climate change.

Soil cover is the key, in irrigated farmland, there would be a crop cover all the time whereas in rainfed areas, a lot of erosion happened because the top soil remained exposed and got washed away easily with rains. While the problem was

well-known, the solution was less talked about. Resource-intensive, chemical and energy intensive cropping patterns and practices work well in irrigated farms but are unsustainable in rainfed farms (Jagdish 2023).

A round 66 per cent of the farmland in India remains rainfed, according to the Pocket Book of Agricultural Statistics 2020, released by the Union Agriculture and Farmers' Welfare in May 2021.

India has a little over 71 mha of forestland, according to the India State of Forest Report 2019, released by the Union Ministry of Environment, Forest and Climate Change. Of this, 30 per cent or a little more than 21 mha of forestland is degraded. It adds that vegetation degradation (96 per cent) is the major reason for forest degradation. Vegetation degradation is referred to as reduction in the biomass and/or decline

Table 3 The Egyptian National Program on combating desertification

1. Principal programs, including	a. Evaluating and monitoring desertification b. Capacity building
2. Pastures Improvement programs, including	a. Rehabilitating degraded pasture/range lands b. Preserving land and water resources c. Managing natural grazing lands
3. Sand dunes stabilization programs, including	a. Protecting Nasser Lake shores against sand dunes b. Stabilizing sand dunes in Siwa oasis c. Stabilizing sand dunes in north Sinai
4. Irrigated agriculture programs, including	a. Improving and modernizing irrigation techniques b. Integrated management of irrigation projects c. Managing and improving lands d. Treating soil and water pollution e. Treating environmental pollution in Wadi Al-Rayan pan/Depression
5. Rainfed agriculture programs, including	a. Planning land usage in the north coast b. Improving animal wealth c. Improving small ruminant animals' productivity in the north part of Sinai d. Limiting soil erosion

in the vegetative ground cover, as a result of deforestation and/or overgrazing. Such degradation is a major contributory factor to soil degradation particularly with regard to soil erosion and loss of soil organic matter. Anthropogenic pressures are reducing both the quantity and quality of forests. Deforestation for a variety of developmental needs is reducing the extent of natural forests. On the other hand, drivers of degradation such as grazing, lack of natural regeneration, short rotation harvesting are causing deterioration of growing stocks in forests of India.

Desertification and Land Degradation Atlas shows that land degradation and desertification has increased significantly in recent years. The Atlas provides a state wise area of degraded lands for the time frame 2018–19. It also provides the change analysis for the duration of 15 years, from 2003–05 to 2018–19.

5.1 Land degradation status

Some 97.85 million hectares (29.7%) of India's total geographical area (TGA) of 328.72 mha underwent land degradation during 2018–19. In 2003–05, 94.53 mha (28.76% of the TGA) underwent land degradation. The number increased to 96.40 mha (29.32% of the TGA) in 2011–13.

5.2 Desertification status

Some 83.69 mha underwent desertification in 2018–19. This was greater than the 81.48 mha in 2003–2005 and 82.64 mha in 2011–13 that underwent desertification. Around 23.79% of the area undergoing desertification / land degradation with

respect to TGA of the country was contributed by Rajasthan, Maharashtra, Gujarat, Karnataka, Ladakh, Jharkhand, Odisha, Madhya Pradesh and Telangana. India witnessed an increase in the level of desertification in 28 of 31 states and Union territories between 2011–13 and 2018–19, a closer look at data in the atlas showed.

5.3 Causes of land degradation and desertification

- Loss of Soil Cover, mainly due to rainfall and surface runoff, is one of the biggest reasons for desertification. It is responsible for 11.01% of the desertification in the country. Cutting forests adversely affect the soil and cause degradation. As urbanization increases, the demand for resources is also increasing.
- Vegetation Degradation manifestations are summarized in the temporary or permanent reduction in the density, structure, species composition or productivity of vegetation cover. It is found to be responsible for 9.15% of desertification in the country.
- Water erosion results in Badland Topography which itself is an initial stage of desertification. Badlands are a type of dry terrain where softer sedimentary rocks and clay-rich soils have been extensively eroded. In 2011–13, water erosion was responsible for 10.98% of desertification in the country.
- Wind erosion: sand encroachment by wind reduces fertility of the soil making the land susceptible to desertification. It was found to be responsible for 5.46% of the desertification in India.

- Climate change may exacerbate desertification through alteration of spatial and temporal patterns in temperature, rainfall, solar radiation and winds.

5.4 Impact of land degradation and desertification

- Economic impact: land degradation threatens agricultural productivity. It reduces soil health, thus in turn impacting the livelihood of rural people.
- Climate change: it is exacerbating climate change events, which in turn, are causing even greater degradation. For e.g. degraded land loses its capacity to absorb carbon-dioxide (CO₂), a greenhouse gas (GHG) that is the biggest factor in worsening global warming.
- Water scarcity: land degradation has resulted in a deterioration in the quantity and quality of both surface and groundwater resources. The dryland population vulnerable to water stress and drought intensity is projected to reach 178 million under the most ideal conditions of 1.5 deg-C warming by 2050.
- Rights of indigenous people: insecure land tenure affects the ability of people and communities to fight climate change, which is further endangered by land degradation.

5.5 Measures taken by India to curb desertification/land degradation

- Integrated Watershed Management Programme: it aims to restore ecological balance by harnessing, conserving and developing degraded natural resources with the creation of Rural Employment. Now it is subsumed under Pradhan Mantri Krishi Sinchai Yojana which is being implemented by NITI Ayog.
- Desert Development Programme: it was launched in 1995 to minimize the adverse effect of drought and to rejuvenate the natural resource base of the identified desert areas. It was launched for hot desert areas of Rajasthan, Gujarat, Haryana and cold desert areas of Jammu & Kashmir and Himachal Pradesh.
- United Nations Convention to Combat Desertification (UNCCD): India became a signatory to the UNCCD in 1994 and ratified in 1996. India is working to restore 26 million hectares of degraded land by 2030. India is working hard to achieve its national commitment on Land Degradation Neutrality (LDN) (Sustainable Development Goal target 15.3). LDN is a state whereby the amount and quality of land resources, necessary to support ecosystem functions and services and enhance food security, remains stable or increases within specified temporal and spatial scales and Ecosystems.
- National Afforestation Programme: it has been implemented since 2000 for the afforestation of degraded forest

lands. It is being implemented by the Ministry of Environment, Forest and Climate Change

- National Action Programme to Combat Desertification: it was prepared in 2001 to address issues of increasing desertification and to take appropriate actions.
- National Mission on Green India: it was approved in 2014 with the objective of protecting, restoring and enhancing India's diminishing forest cover with a deadline of 10 years.

6 Case studies

Two studied areas were selected for this chapter:

6.1 First case study (AbdelRahman et al. 2008; AbdelRahman 2009)

The first case study field is located in the North Eastern part of the Nile Delta; it covers Port Said Governorate for land degradation assessment. It was selected on the basis of being representative of most of the physiographic units of north Sinai and the eastern outskirts of Nile Delta region. It was geographically described, using a topographic maps (scale 1:100,000), published by the Land Survey Authority of Egypt (1990). The area is situated in the two sides of Suez canal, lying between Latitudes 31°22'11.30 and 30°54'0.12 North and Longitudes 32°3'5.93 and 32°33'18.90 East, with total area of 135,008.14 hectares (321,448 feddans), having an elevation from the base of sea level in the shoreline to 13 m above sea level along some aeolian deposits.

The water resources in the study area depend mainly on the Nile water flowing to the area through El-Salam Canal, crossing the western part by open canal pathing to the eastern part by two under-ground tubes under the bottom of the Suez Canal. One of them is situated south of Port Said city about 26 km, carrying water eastwards to El-Shiekh Gaber irrigation canal. Another main canal is El-Shiekh Zayed irrigation canal. It is fed from El-Suez irrigation canal through a syphon at El-Defrisuar, which is already conveying the water to Sinai irrigation canal; the drainage system includes Bahr El-Baqar Drain.

The entire territory of Port-Said Governorate is located in a zone which is affected by long, dry and hot summers and short, nearly rainless and cold winter. This type of climate could be described aridic since the evaporation rate, generally, exceeds the precipitation during most time of the year.

The aim of the current study is to develop advanced techniques for land degradation assessment. Physiographic and soil mapping are primarily produced in order to achieve the ultimate goal of the present work. The interpretation of the

remotely sensed data for mapping the physiographic units of the area under investigation had been implemented through visual interpretation of the 3D view of the color composite of ASTER data band 6, 3 and 1. The 3D view was created by draping the color composite over the DEM which was generated from the digitized contour map of the area. The classified image shows the physiographic units, the northern portion of the area is occupied by the marine sediments. This area was formed from Sea where the Fluvio-marine plain is occupied by marine and alluvium deposits. This area was formed from the sea and river Nile (Plusium branch). This Deltaic Plain was formed from alluvial parent material that were transported by a long stream which deposited its load in and near the sea after the water velocity decreased and the loads became relatively finer fractions. It covers most of the studied area. Aeolian deposits were formed through the action of wind and it covers small part in the south east of the studied area.

The pedogenic process occurred in the study area as the development of diagnostic horizons, which were identified in the soils as salic, gypsic and calcic, horizons. These horizons were inherited from their parent materials under the prevailing conditions of arid climate, having a pathogenic origin.

Soils in the study area are classified according to Soil Taxonomy System (USDA 2006) under tree soil orders, Aridisols, Vertisols and Entisols. The studied soils were classified to sub great group for mapping units, while to family level for the profile description. The soil sets of the mapping unit were the following:

1-Aridisols: *Gypsic Aquisalids (Aquic Salitorrerts, clayey, thermic).*

2-Vertisols: *Typic Salitorries (Typic Gypstorreerts, clayey, thermic; Vertisols Typic Gypstorries (Typic Gypstorres; Typic Aquisalids, sandy, mixed, thermic).*

3-Entisols: *Typic Torripsamments, mixed, thermic.*

The final goal of this study was to present the land degradation assessment and change detection methods. There were five factors calculated by USLE for assessing land degradation in studied area: water erosion, wind erosion, physical degradation, salinization and alkalization. The application of the parametric approach on different soil profiles to estimate the risk of soil degradation and the present day soil degradation. The general form of universal soil loss equation (USLE) of the used parametric formula is:

$$D = f(C, S, T, V, L, M)$$

where D = soil degradation; C = climatic factor; S = soil factor; T = topographic factor; V = natural vegetation factor; L = land use factor; M = management factor.

Geostatistical analyses were based on the fundamental geographic principal, namely, things that were closer

together tend to be more alike than things that are farther apart and widely used in many fields. The IDW and Kriging interpolation of geostatistical analysis were selected to interpolate different types of degradation processes in the study area and use cross-validation to compare the results of interpolation.

The geostatistical approaches for GIS was used to produce the spatial variability for degradation processes maps for the studied area. The GIS geostatistical software was used for kriging method to interpolation degradation processes in different soil profiles.

The results showed that the more active degradation in the studies area were salinization, alkalization and physical degradation. The kriging method was performed for all degradation types (salinization, alkalization, water and wind erosion) in the studied area.

The results revealed are consistent with the change detection techniques applied for study area. These techniques were studied independently with available images of the Landsat TM and the ASTER of two dates. This was done to understand, analyze and evaluate the different detected changes that appeared.

This research work demonstrates the ability of GIS and Remote Sensing to capture spatial–temporal data. An attempt has been made to capture as much accurate as possible the five land use/land cover classes as they change through time.

The overall accuracy of the land use/land cover map for 1984 and 2005 were 90.57% and 85.43%. It is obvious that these data have reasonably high accuracy and, thus are sufficient to detect urban growth.

The land use and land cover change matrix for the different types of the East Delta area from 1984 to 2005. Urban expansion in the East Delta, from 1984 to 2005 was 48.79%, (16,743.64916 feddan) increase in urban or built-up land, and decreased in old vegetation area (30.91%). Also, the agriculture land was increased.

In Egypt, degradation problem has different forms. The northern coast, which extends for about 700 km from the east to the west, with an average width of about 30 km to the south is mainly rangeland. The overgrazing in these areas has caused non favorable grasses to develop in the rangeland. The irrigation by wells and springs which is practiced in the northern coast has brought huge amounts of salt on the soil surface, though the salt content in this water was less than 2000 ppm. This salinization unable the natural vegetation to survive and hence replaced by less economic ones. The brick yards are spread in the study area, using the scrapped soil surfaces which contain a considerable part of soil.

The study of the climate is very important for understanding the magnitude and nature of the problem. However, the meteorological synoptically stations are very scarce in the

desert area because of the economic factor and the harsh nature of the deserts. The collection of the meteorological data can be done by installing automated stations in remote locations. These stations are able to monitor the wind speed and direction, Temperature, humidity, rainfall and barometric pressure. They also include dust particle counters to monitor sand and dust storms and give early warnings of their development. Data from these meteorological stations can be transmitted by radio to the earth orbiting satellite which will have receiving capabilities. These satellites can then send the data to the earth receiving stations for analysis.

The human factor is a considerable factor in both accelerating and initiating the problem of desertification. The human activity, e.g. vegetation degradation brick making, irrigation, etc. causes many changes in the landscape which will have an impact on the rate of degradation expansion.

The study revealed five of the important degradation processes occurring in the study area: wind erosion, water erosion, physical degradation alkalization and salinization. The wind erosion works on the aeolian formation in the coastal area and builds different types of sand sheets. The water erosion, during occasional thunderstorms, is working upon the study area and caused debris material to accumulate in the study area. The study area is also exposed to a high risk of alkalization and salinization which draw the attention for the importance of good management of proper irrigation and drainage techniques. A good management of controlling wind erosion, controlling the excess of water during thunderstorms, supervising the irrigation and drainage techniques is essential.

Management and planning of agriculture and a warning and prevention system for natural disasters are urgently needed. The arid regions are the most in need for these aspects. In arid lands, remote sensing techniques can be used in a good way because of the scarcity of vegetation and consequently a favorable exposure of the surface. Interpretation of remote sensing data is an effective and inexpensive technique for mapping and providing data for the assessment of soil degradation. It is especially useful in areas where the necessary data are missing and which are characterized by a pronounced physiographic.

Soil degradation processes are occurring in different areas of Egypt. Obviously, the desert fringes, which are the hope of a future agriculture expansion, are also subject to degradation processes. Thus, very detailed studies must be performed to evaluate these areas in order to establish a good planning for these projects. The preliminary FAO/UNEP and UNESCO (1979) methodology and the world soil degradation map and the soil map of Egypt can be used as a framework for studies on a larger scale.

6.1.1 Physiographic units of the study area

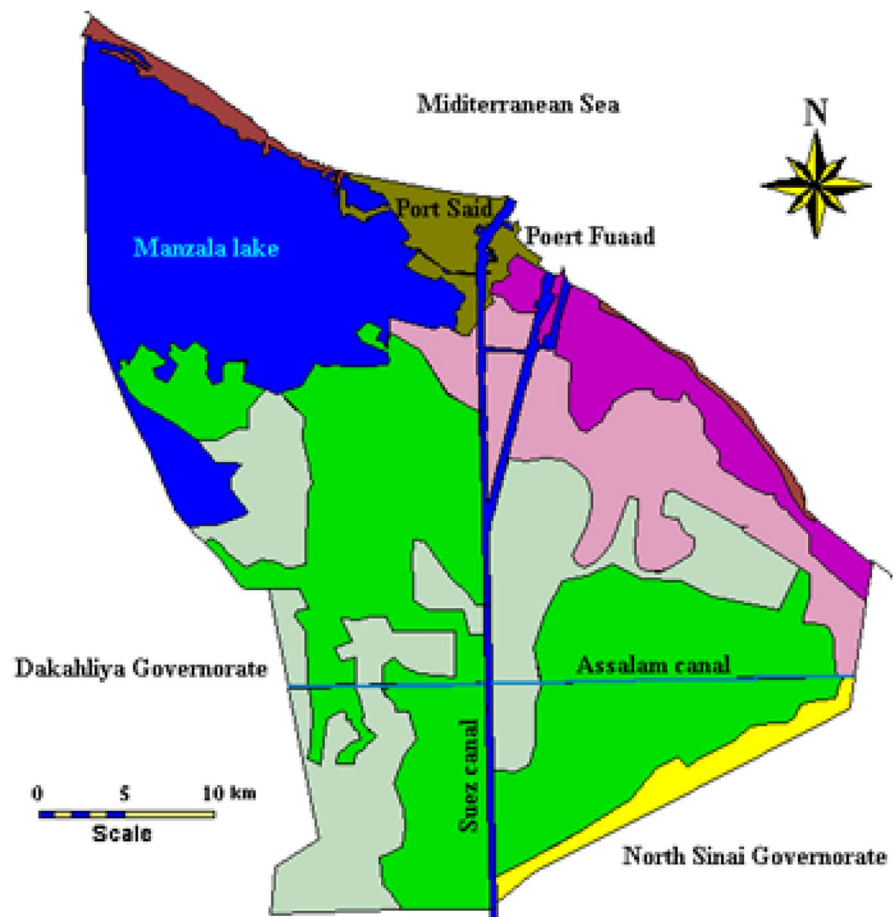
Physiography can be defined as the study and description of the physical features of the earth's surface, including the processes responsible for their formation and evolution. Therefore, there is a difference between geomorphology and physiography. Physiography is based on geomorphology and can provide a good basis for explaining geomorphology by interpreting aerospace images using physiographic analysis, which identifies a certain physiographic process, which in turn, provides an important clue for delineating soil patterns after predicting some certain soil properties (Goosen 1967).

In the study area, identification in terms of physiographic units was generally based on specifying some geomorphic units, which reflect most of the landscape forms and their genesis. These units were described, grouped or split off by the remote sensing data interpretation. The physiographic features of the study area were delineated, termed and presented in Fig. 2, and described as follows:

6.1.1.1 Deltaic plain This Deltaic Plain was formed from alluvial parent material that were transported by a long stream which deposited its load in and near the sea after the water velocity decreased and the loads became relatively finer fractions. This alluvium was transported and deposited by the River Nile Pelusium branch. The surface is flat, covered with a salt crust in areas that are still virgin, but not in those, that were reclaimed. Sneh and Weissbrod (1975) stated that the Pelusium branch is one of the ancient seven major deltaic branches of the River Nile. Five of those branches including the Pelusium one are silted up in the course of history. At the mouth of Pelusium branch, the city of Pelusium was situated. El-Shazly and Abdel-Ghaphour (1990) considered this deltaic plain as fluvio-lacustrine sediments including El Tina Bay, which lies between Port Said in the west and El-Bardawil Lake. He concluded that the parent material of these fluvio-lacustrine deposits was deposited by the action of the fresh water of river Nile. According to the landscape genesis and for more physiographic attributes homogeneity, Afify et al. (2005) split out this unit from the pro deltaic plain. Logged and submerged estuarine sediments and the estuarine bay to be defined as inter deltaic plain. The definition based also on the fact that, the term lacustrine is conditioned to be inland and far from the shoreline and not originated as marine sediments. Before the time of road construction that are crossing many parts of El-Tina area, it was difficult for getting complete ground truth as could be currently done.

6.1.1.2 Fluvio-marine plain These sediments form the natural extension of the Deltaic Plain, having two different parent materials. The epi-sediments are the alluvium that was deposited by the Plusium branch before its silting up. The

Fig. 2 Physiographic units of the study area



Physiographic units	Taxonomic units
■ Deltaic plain	Typic Gypsiteggers, clayey, thermic Halci Haploteggers, clayey, thermic
■ Deltaic plain Water logged	Aquic Saliteggers, clayey, thermic Halci Haploteggers, clayey, thermic
■ Fluvio-marine sediments	Gypsic Aquisalids, fine loamy over sandy, thermic Gypsic Aquisalids, fine loamy, thermic
■ Marine sediments	Typic Aquisalids, sandy, mixed, thermic
■ Aelion	Typic Torripsamments, mixed, thermic
■ Marine bay bar	
■ Urban	
■ Al Manzala Lake	
 Suez Canal	
— Assalam Canal	

substratum relates to marine sediments deposited by the sea before being covered by alluvium. These sediments are low-lying and poorly drained. This fluvio-marine plain constitutes a limited strip adjacent to the Delta Plain, separating it from the marine sediments. It can have an alternative name as done by Afify et al. (2005) as pro delta plain.

6.1.1.3 Marine sediments These sediments were originated from the materials that were carried by stream action, and deposited in the sea. The coarse fractions were deposited near the shore, but the finer at a distance further away. These sediments are mostly elastic raised above sea level and gave origin to large areas of marine soils which contain low nutrients and are often sandy with high contents of silica (FAO

1966). Sneh and Weissbrod (1975) identified marine sediments in North Sinai in areas near the current study area as strand plain, built of numerous low ridges composed of fine- and coarse-grained elastic sediments. The age of the earliest beach ridge (the one farthest inland), therefore a crucial stage of stream silting-up which resulted in degeneration of the lower reaches of the branch. In this zone the huge mound of the ancient (Fifth Century B.C.) city of Pelusium (Tell El-Farma) has been identified. Towards the Mediterranean coast a series of low beaches ridges mark ancient coastlines. Radiocarbon (C14) dating of mollusks found in the beach ridges indicates an age of 1925 ± 90 years before the present for the southernmost ones (located today up to 12 km inland). From that time onward, the prograding beach has moved the shoreline to the north.

In the current study, the interpretation indicates that beaches consisted of sand ripples within the zone of the foreshore. In the areas that are relatively higher than the foreshore zone, the surface is flat and locally covered by overblown sand and scattered natural halophytic vegetation. These marine sediments include coastal forms that were mainly deposited by sea water activity due to wind, waves and currents. These sediments occupy a strip along the shoreline of the coastal zone in the study area. This pattern is dominated by beaches with some localized lagoons. This physiographic unit was represented by profile this unit includes submerged depressed areas, either of marine sediments in the back-shore or in lagoons. The back-shore is located in the zone of the tidal effect behind the beach strip. In this area, the land is somewhat depressed. The surface of these marine sediments is mostly covered by sea water, being linked to the high tide. These submerged sediments occur north of the fluvio-marine plain in the northwest part of the study area.

6.1.1.4 Aeolian deposits These deposits were formed through the action of wind. Neev et al (1982) studied the genesis of the Aeolian deposits in north Sinai. They reported that, concerning the swarms of lineaments in North West Sinai, it is characterized by dense and very long parallelisms with occasional smooth sinuosity or radial convergence. Linear sand ridges should not always be considered reliable indicators of the regional atmospheric circulation because the tectonic liniments may deflect and channel the prevailing low level winds to form Aeolian landforms along them.

6.1.1.5 Bay bar This Bay Bar is somewhat consolidated sediments and is considered as a natural protective bar against sea water erosion. This unit is an elongated semi-ridge, separating the sea water from the inland sediments. Frihy et al. (1999) stated that these ridges along the shoreline facing the deltaic sediments of River Nile were normally formed by littoral currents along downslope areas of

depositional sinks formed of very fine- to coarse-grained sands rich in light minerals and shell debris.

6.1.2 Soils of the investigated area

The area contains three different soil orders that can be identified as Aridisols, Vertisols and Entisols.

6.1.2.1 Aridisols These soils were developed under the prevailing climatic conditions in Egypt as arid climate, which is specified within soil strata as an aridic moisture regime and hyperthermic temperature regime. The soils of this order have an ochric epipedon, including one or more of the diagnostic horizon as salic, gypsic and calcic. Soils as their taxa are categorized within Aridisols in collective taxonomic units to the family level using soil taxa. Salids includes the salic horizon at the sub order level. And studied salids have the water table causing redoxmorphic features, so they were categorized as Aquisalids at the level of Great Group. These Aquisalids have gypsic horizon to be classified as Gypsic Aquisalids. As the soil control Sect. (25 to 100 cm.) have two contrasting particle size classes (sandy clay loam underlain by loamy), the soils were categorized as fine loamy over sandy at the family level. Since these soils located within the zone of thermic temperature regime, the soil family was characterized as thermic.

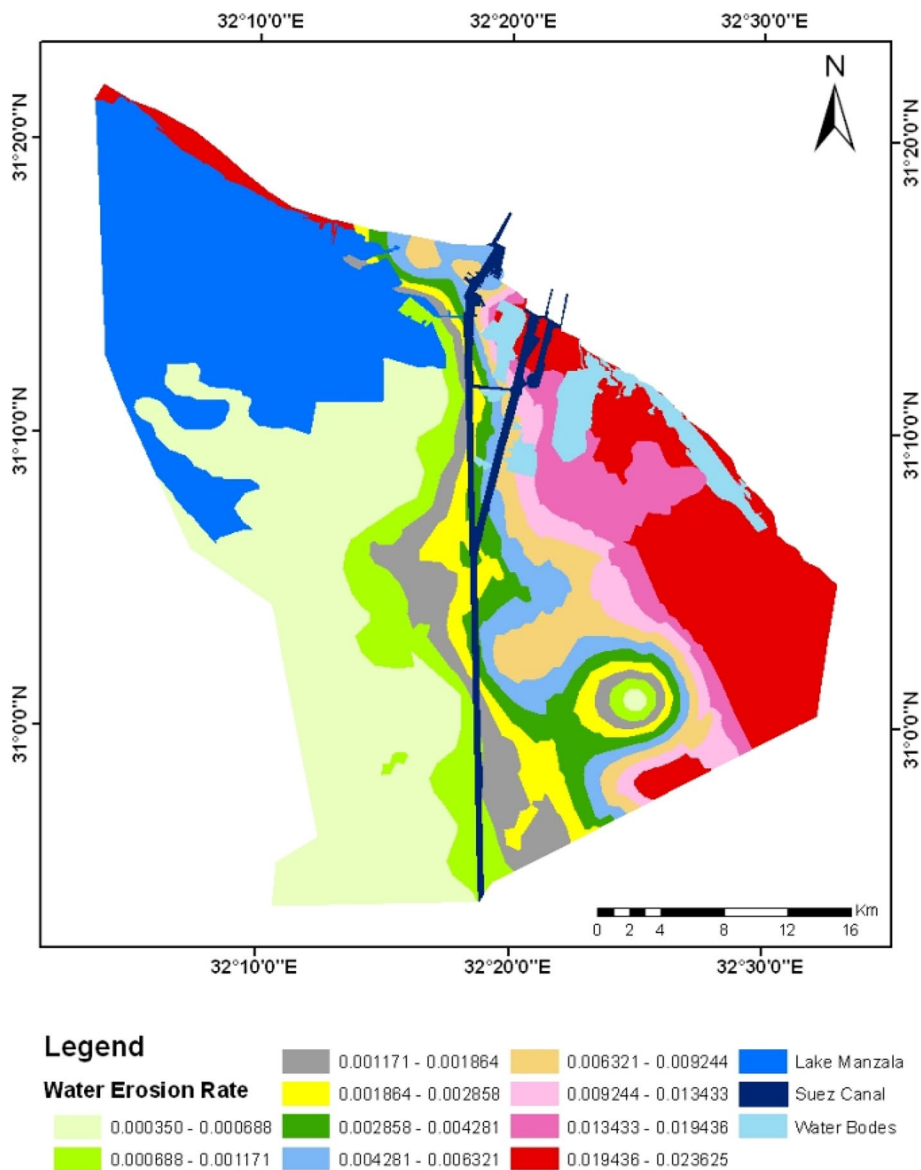
6.1.2.2 Vertisols Vertisols means that the soil turns upside down as a result of the presence of high percentage of clay especially smectites. Dryness and subsequent shrinkage lead to the formation of wide deep cracks, which are filled with the material from the soil surface. Then after the soil eventually swells, it will be subjected to pressure due to the new filling material, which result in compacted soil slices—‘the slickensides’ (the surface soils materials move ‘down’ and the subsurface materials move ‘up’). This increase in soil volume leads in increase of the surface area, thus so-called ‘soil gilgai’ occurs. Slickensides and gilgai features are clues for the Vertisols identification, but the problem arose when these clues do not appear when soil conditions are not favorable. As the Vertisols have a unique behavior to the root zone, drainage condition, permeability, fertility and salinization process, (especially in the arid climate as in Egypt), it become very important to identify the Vertisols according to the reasons why they are Vertisols and their effect on plant growth. On the other hand, the shift of Vertisols to Aridisols when any of the diagnostic horizons appears, or to Entisols when they do not appear, may cause misleading identification in soil management. When the Vertisols order is well identified, the soil characteristics are quite expected, but if the same soils are shifted to Aridisols or Entisols, their wide range of the textural classes such as sands through clays, necessitates a data at different taxo-

onomic levels. Soils with dominant montmorillonitic (semec-titic) clays have certain effects on the plant growth, which requires specific management for successful planting. When the soil moisture condition is favorable, tracing the clues of Vertisols is helpful. In the current study, four Vertisol families were identified in the El-Kantara-Pelusium area.

6.1.2.3 Entisols Entisols are those recent soils that are not exhibiting any sign of parent material maturity under the prevailing arid climate. Smith (1986) considered the Entisols to be truly azonal soils and no statements can be made about Entisols except the lack of subsurface diagnostic horizons. The arid climate is shown only at the great group level because suborder level is first sorted out according to the reasons as why they had no subsurface diagnostic horizon. The soils of Entisols are either losing material too rapidly

through truncation or receiving additions too rapidly for horizons to form. Entisols of the study area are categorized in collective taxonomic units to the family level as *Typic Torripsamments*, mixed (Calcareous). These soils of psamments have less than 35% by volume rock fragments below a depth of 25 cm and have texture of loamy fine sand or coarser in all subhorizons. These psamments are characterized by the torric moisture regime. Soil taxa of these Torripsamments are fitting the central concept of this category to be Typic. The fine earth in the soil control section between the depths 25 cm to 50 cm effervesces in all parts with cold dilutes HCl (i.e. calcareous).

Fig. 3 Rates of water erosion for in study area



6.1.3 Active land degradation process in the studied area

Five major factors were calculated by USLE (Universal Soil Loss Equation) for promoting land degradation in the studied area. These are water erosion, wind erosion, physical degradation, Salinization and alkalization. The application of the parametric approach on different soil profiles to estimating the risk of soil degradation and the present day soil degradation. The general form of universal soil loss equation (USLE) of the used parametric formula is:

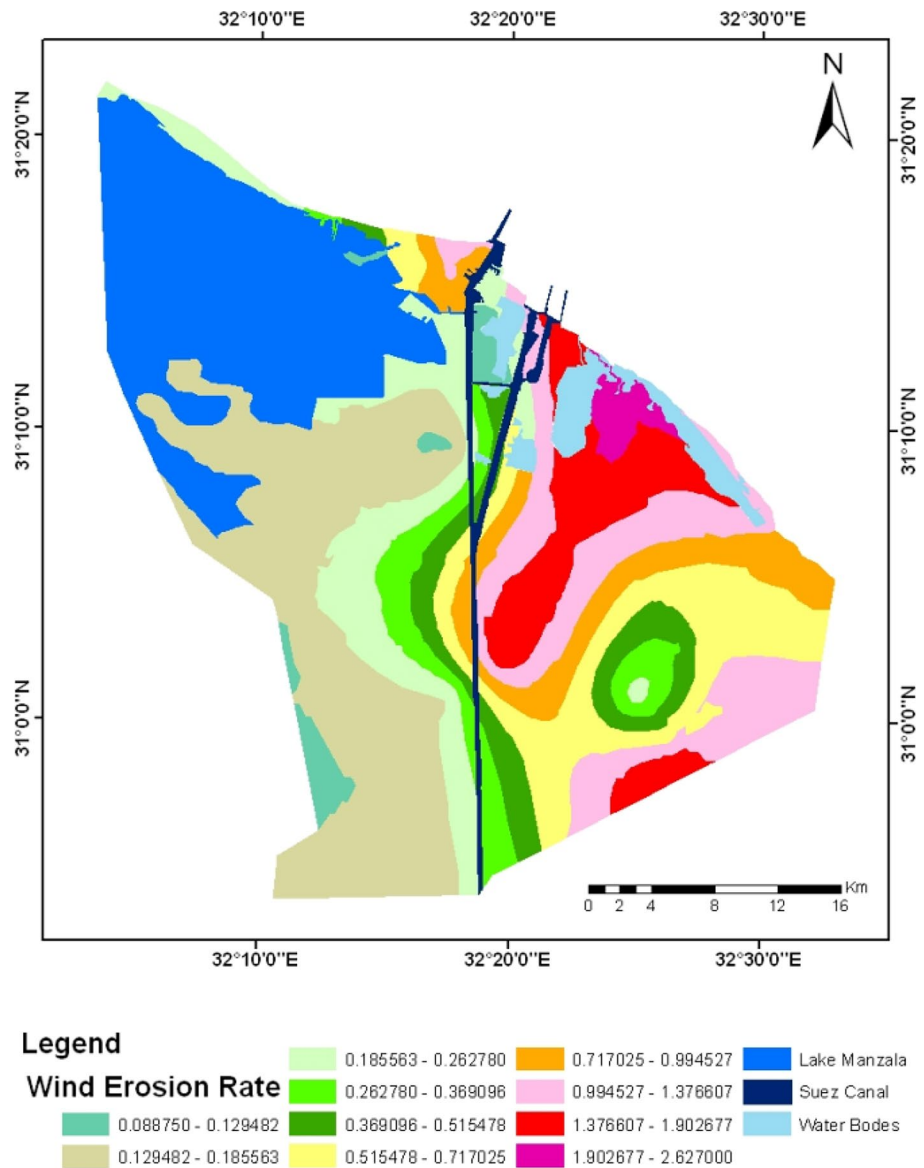
$$D = f(C, S, T, V, L, M)$$

where D=soil degradation; C=climatic factor; S=soil factor; T=topographic factor; V=natural vegetation factor; L=land use factor; M=mane gent factor

6.1.3.1 Water erosion The soil degradation by water erosion in the studied area was obvious that the slight water erosion (less than $0.02 \text{ t}^{-1} \text{ ha}^{-1} \text{ year}^{-1}$). However, the high value of water erosion was located in the north study area. Map in the Fig. 3 shows the water erosion rate in the study area. It is obvious that the relative increase of water erosion is related to the strong dissection of the climatic and soil condition. The coastal plain in the study area is characterized by high value of water erosion due to it has sandy soil texture. The south Manzala Lake has the low value of water erosion because it has heavy clay soil texture.

6.1.3.2 Wind erosion The whole study area is subjected to slight wind erosion (less than 2.63 t/ha/year). Most of the east Suez Canal is characterized by high of wind erosion rate ($0.5\text{--}2.63 \text{ t}^{-1} \text{ ha}^{-1} \text{ year}^{-1}$). The soil texture and

Fig. 4 Rates of wind erosion for in study area



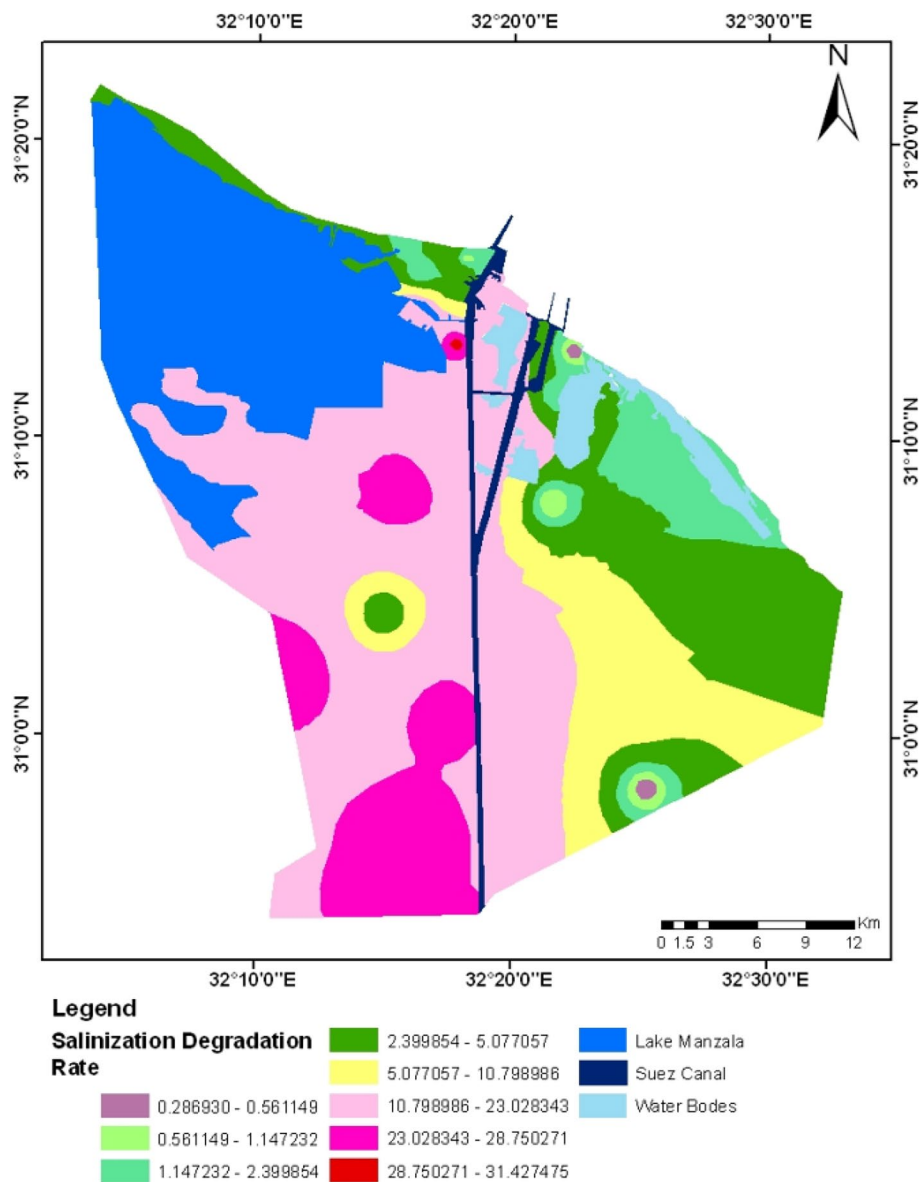
human activity are the main factors in the wind erosion of the study area. For the east Suez Canal has low vegetation cover comparing to the west Suez Canal. Geostatistical analysis is based on the fundamental geographic things that are closer together tend to be more alike than things that are farther apart and widely used in many fields. The IDW and Kriging interpolation of geostatistics analyst were selected to interpolate wind erosion rate and use cross-validation to compare the results of interpolation. The geostatistical approaches for GIS software was used to produce the spatial variability for wind erosion maps for the studied area. Figure 4 shows the wind erosion by GIS. The GIS geostatistical software was used for kriging method to interpolation wind erosion rate in different soil profiles. Also, GS + geostatistical software was used for IDW method to interpolation wind erosion rate in different soil profiles. Comparing the results

between kriging and IDW, the Simple Kriging owns the highest interpolation precision and has fine feature to reflect wind erosion rate changing than IDW.

6.1.3.3 Salinization Agricultural practices in study area lack water management techniques with emphasis on conventional surface irrigation systems that do not surpass 80% efficiency. Using agricultural water run-off mixed with water from canals only increases the salinity of the irrigation water to be used making it inappropriate for the practice. The studied area has revealed that 90% of irrigated lands have been intruded by saltwater.

The present state of salinization in the study area is slight to very high. The risk of salinization in west of Suez Canal is higher than east of Suez Canal and coastal. These estimations are based upon the calculated climatic index without

Fig. 5 Rates of salinization degradation for in study area



considering the salinity of the ground water. The soil, topography and human activity cause higher values for the present state and risk of degradation by salinization. In fact, the amount of salt, which might be brought to the fields by normal irrigation practices, may be enormous. Some studies show that a moderate irrigation depth of 300 mm with an average salt content of 400 ppm brings on the field, in arid conditions, 1200 kg of pure salt per half, there is no natural or artificial drainage, this salt remains in the soil and increase over the years to enormous quantities. This stresses the importance of a good management of the new cultivation projects in the study area taking more care for the use of appropriate irrigation and drainage techniques. The geostatistical approaches for GIS was used to produce the spatial variability for Salinization maps for the studied area. Figure 5 shows the Salinization by GIS software. The

GIS geostatistical software was used for kriging method to interpolation Salinization rate in different soil profiles. The kriging performed best for spatial variability in salinization than IDW methods.

6.1.3.4 Sodification (alkalinization) The present state of salinization in the study area is slight to very high. The risk of Sodification in west of Suez Canal is higher than East of Suez Canal and coastal zone. These estimations are based upon the calculated climatic index without considering the alkalinity of the ground water. The soil, topography and human activity cause higher values for the present state and risk of degradation by sodification. The geostatistical approaches for GIS was used to produce the spatial variability for Sodification maps for the studied area. Figure 6 show the salinization by GIS software. The GIS geostatisti-

Fig. 6 Rates of sodification degradation for in study area

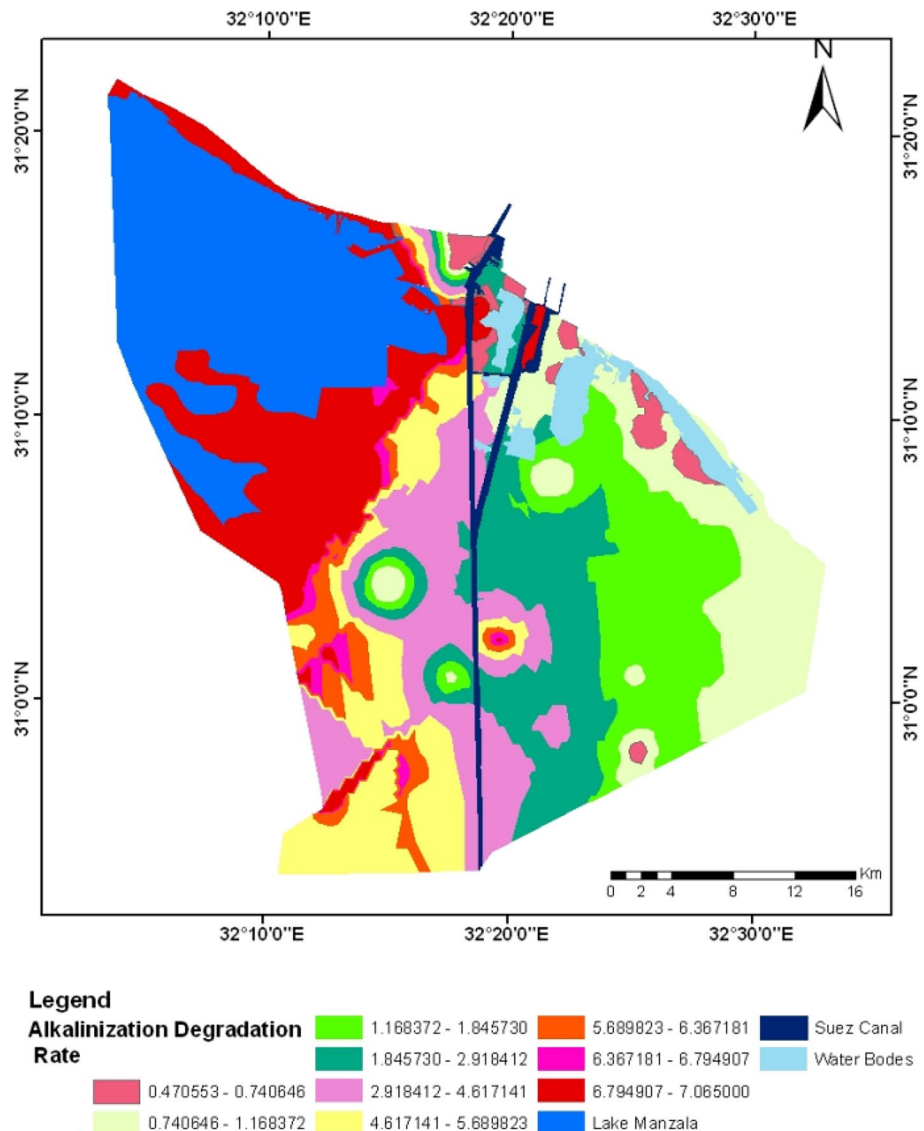
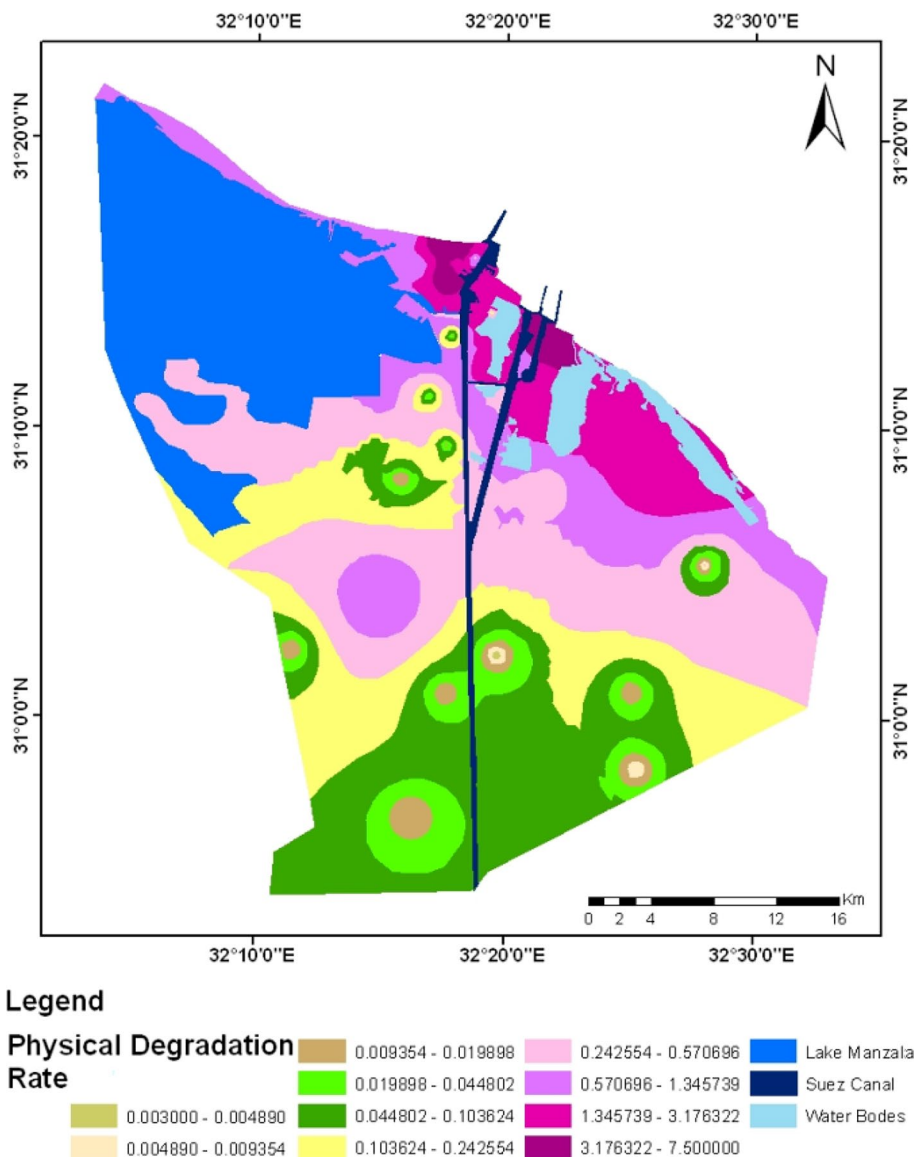


Fig. 7 Physical degradation for study area



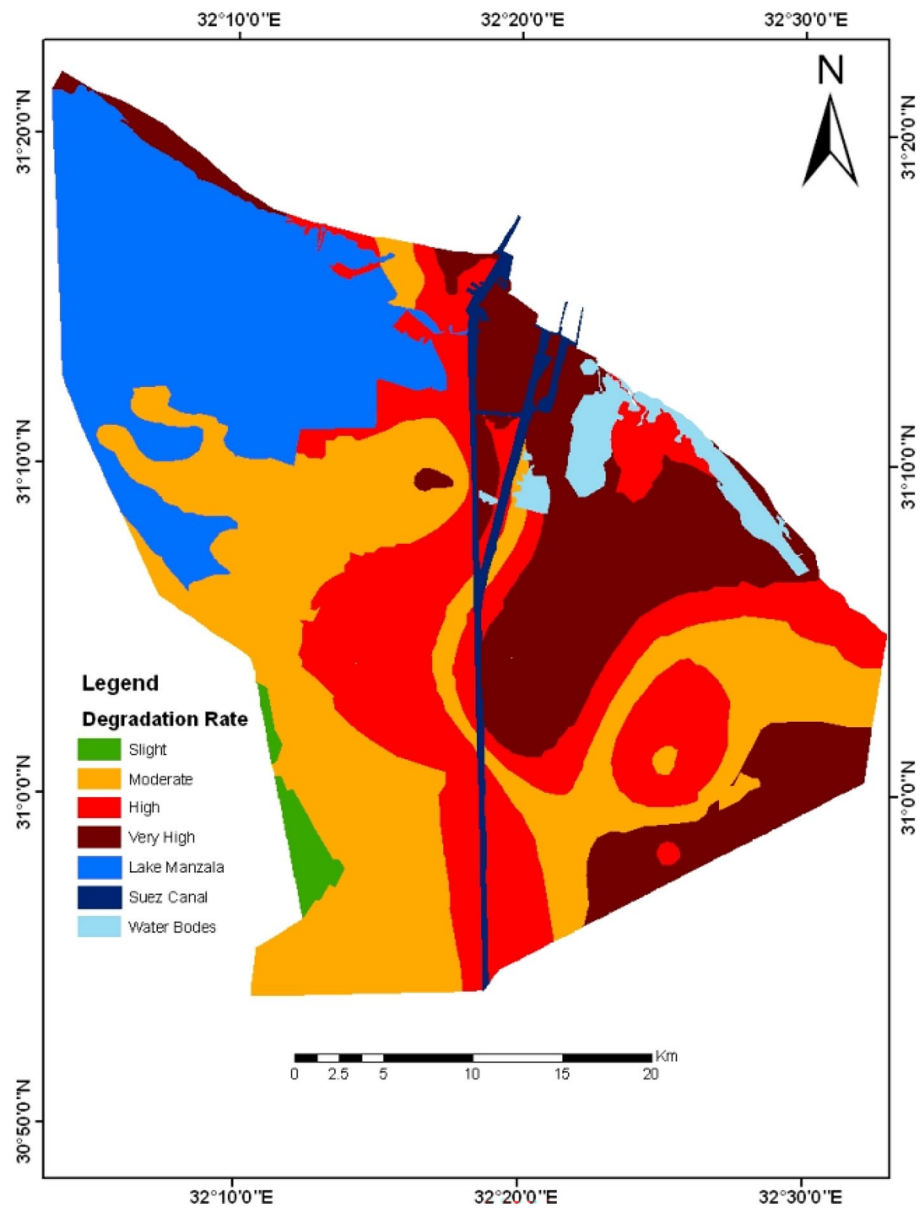
cal software was used for kriging method to interpolation Sodification rate in different soil profiles. The kriging performed best for spatial variability in Sodification than IDW methods.

6.1.3.5 Physical degradation Figure 7 shows the present approximate state of physical degradation (in $t^{-1} ha^{-1} year^{-1}$) for the study area, calculated by using the climatic, soil, topography and human activity factors in the studied area. The whole studied area is subjected to slight to high physical degradation (from 0.01 to $7.5 t^{-1} ha^{-1} year^{-1}$). Most of the south to middle studied area are characterized by slight to a moderate class of physical degradation. On the other hand the middle to north of the studied area are characterized by moderate to high. Climatic and soil factors are the dominant factors caus-

ing the risk of physical degradation in the studied area. The geostatistical approaches for GIS used to produce the spatial variability for produce physical degradation maps for the studied area. Figure 7 shows the physical degradation by GIS software. The GIS geostatistical software was used for IDW method to interpolation physical degradation rate in different soil profiles. The results of IDW from GIS software were performed similar spatial variability of physical degradation with results of IDW in GIS software.

6.1.3.6 Overall land degradation Arc GIS Model Builder was used to develop a final overlay map for land degradation types in the studied area (Fig. 8). The maps resulting from the interpolation techniques were introduced into a GIS and their values reclassified.

Fig. 8 Overlay map of land degradation types in the studied area



6.2 Second case study

The second case study provides the results of the investigation carried out on assessment of land degradation in Chamrajanagar District, Karnataka (AbdelRahman 2014; AbdelRahman et al. 2016; AbdelRahman et al. 2019b)

6.2.1 Physiographic units of the study area

Physiography can be defined as the study and description of physical earth surface features, including the processes responsible for their formation and evolution. Therefore,

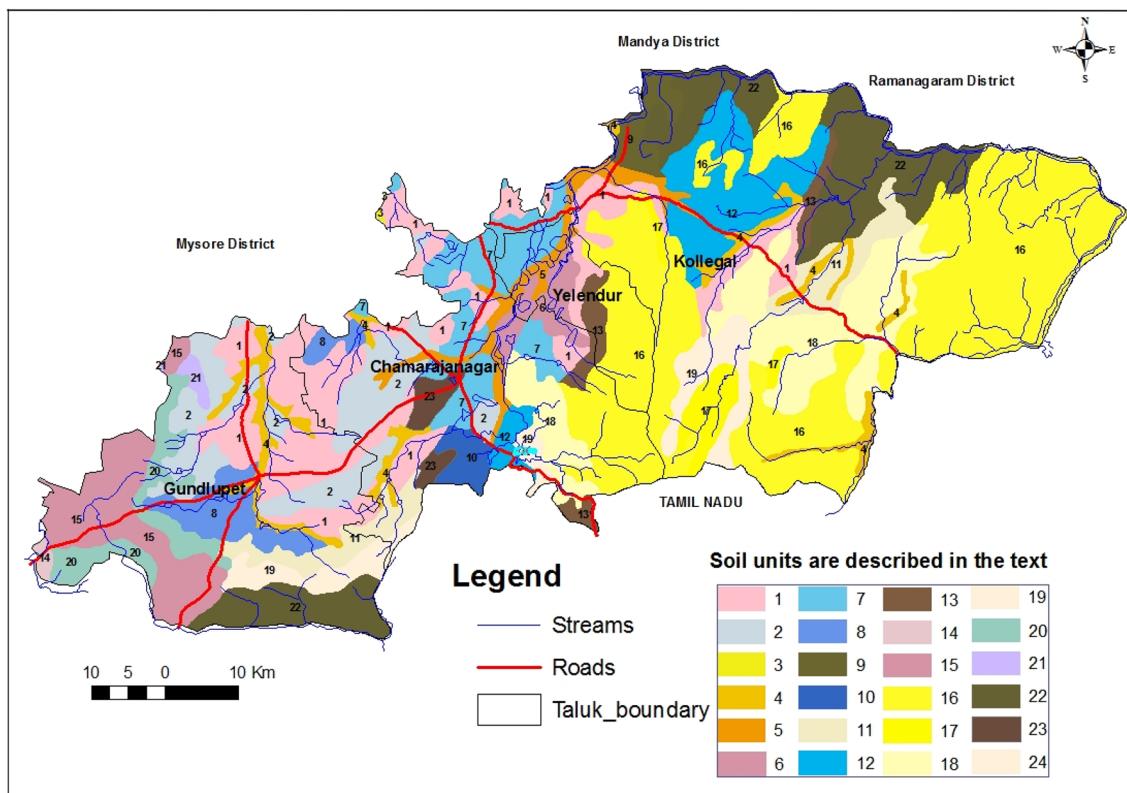
there is a difference between geomorphology and physiography. Physiography is based on geomorphology and can provide a good basis for explaining geomorphology through the aerospace images interpretation, using physiographic analysis, that identifies a certain physiographic process, which in turn, provides an important element clue for delineating soil patterns after predicting some certain soil properties (Goosen 1967). In the study area, identification in terms of physiographic units was generally based on specifying some geomorphic units, which reflect most of the landscape forms and their genesis. When these units were described, grouped or split off by

Table 4 Soil unit description and soil taxonomy

No in Fig. 10	Soil unit description	Soil taxonomy
1	Very deep, well drained, clayey soils on undulating interfluves, with slight erosion; associated with: Shallow, somewhat excessively drained, gravelly clay soils, moderately eroded	(Fine, mixed, Rhodic Paleustalfs) (Clayey-skeletal, mixed, Lithic Ustropepts)
2	Moderately shallow, well drained, gravelly clay soils with very low AWC on undulating interfluves, with moderate erosion; associated with: Moderately deep, well drained, gravelly clay soils with very low AWC	(Clayey-skeletal, mixed, Typic Rhodustalfs) (Clayey-skeletal, mixed Typic Haplustalfs)
3	Shallow, well drained, gravelly clay soils with very low AWC, strongly gravelly in the subsoil on undulating interfluves; associated with: very deep, moderately well drained, calcareous, cracking clay soils, moderately eroded	(Clayey-skeletal, mixed, Typic Ustropepts) (Very-fine, montmorillonitic, Typic Pellusterts)
4	Very deep, moderately well drained, clayey soils of valleys, with problems of drainage and slight salinity in patches; associated with: Moderately deep, well drained, loamy soils	(Fine, mixed, Typic Ustropepts) (Clayey over loamy, mixed, Typic Ustifluvents)
5	Deep, moderately well drained, clayey soils of valleys, with problems of drainage and slight salinity in patches; associated with: Deep, imperfectly drained, clayey over sandy soils	(Fine, mixed, TypicUstropepts) (Fine, mixed, Typic Ustifluvents)
6	Deep, well drained, calcareous, cracking clay soils on undulating interfluves, with moderate erosion; associated with: Moderately deep, well drained, calcareous, clayey soils with slight salinity under irrigation	(Very-fine, montmorillonitic, Typic Chromusterts) (Fine, montmorillonitic, Verticustropepts)
7	Very deep, moderately well drained, calcareous, cracking clay soils on gently sloping interfluves, with slight erosion; associated with: Deep, well drained, calcareous, clayey soils, moderately eroded	(Very-fine, montmorillonitic, Typic Pellusterts) (Fine, montmorillonitic, Vertic Ustropepts)
8	Very deep, well drained, gravelly loam soils, strongly gravelly in the subsoil on rolling lands, with moderate erosion; associated with: Shallow, somewhat excessively drained, gravelly clay soils with very low AWC	(Loamy-skeletal, mixed Typic Ustrorthents) (Clayey-skeletal, mixed, Lithic Ustrorthents)
9	Rock outcrops	Rock land
10	Very deep, well drained, gravelly clay soils, strongly gravelly in the subsoil on steeply sloping high hill ranges, with moderate erosion; associated with: Very deep, well drained, clayey soils	(Clayey-skeletal, kaolinitic, Typic Kandiestalfs) (Fine, kaolinitic, Kandic Paleustalfs)
11	Moderately deep, well drained, gravelly clay soils with low AWC, strongly gravelly in the subsoil on rolling lands; associated with: Moderately deep, well drained, gravelly clay soils with very low AWC	(Clayey-skeletal, mixed, Typic Paleustalfs) (Clayey-skeletal, mixed, Rhodic Paleustalfs)
12	Deep, well drained, gravelly clay soils with low AWC on rolling lands, with moderate erosion; associated with: Moderately deep, well drained, gravelly clay soils with very low AWC	(Clayey-skeletal, mixed, Typic Rhodustalfs) (Clayey-skeletal, mixed, Typic Ustropepts)
13	Moderately deep, well drained, clayey soils on escarpment slopes, with severe erosion; associated with: Deep, somewhat excessively drained, gravelly clay soils, moderately eroded	(Fine, mixed, Typic Haplustalfs) (Clayey-skeletal, mixed, Typic Rhodustalfs)
14	Deep, well drained, gravelly clay soils with low AWC on undulating uplands, with moderate erosion; associated with: Moderately deep, well drained, gravelly clay soils with very low AWC	(Clayey-skeletal, kaolinitic, Kanhaplic Haplustalfs) (Clayey-skeletal, kaolinitic, Oxic Ustropepts)
15	Moderately deep, well drained, clayey soils with low AWC on undulating uplands and Valleys; associated with: Deep, well drained, clayey soils, moderately eroded	(Fine, kaolinitic, Kanhaplic Haplustalfs) (Fine, kaolinitic, kandic Paleustalfs)
16	Moderately shallow, well drained, gravelly clay soils on hills and ridges, with moderate erosion; associated with: Shallow, well drained, gravelly clay soils with very low AWC	(Clayey-skeletal, mixed, TypicUstropepts) (Clayey-skeletal, mixed, Lithic Ustropepts)
17	Moderately shallow, somewhat excessively drained, clayey soils on hills and ridges, with severe erosion; associated with: Shallow, somewhat excessively drained, clayey soils	(Fine, mixed, TypicUstropepts) (Clayey, mixed, Lithic Ustropepts)
18	Shallow, somewhat excessively drained, gravelly clay soils on steep ridges, with severe erosion; associated with: Shallow, somewhat excessively drained, gravelly loam soils	(Clayey-skeletal, mixed, lithic Ustorthents) (Loamy-skeletal, mixed, Lithic Ustorthents)
19	Very shallow, somewhat excessively drained, loam soils on ridges, with severe erosion; associated with: Shallow, somewhat excessively drained, loamy soils	(Loamy-skeletal, mixed, Lithic Ustorthents) (Loamy, mixed, Lithic Haplustalfs)

Table 4 (continued)

No in Fig. 10	Soil unit description	Soil taxonomy
20	Very deep, well drained, gravelly clay soils with low AWC on low hill ranges, with moderate erosion; associated with: moderately deep, somewhat excessively drained, gravelly clay soils	(Clayey-skeletal, kaolinitic, Ustic Haplohumults) (Clayey-skeletal, kaolinitic, Ustic Kanhaplohumults)
21	Deep, well drained, clayey soils on undulating up lands, with moderate erosion; associated with: deep, well drained, gravelly clay soils, with low AWC	(Clayey, Kaolinitic, Kanhaplic Haplustults) (Clayey-skeletal, mixed, Kanhaplic Rhodustalfs)
22	Rook outcrops; associated with: shallow, somewhat excessively drained, gravelly loamy soils on ridges, with severe erosion	(Rock land) (Loamy-skeletal, mixed, Typic Ustropepts)
23	Rook outcrops	(Rock land)
24	Very shallow, somewhat excessively drained, loam soils on ridges, with severe erosion; associated with: shallow, somewhat excessively drained, loamy soils	(Loamy-skeletal, mixed, Lithic Ustorthents) (Loamy, mixed, Lithic Haplustalfs)

**Fig. 9** Physiographic units of the study area

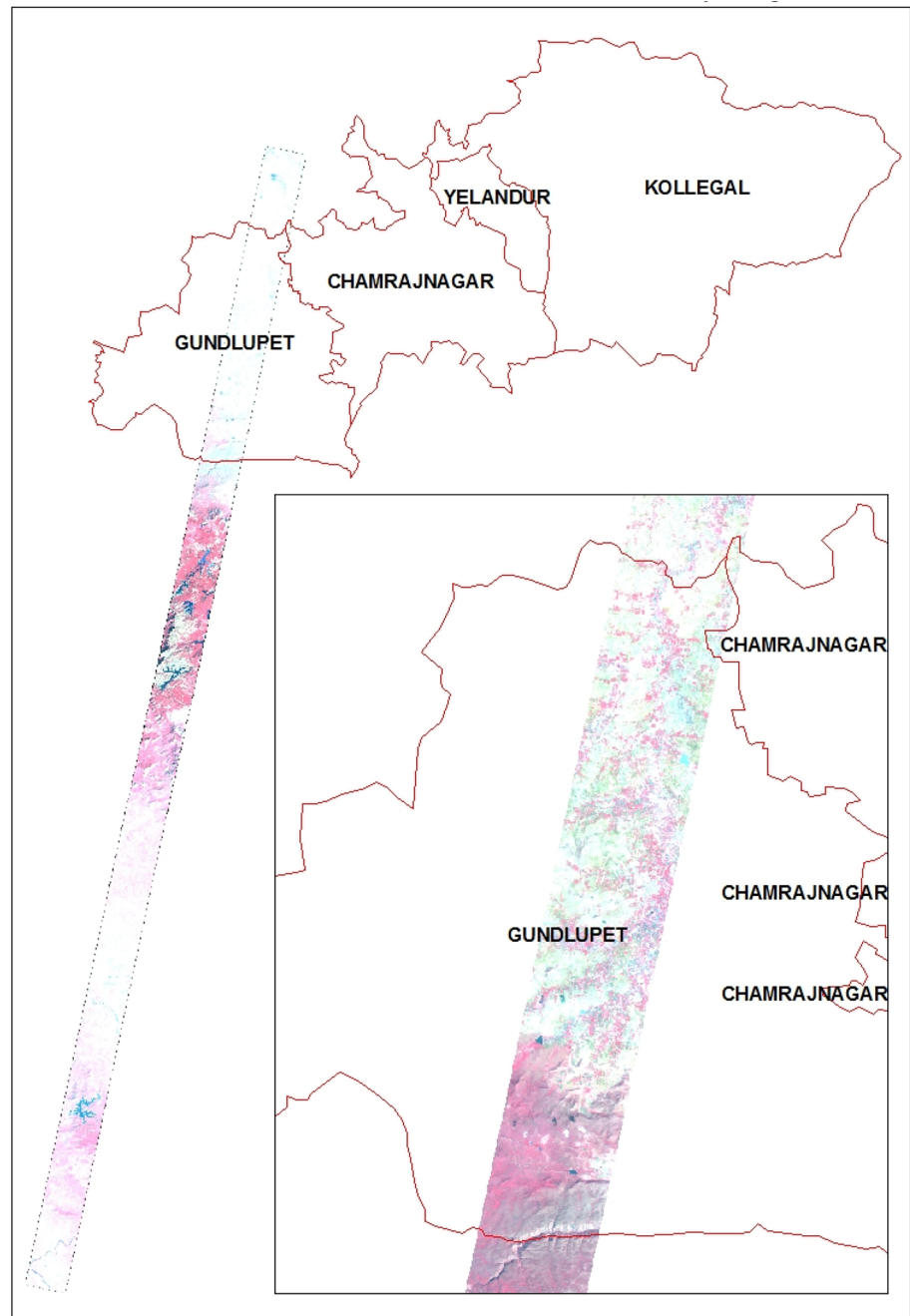
the remote sensing data interpretation, the term ‘physiographic’ replaces the other one of geomorphology.

Chamrajnagar district was divided into three major geomorphologic divisions, namely, Plateau which is part of South Deccan plateau of Karnataka occupying 29.89% of the total area of the district, Eastern Ghats occupying 57.24% and Western Ghats occupying 12.89%. These divisions were divided into subdivisions of Physiography namely, Dissected Hill 5.62%, Escarpment 24%,

Hill 10.05%, Peneplain 12.56%, Piedmont 2.86%, Plain 28.85% and Ridge 16.06%.

6.2.2 Soil map of the study area

The soil map has 24 mapping unit consisting of soil family associations with dominant phases based on land form analysis, field survey, laboratory investigation, field reviews and after (Prasad et al. 1998). Soil Unit Description and Soil Taxonomy are described in the following Table 4 and Fig. 9.

Fig. 10 Hyperion Scene

6.2.3 Detection of salt affected soil using hyperspectral and Indian Remote sensing (IRS) satellite imageries

The Hyperion Scene Characteristics are covered part of the study area using Hyperion is shown in Fig. 10. This product was created by the United States Geological Survey (USGS) and contains EO-1 Hyperion data files in Hierarchical Data Format (HDF) or Geographic Tagged Image-File Format (GeoTIFF). EO-1 was launched as a one-year technology demonstration/validation mission. After the initial technology mission was completed, National Aeronautics and

Space Administration (NASA) and the USGS agreed to the continuation of the EO-1 program as an extended mission. Information about the EO-1 satellite and the Hyperion sensor are available at the USGS and NASA web sites: <http://eo1.usgs.gov> B) <http://eo1.gsfc.nasa.gov>

6.2.3.1 Indices ENVI software (ITT Visual Information Solutions, Boulder, CO) was used to calculate different indices from a spectral input image. The input spectral data were been atmospherically corrected and calibrated to reflectance.

Many natural surfaces are almost equally bright in red and near-infrared part of the spectrum with notable exception of green vegetation. Red light is strongly absorbed by photosynthetic pigments (such as chlorophyll) found in green leaves, while near infrared light either passes through or is reflected by live tissues, regardless of their color. It means that the areas of bare soil having little or no green plant material are similar in both red and near infrared wavelengths, while areas with much green vegetation show more brightness in the near-infrared and are very dark in red part of the spectrum. The healthy vegetation can absorb the red light and is found to have very dark tone and thus are present as higher digital value pixels. While bright tone represents the barren soil and stressed vegetation with minimum digital pixel values. But in near-infrared band all classes are found to have very bright tones. Salinity creates water stress in plant tissues, which, as a result creates change in the amount of chlorophyll. The signature of salt affected soil differs from the healthy vegetated soil.

Detection of soil salinity is usually done by laborious soil sampling. To delineate surface soil salinity in selected area of Chamarajanagar, the study employed an index-based approach of using optical remote sensing data in combination with geographic information system. The effectiveness

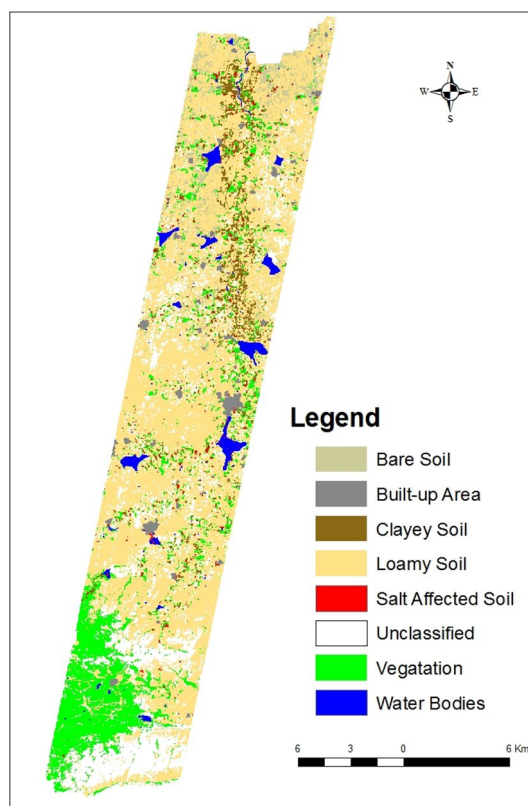


Fig. 12 Normalized Difference Salinity Index using Hyperion

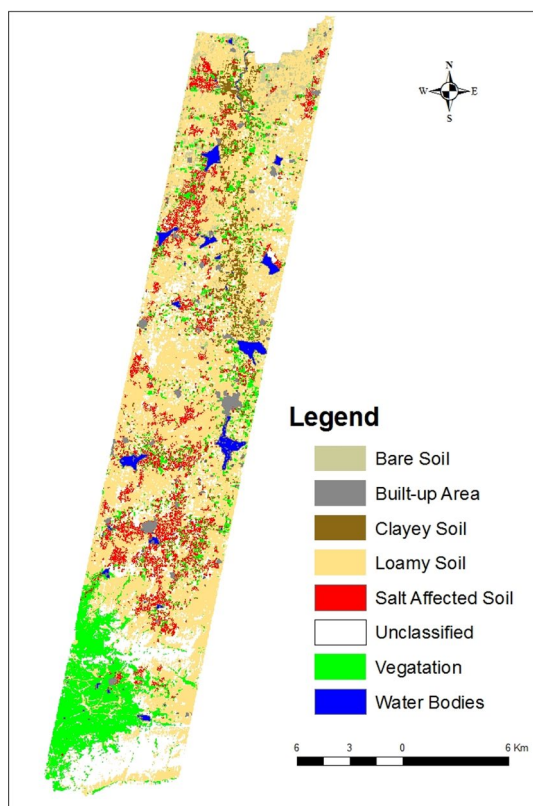


Fig. 11 Salinity Index using Hyperion

of different satellite imagery indicators was examined. Several combinations of the ratio of signals received in different spectral bands were used for development of this index. Near infrared and thermal IR spectral bands proved to be most effective as this combination helped easy detection of salt affected area from the non-saline area. Results showed that 8.9% of Hyperion image area (32610 hectares) in the selected area of Chamarajanagar district is salt affected using Salinity index (SI) and 1.8% using Normalized Difference Salinity Index (NDSI) using Hyperion as shown in Figs. 11 and 12, respectively. These results are in agreement with the field survey data.

The approach to the problem of delineating saline soils using remote sensing data and geographical information system (GIS) techniques has been proved efficient in many recent studies (Dwivedi 1992; Dwivedi and Sreenivas 1998; Iqbal and Mehdi 2008; Khan et al. 2005; Rao et al. 1991; Sharma and Bhargawa 1988). Buces et al. (2005) described the method of soil salinity mapping using a combined spectral response index for bare soil and vegetation. The combination of remote sensing with GIS is very promising, especially for the monitoring of soil salinization (Goossens et al. 1993). An approach using remote sensing indicators, different salinity indices (SI), vegetation indices and supervised classification, which are based on spectral characteristics of

different kind of surfaces, has been applied for this study as digital image processing (DIP) and GIS techniques (Goossens et al. 1993; Naseri 1998; Steven et al. 1992). However, the work has been accomplished with the use of the functionality of Arc GIS and IDRISI for windows (Eastman 1995; Khan and Sato 2001; Metternicht and Zinck 2003; Khan et al. 2005) through its special modules and mathematical operator functions for remote sensing data processing and analysis.

Maximum reflectance of salt affected soils was observed in the range of 10.5–12.5 μm and minimum reflectance in the range of 0.76–0.90 μm . With the help of maximum and minimum reflectance value bands, the relative maximum differences values bands were selected for developing a salinity index. Built-up area and barren soil were represented by same reflectance in all bands other than 10.5–12.5 μm and 2.08–2.35 μm ranges. The selected bands were added and the minimum reflectance value band was subtracted from maximum reflectance band. Finally, subtraction of bands was divided by addition of bands to extract the salt affected area. The extracted salt affected area and cropped areas were compared with NDVI, simple ratio of 4th and 5th spectral bands and MSI. The result of MSI and NDVI was used to mask the vegetation area (Vidal et al. 1996). Built up area was also detected by the simple ratio of 0.75–0.90 μm and 0.63–0.69 μm spectral bands (Rock et al. 1986) and by the subtraction of 0.76–0.9 μm to 1.55–1.75 μm . The extracted data in raster format was added to mask the built up area and then was converted into vector using ArcGIS (Iqbal 2008). Extracted polygons were generalized using majority

filter; the resulting built up area was corrected using visual interpretation. The salt affected area was extracted by NDSI and Salinity Index developed by (Khan et al. 2005). The new NDSI was developed with selected bands having maximum and minimum reflectance for salinity (Iqbal and Mehdi 2008; Iqbal 2010). The salt affected soil gave maximum reflectance value in Thermal IR band and minimum in 0.76–0.90 μm range (Iqbal 2008). The results of both salinity indices were compared. Then the salt affected areas of both equations were reclassified into 1 and 0 and both the NDSI results in raster format were overlaid to delineate the common salt affected areas.

6.2.3.2 GIS analysis To generalize the extracted salt affected area, majority filter of 8×8 was applied. The area under salinity and the built up area were masked by NDBI and MSI. The built up area was subtracted from salt affected area which was delineated by supervised classification, NDBI and visual interpretation in initial session. The extracted soil through satellite imagery was superimposed with the salinity maps extracted through soil association map which consisted of Eminabad and Satghara association, same result was reported by (Iqbal 2008). Finally the overlay of both NDSI was performed to extract the common saline areas. The vegetation area was masked by NDVI and MSI and overlapped with built-up area to prepare the final map of land cover.

Fig. 13 Salinity Index using IRS

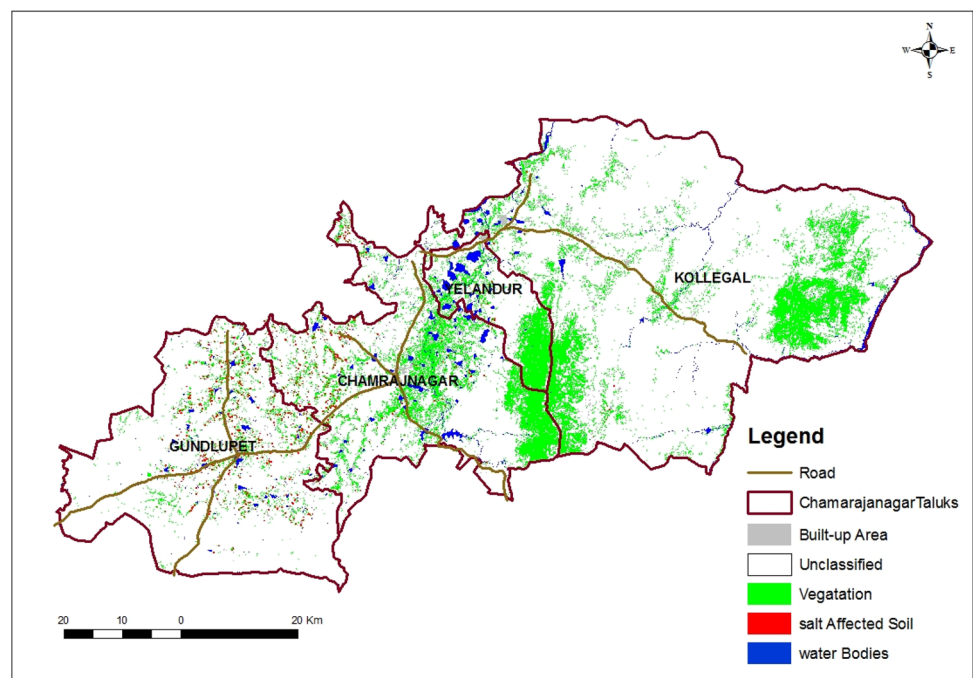
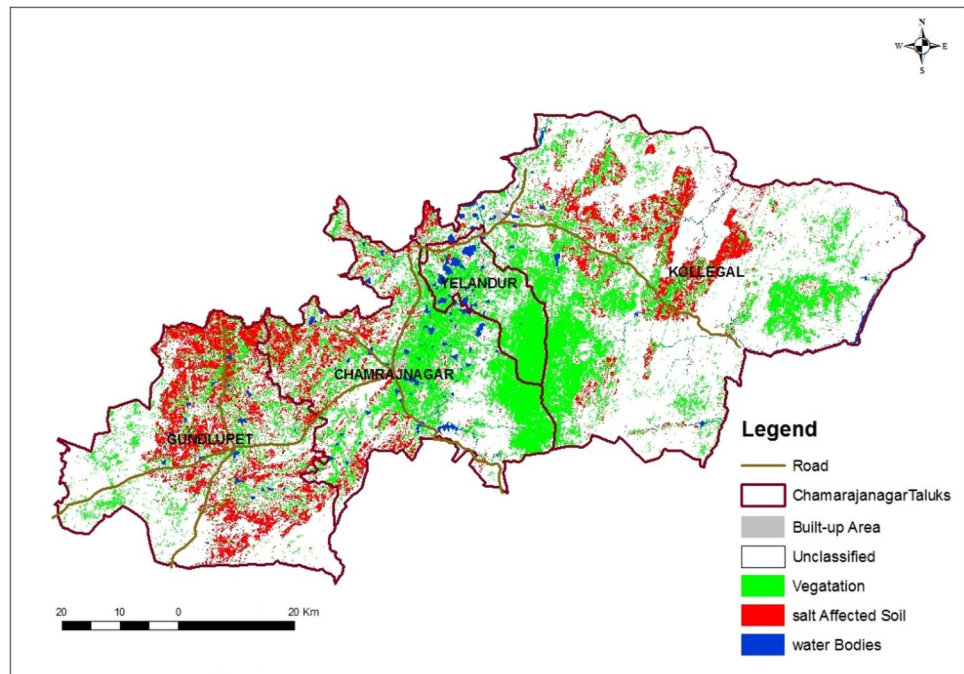


Fig. 14 Normalized Difference Salinity Index using IRS



6.2.3.3 Salinity indices Tripathi et al. (1997) To enhance the saline zones and suppressing the vegetation, two indices: Salinity Index (SI) and Normalized Difference Salinity Index (NDSI) are proposed in this study. SI is the ratio of red band to near infrared (NIR) band while is the ratio of the difference of the red to NIR and divided by the summation of the two. This concept has emerged from the Red Edge concept for vegetation mapping. In red edge concept, the spectral reflectance of NIR is radioed with red band which gives very high values for vegetation than other features on Earth. Here if the inverse is considered then for vegetation low values will be obtained thus suppressing the vegetation and highlighting the soil. SI and NDSI are computed as follows:

$$SI = (\text{Band 3}/\text{Band 4}) * 100$$

$$NDSI = [(\text{Band 3} - \text{Band 4})/(\text{Band 3} + \text{Band 4})] * 100$$

These are found useful than individual bands particularly in emphasizing saline soil regions.

Results showed that 0.11% of ChamaraJanagar district is salt affected using IRS Salinity index (SI) and 11.4% using Normalized Difference Salinity Index (NDSI) using IRS as shown in Figs. 12, 13 and 14, respectively.

6.2.4 Land degradation indicators, types, and hazard and status maps

Land degradation indicators were collected from the direct observations from field and served as ground truth to verify results obtained from remote sensing image interpretation. Survey was based on direct field observations, using diagnostic criteria and simple and visual indices given in Annex I, (FAO/UNEP and UNESCO 1979).

The provisional methodology for soil degradation assessment (FAO/UNEP and UNESCO 1979) aimed to investigate the purpose of identification, mapping and detecting the potential and present day land degradation. These methodologies were established in a ‘scale-independent’ way to be applicable at regional, detailed and very detailed levels. The application of the parametric approach on different units resulted in estimating the risk of land degradation and the present day land degradation. The general form off the used parametric formula is:

$$D = f(C, S, T, V, L, M)$$

where, D = soil degradation; C = climatic factor; S = soil factor; T = topographic factor; V = natural vegetation factor; L = land use factor; M = mane gent factor.

The values of the variables are chosen in such a way that the solving of the equation gives the numerical indication of the degradation rate. However, since the formula describes the processes only approximately, and the values assigned to each factor can themselves only are approximate in the present state of knowledge, the final results should not be

Fig. 15 Assessment of the risk of water erosion

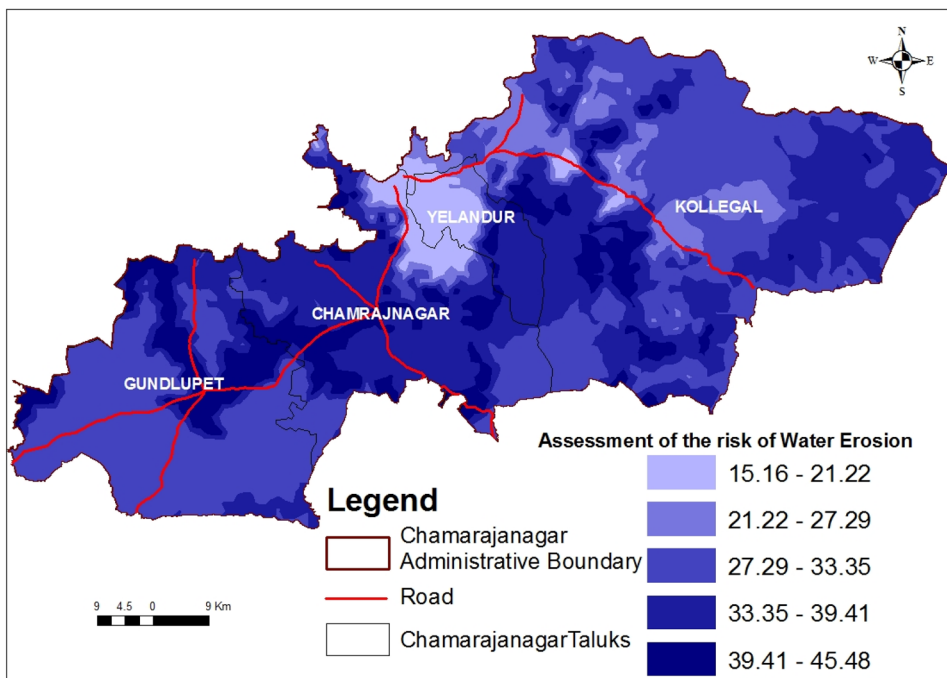
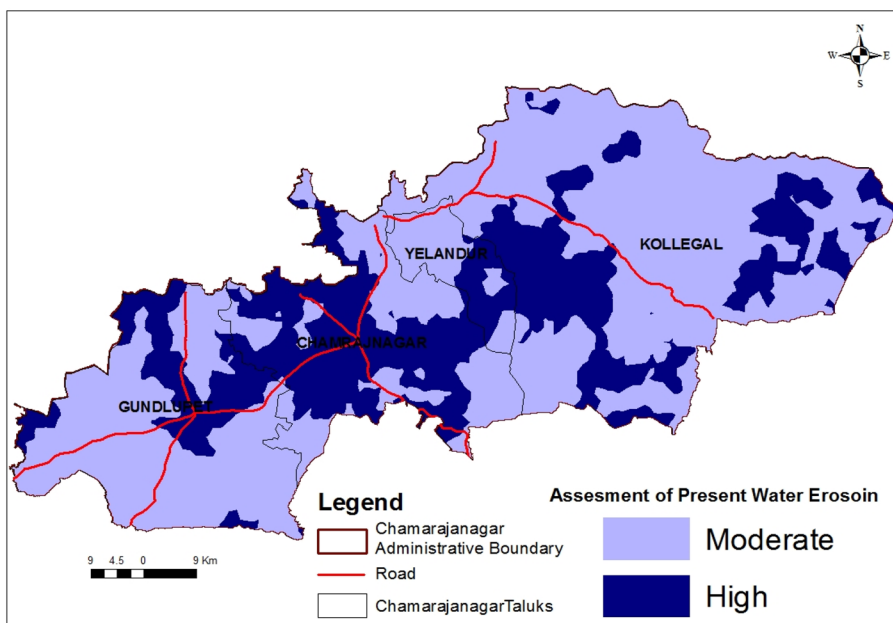


Fig. 16 Assessment of present water erosion

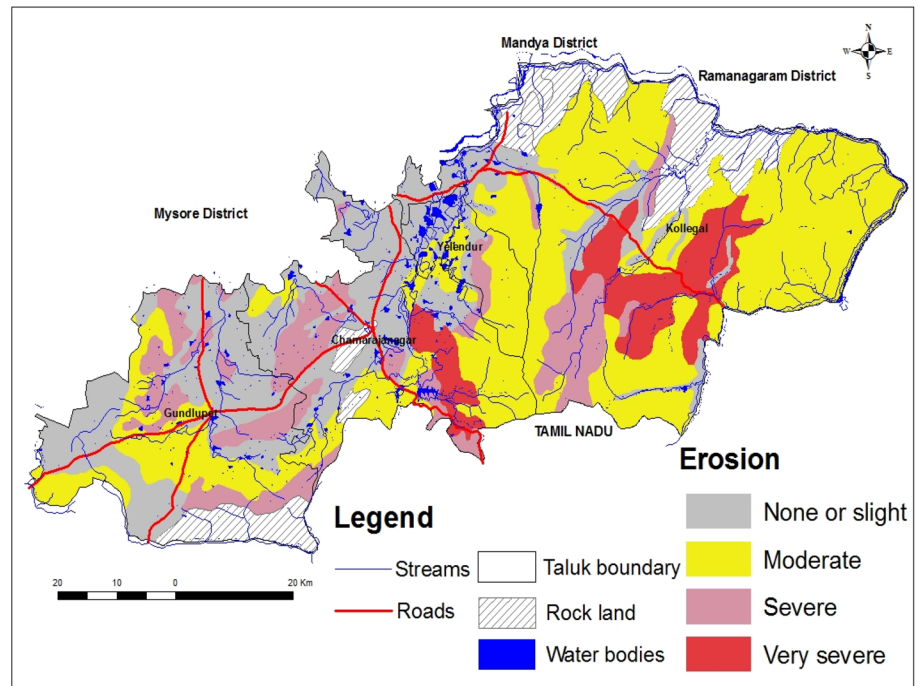


regarded as absolute values for the soil loss or soil degradation. These values are merely giving an approximate indication of likely magnitude of degradation.

To understand the variation of land degradation types, graphical interpretation of parametric factors of land degradation were performed using geostatistics. A dataset of parametric factors of USLE for land degradation for each soil profile was created with their geo-referenced position in the field by using the ARCGIS Before creating surface

diagrams; the distribution of data was analyzed to get a better understanding of trends, directional influences and obvious errors. Co-kriging was used for the creation of several maps for active land degradation types in the studied area. Prior to the creation of the maps, semi-variograms were produced for each type of land degradation. Cross validation was used to compare the prediction performances of the semivariograms.

Fig. 17 Degrees of water erosion based on satellite images



6.2.4.1 Water erosion The RUSLE calculation considered all the variables that take into account the soil erosion. These parameters have been generated from fieldwork data and have been classified in integer values to obtain the ranges for the assessment of the risk of Water Erosion (Fig. 15) and assessment of present Water Erosion (Fig. 16).

Integrating different types of the factors affecting land erosion, the results show that the majority of the study area fall under the moderate land erosion classes occupying 72.2% of the total area. High land degradation class occupying 27.8% has been found also in areas affected by high soil loss. These outputs have been analyzed and weighted in terms of degradation classes.

FCCs obtained from LISS III and IV sensors (with 24 m spatial resolution) was evaluated for delineation of eroded areas. It was observed that the data enabled better delineation of small units of eroded areas. Based on soil, slope, and land use/land cover, current soil erosion status was mapped. Visual interpretation involves identification and delineation of degraded lands that are manifested on False Color Composite (FCC).

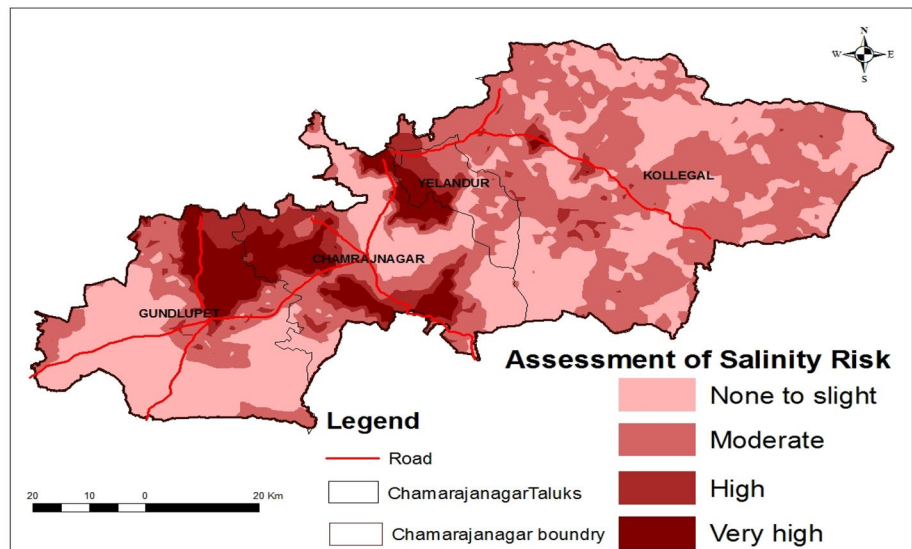
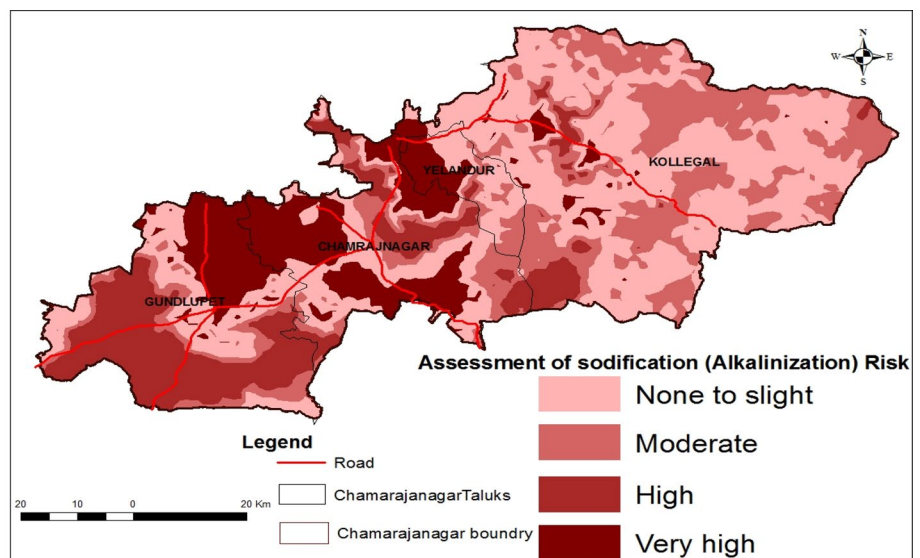
The False Color Composites are analyzed initially with the help of topographical maps, published reports and other available ancillary data; broad categories of degraded lands were delineated. The distribution of various land degradation categories delineated through visual interpretation of IRS data as shown in the Fig. 17 Land degradation has numerous environmental, economic, social and ecological consequences.

Every ecosystem on the earth is affected by some or the other form of land degradation. When land is degraded, the ecology is damaged. There can be rather serious effects in terms of soil erosion, loss of soil fertility and thus reduced plant growth or crop productivity, clogging up of rivers and drainage systems, extensive floods and water shortages. Accelerated erosion adversely affects the quality of soil on site (Norton et al. 1998; Lowery et al. 1998; Lal et al. 1998) and its agronomic productivity (Olson et al. 1998; Lal 1998). The eroded areas were identified distinctly on the FCC as a result of erosion of soil by running water. They are more common on sloping surface. Figure 17 shows the soil erosion map of the site on 1:50,000 scale.

6.2.4.2 Wind erosion According to both USLE 1979 and RUSLE 1997 calculations the whole study area is subjected to non to slight wind erosion hence it has wind speed ranges from 8.4 to 14.1 km h⁻¹. The RUSLE model equation (Renard et al. 1997) is a multiplicative function of five factors controlling erosion:

$$A = R * K * LS * C * P$$

Where, A is the mean annual soil loss expressed in ton ha⁻¹ yr⁻¹; R is rainfall and runoff erosivity index (in MJ*mm ha⁻¹ yr⁻¹); K is soil erodibility factor (in ton*ha*h ha⁻¹*MJ*mm); LS is slope and length factor (dimensionless); C is the cover factor (dimensionless); P is the conservation practice factor (dimensionless).

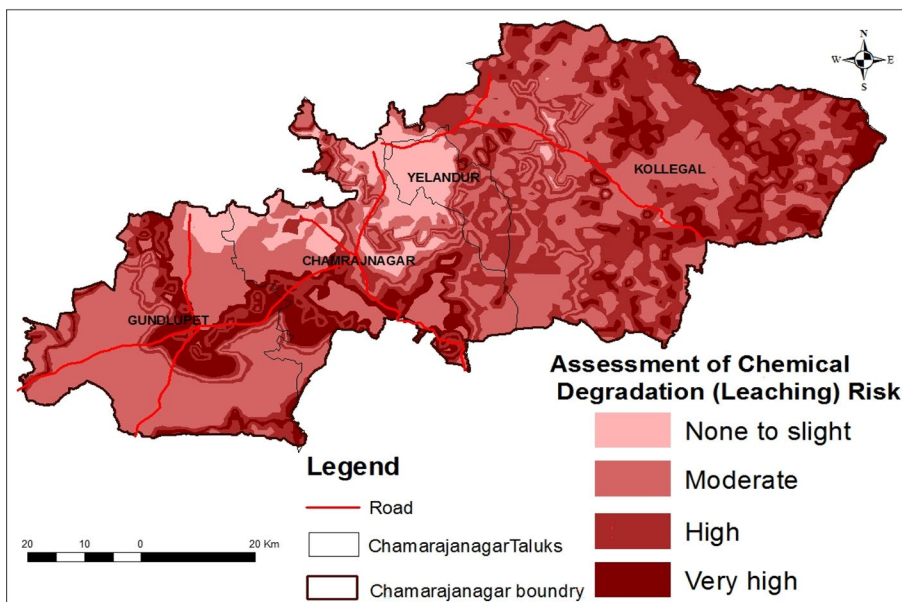
Fig. 18 Assessment of salinity risk**Fig. 19** Assessment of sodification (alkalinization) risk

6.2.4.3 Salinization The risk of salinization in Chamrajanagar is slight to very high. These estimations are based upon the calculated climatic index without considering the salinity of the ground water. The soil, topography and human activity cause higher values for the present state and risk of degradation by salinization. This salt remains in the soil and increase over the years to enormous quantities. This stresses the importance of a good management of the new cultivation projects in the study area taking more care for the use of appropriate irrigation and drainage techniques. The geostatistical approaches for GIS was used to produce the spatial variability for Salinization maps for the studied area. Assessment of Salinization risk was classified into four classes according to the USLE as shown in Fig. 18; none

to slight occupying 41.41%, Moderate 42.92%, High 7.40% and Very high 8.27% of the total area.

6.2.4.4 Sodification (alkalinization) The present state of Sodification in the study area is slight to very high. These estimations are based upon the calculated climatic index without considering the alkalinity of the ground water. The soil, topography and human activity cause higher values for the present state and risk of degradation by sodification. The geostatistical approaches for GIS was used to produce the spatial variability for Sodification maps for the studied area. Assessment of Sodification risk was classified into four classes according to the USLE as shown in Fig. 19; none to slight occupying 15.85%, Moderate 25.56%, High 42.92% and Very high 15.67% of the total area.

Fig. 20 Assessment of chemical degradation (leaching) Risk



6.2.4.5 Chemical degradation (leaching) Leaching of bases: soils with free drainage and low cation exchange capacity lose its bases through leaching. This loss of bases leads to the soil becoming more acid in reaction, the main cause of this is the rainfall upon the upper portions of highland of land form which coarse in texture as result of erosion, may also be lost each year by leaching down to lower horizons beyond the reach of crop roots. The geostatistical approaches for GIS was used to produce the spatial variability for Sodification maps for the studied area. Assessment of Chemical Degradation (Leaching) Risk was classified into four classes according to the USLE as shown in Fig. 20; none to slight occupying 7.71%, Moderate 46.25%, High 31.79% and Very high 14.25% of the total area.

6.2.4.6 Physical degradation It is almost impossible to avoid topsoil compaction. On the other hand, tillage and natural processes can re-loosen the topsoil. Subsoil compaction is much more persistent and difficult to remove. Artificial loosening of the subsoil has proven to be disappointing. The loosened subsoil is re-compacted very easily and many physical properties are strongly reduced.

Subsoil compaction should be prevented instead of being repaired or compensated. Even on weak soils, relatively high wheel loads are possible by using large tires with low inflation pressures or well-designed tracks. Subsoil compaction during ploughing can be prevented by using improved steering systems and adapted ploughs allowing the tractor to drive with all wheels on the untilled land. It is also possible to

Fig. 21 Assessment of Bulk density

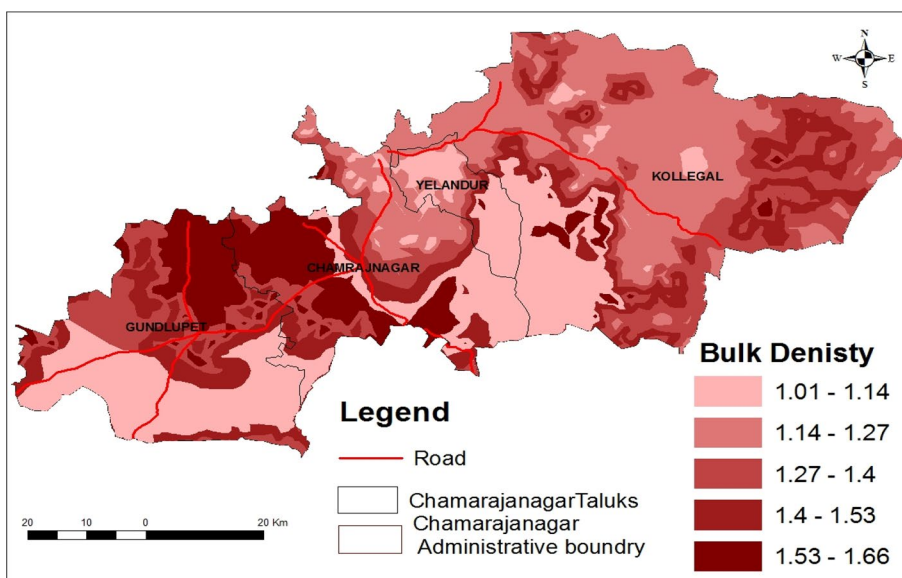


Fig. 22 Assessment Physical degradation risk initial levels

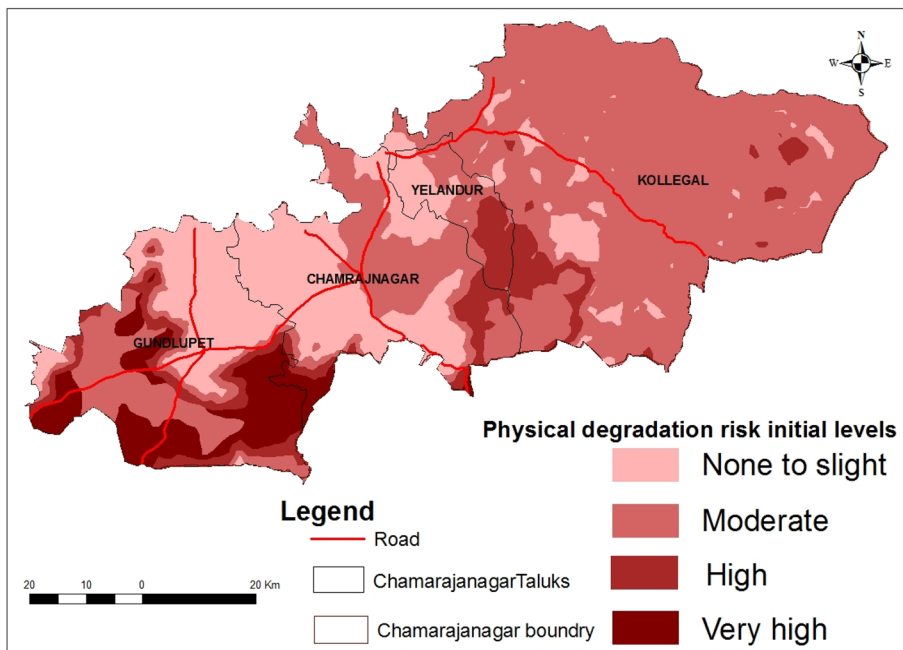
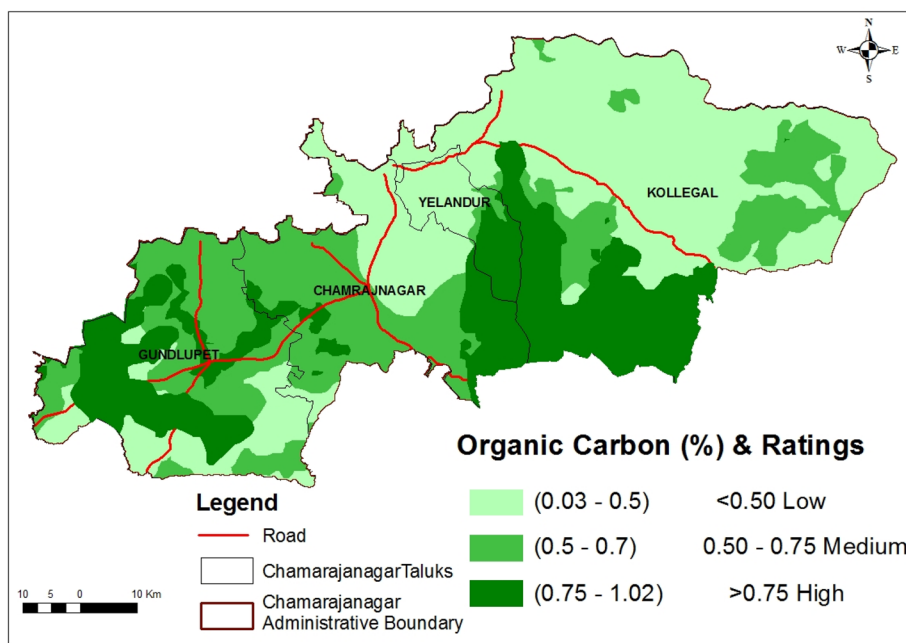


Fig. 23 Organic carbon ratings of Chamarajanagar district



concentrate wheel loads on permanent traffic lanes and limit the compaction to these sacrificed wheel ways. By using gantries, the sacrificed area can be limited. However, these solutions are rarely used because of short-term economical constraints, lack of awareness, and negligence because the damage to the subsoil is not readily visible. Also the limited knowledge and data on soil strength under dynamic loading makes prevention of subsoil compaction difficult.

Provisional map of Bulk density and Physical degradation risk initial levels of soil in investigated area to

compaction, based on soil properties alone. Further input data are required on climate and land use before vulnerability to compaction of subsoil in the investigated area can be inferred from the map shown in Figs. 21 and 22. Assessment of Physical degradation risk initial levels was classified into four classes according to the USLE; none to slight occupying 23.30%, Moderate 60.73%, High 8.68% and Very high 7.29% of the total area.

Fig. 24 Organic matter distribution

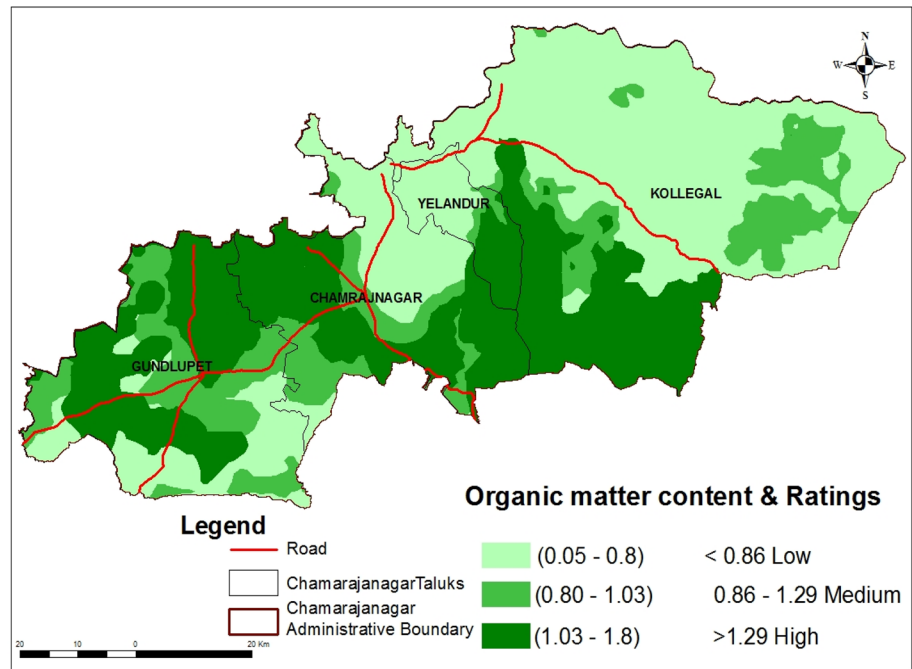
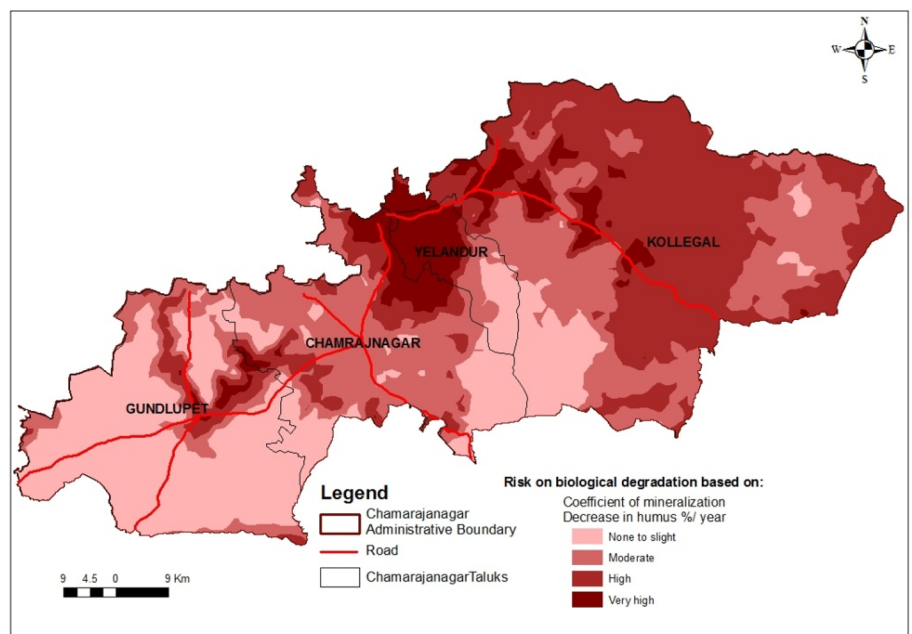


Fig. 25 Risk on biological degradation



6.2.4.7 Biological degradation From Figs. 23, 24, and 25 we can make out that in the content of organic matter is directly and positively related to length of cultivation of crops. This is because additional amounts of organic matter by physical application as organic manures and through the addition of high amount of crop residues in such fields (Hegde and Sudhakar 2001; Naidu 2002). Irrespective of its location in the landscape, wherever farmers are cultivating with the help of irrigation wells, the organic matter

content is high. The fields without water supply are cultivated with one crop under rainfed conditions. Here the organic matter content is low. Low organic matter content combined with lighter soils is prone for more soil erosion and loss of soil nutrients. The upland soils cultivated with only rainfed crops are more prone to such problems in the region.

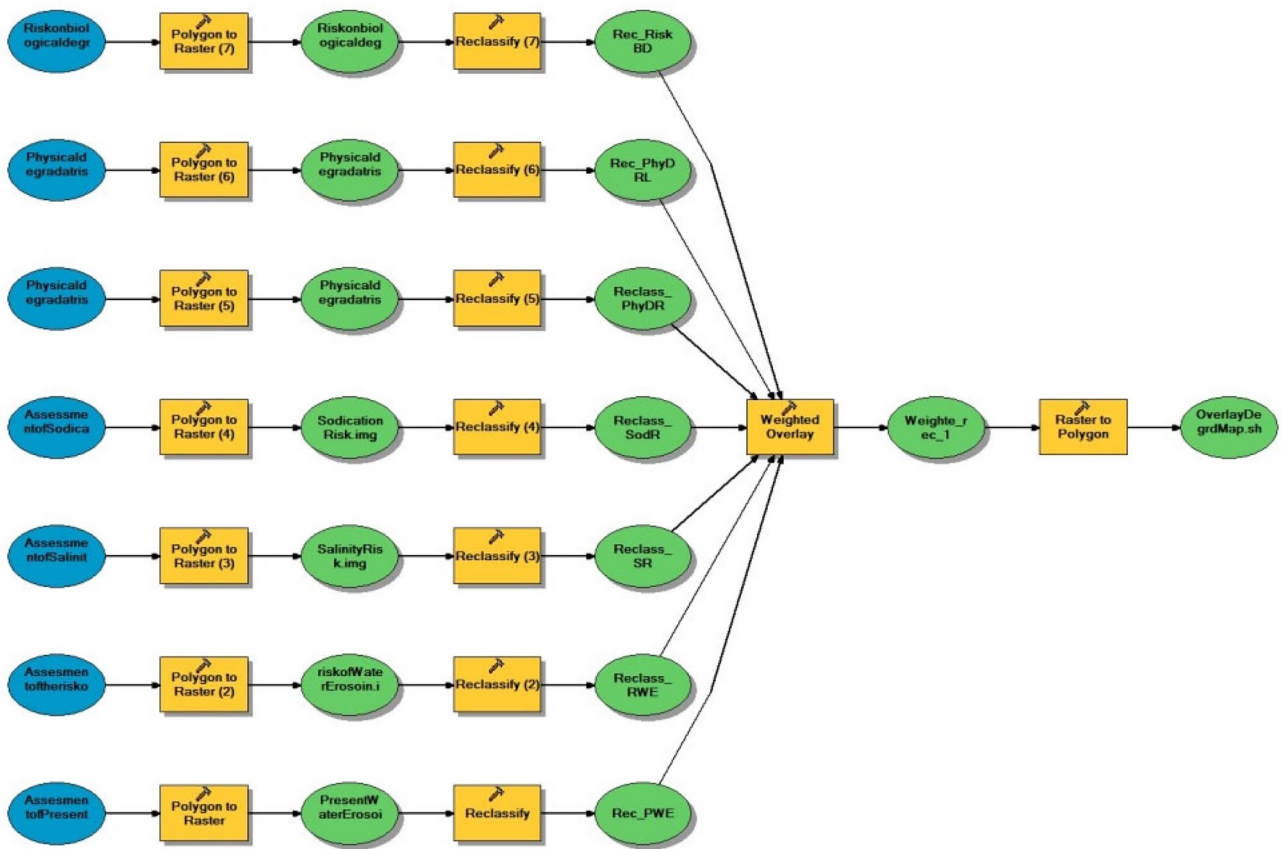
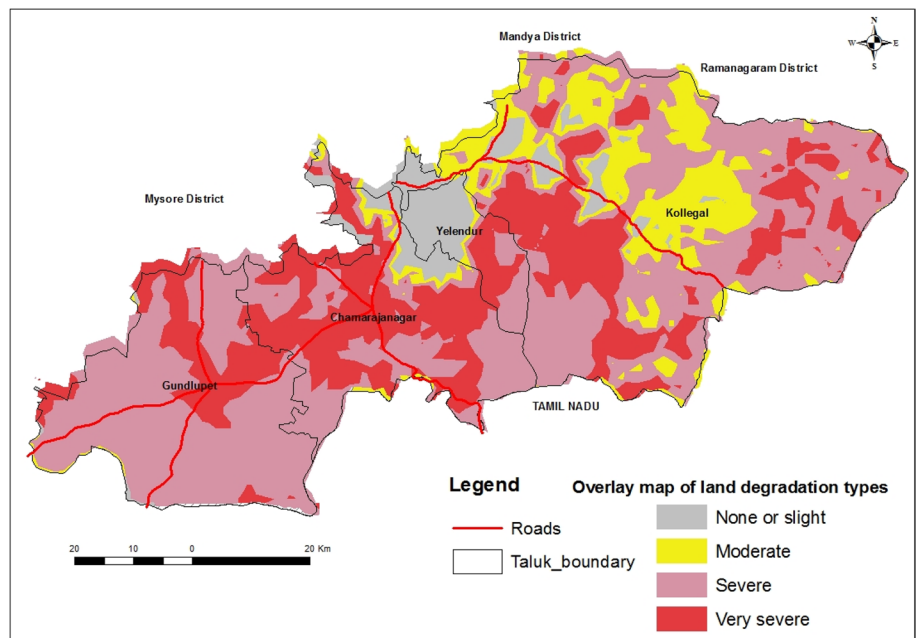


Fig. 26 Overlay Model of land degradation types

Fig. 27 Overlay map of land degradation types



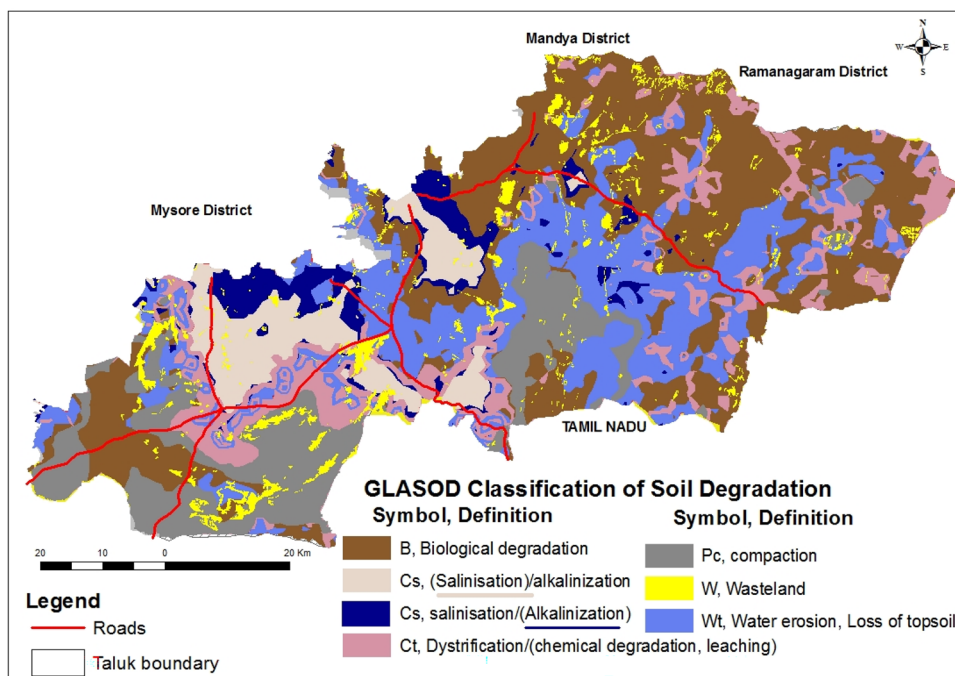
As it is obvious from Fig. 25 risk on biological degradation and its assessment of present degradation should be low under natural vegetation; for the cultivated areas, it is dependent upon the length of the cropping period, on the amount of crop residue left after harvest and on management techniques such as recycling of organic material. The C/N ratio of the raw organic material added to the soil is also very important. At present, biological degradation of the cultivated areas is likely to be at least moderate. Biological degradation was classified according to the USLE into four classes; none to slight occupying 25.49%, Moderate 35.96%, High 28.05% and Very high 10.51% of the total area.

Some of the observations which are considered as simple criteria of biological degradation are increased sealing, crusting, and runoff; decreased aggregation of soil particles in surface, and decrease of earthworm, ants and rodents, and most of the criteria are used for identification of physical degradation.

6.2.5 Overall land degradation

Arc GIS Model Builder Fig. 26 was used to develop a final overlay map for land degradation types in the studied area. The overall of land degradation types in the studied area shown at Fig. 27. The maps resulting from the interpolation techniques were introduced into a GIS and their values reclassified. Assessment of Overall land degradation types was classified into four classes according to the USLE; none to slight occupying 6.14%, Moderate 12.80%, High 53.32% and Very high 27.74% of the total area.

Fig. 28 Land degradation types based on different methodologies with integration of GLASOD classification

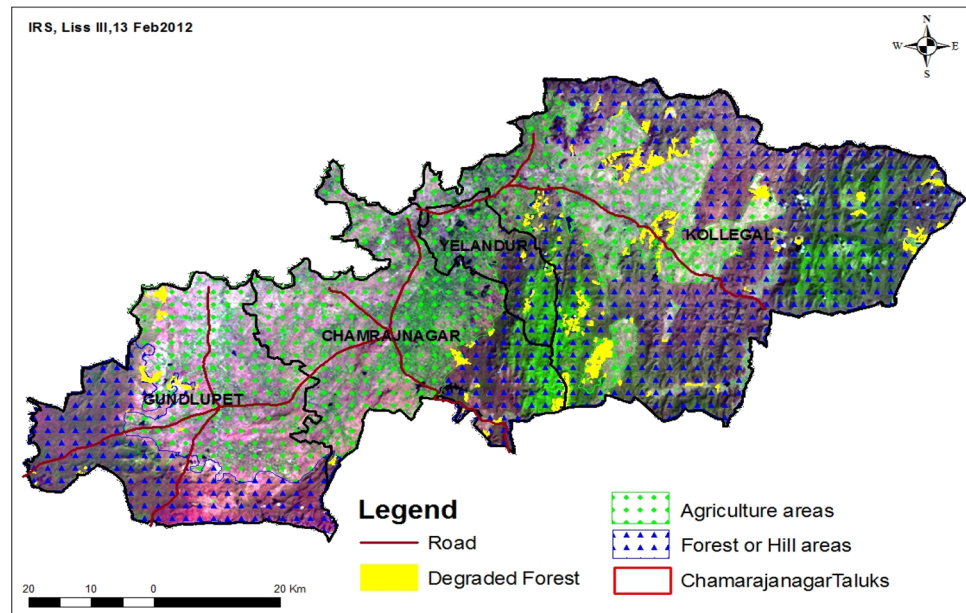


6.2.6 Producing land degradation status maps according to GLASOD 1991

There is a great need for common classifications and methodology to organize existing data and to direct future efforts. In 1991, a first world map on the status of human-induced soil degradation was published by ISRIC, in co-operation with FAO and UNEP (Oldeman et al. 1991). In preparation of the map, a general classification was developed, referred to as the GLASOD (Global Assessment of Soil Deterioration) classification. The classification of type, severity and cause has been reproduced. Methodology for storing and processing data into maps is provided by SOTER (Global soils and terrain digital database) (Van Engelen 1993).

The assessment of the different degradation types in the investigated area has been carried out through integrating remote sensing, GIS and GLASOD approaches. Seven land degradation types according to GLASOD Classification of Soil Degradation (OLDEMAN, 1991) as shown in Fig. 28 based on the integration of the RUSLE according to FAO 1997 and USLE according to FAO 1979 and 2004 have been obtained: B; Biological degradation occupying 32.56 per cent, Cs; salinisation/(Alkalinization) occupying 5.19 per cent, Cs; (Salinisation)/alkalinization occupying 7.86 per cent, Ct; dystrification/(chemical degradation, leaching) occupying 12.46 per cent, Pc; Compaction occupying 14.79 per cent, W; Wasteland occupying 4.58 per cent and Wt, Water erosion, Loss of topsoil occupying 22.57 per cent, of the total area.

Fig. 29 Degraded forest in Chamaranagar district



6.2.7 Forest degradation

Land use definitions measure deforestation by a change in land use. This definition may consider areas to be forest that are not commonly considered as such. An area can be lacking trees but still considered a forest. It may be a land designated for afforestation or an area designated administratively as forest (FAO 2007). Deforestation can include not only conversion to non-forest, but also degradation that reduces forest quality—the density and structure of the trees, the ecological services supplied, the biomass of plants and animals, the species diversity and the genetic diversity. Forest degradation in this study considered as removal of forest cover to an extent that allows for alternative land use. By detecting the changes between Land SAT satellite image 2000 and IRS satellite images 2006 and 2012 found that the forest degraded by reducing in area by 1.73 per cent of total area of district, and 4.16 per cent of forest area as it is shown in Fig. 29.

The present scenario of land degradation in the area is very alarming and needs a proper land use planning and management. The study area is considered as unstable ecosystem due to active degradation resulting from climate, relief, soil properties and improper farming systems.

Conservation practices that can help in overcoming these problems are effective human interaction and intervention to overcome the land degradation in the study area. It is recommended to encourage farmers and decision maker to apply this practice in areas which are highly affected by different types of land degradation. Conservation measures that can help in preventing the land degradation are contour bonding, gabion structures, graded bonding, earthen field bonding,

diversion channel or drain waste weir, bench terracing, land levelling and land grading and stone bonding to conserve the soil loss by water erosion.

7 Effect of land degradation on agriculture

Land degradation is essentially a huge global issue because of its adverse impact on farming efficiency. It also has a bad effect on environmental conditions and food safety (Abebaw 2019). The ecosystem is also affected by degradation, because continuing degradation is now out of the categorizations: it expresses problematic attitudes to ecological growth, dividing the adverse effects on social and economic conditions and agriculture too (Eswaran et al. 2001a,b; Muhammad et al. 2020). Land degradation is the result of natural or atrophic aspects that can cause a decline in production. Within production, land degradation indicates a gap between high soil quality and land use (Gupta 2019; Wassie 2020).

8 Effect of land degradation on environment

Arid lands are disturbed by land degradation, which also affects the character and economy of agricultural lands. Land degradation has a direct impact on biodiversity, agriculture, ecosystems, production, and the climate. By distressing the land through anthropogenically induced or natural processes, it also has an impact on the biophysical ecosystem. Earthquakes, tidal surges, erosion, water overflow, and cyclones

are examples of natural sources. Environmental degradation brought on by anthropological actions has a major impact (Barrow 1991). Global estimates of soil degradation showed that Asia has been severely impacted, whereas Africa and Europe have only been marginally affected (Zika and Erb 2009). Early historical research revealed that volcanic activity has a continuous negative influence on the environment and degrades the land (Leroy et al. 2009).

9 Management of land degradation

Conservation tillage, which requires little labor and is economical, can be used to control land degradation. The goal of Integrated Soil Fertility Management (ISFM) is to restore unproductive areas and increase their productivity. Inorganic fertilizers, soil fertility and productivity can be improved through ISFM initiatives, which also increase nutrient uptake. Crop yields have been boosted through ISFM services, and degraded areas have been restored (SAC I, 2016). Management of irrigation water is key factor to improve soil quality (Chalise et al. 2019; Feng et al. 2022; Getachew and Isral 2022).

10 Conclusion

The present scenario of land degradation in the area is very alarming and needs a proper land use planning and management. The study area is considered as unstable ecosystem due to active degradation resulting from climate, relief, soil properties and improper farming systems.

Agriculture and the environment are both negatively impacted by land degradation. Water erosion, deforestation, soil compaction, desertification, salinization, waterlogging, and many other factors can lead to land deterioration. Because it affects the environment and food security directly or tangentially, it has grown more dangerous. Therefore, it's critical to reduce the losses brought on by soil degradation. According to the findings of the current study, land degradation can be controlled by using drip irrigation, a combination of organic and inorganic fertilizer, and fewer heavy tillage tools. In addition, new regulations are needed to lessen the harm brought on by soil degradation.

Efforts to combat desertification: to prevent and reverse desertification, major policy interventions and changes in management approaches are needed. Such interventions should be implemented at local to global scales, with the active engagement of stakeholders and local communities.

The following can be implemented to combat desertification:

Sustainable land and water use: sustainable land use can fix issues such as overgrazing, overexploitation of plants,

trampling of soils and irrigation practices that cause and worsen desertification.

Increasing vegetation cover: increased vegetation protects land from erosional forces. Protecting soil from wind and water erosion helps to prevent the loss of ecosystem services during droughts.

Sustainable Farming: encourage agro-forestry, organic farming, environmentally sustainable cropping patterns and adoption of efficient irrigation techniques.

Creating economic opportunities outside dry-lands: unpacking new possibilities for people to earn a living, such as urban growth and infrastructure, could relieve and shift pressures underlying the desertification processes.

Blending scientific and traditional practices: applying a combination of traditional techniques with the selective transfer of locally acceptable technology is a major way to prevent desertification.

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Declarations

Conflict of interest The author declares that have no conflict of interest.

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