# Chapter 1

# Introduction

## 1.1 Background

For a geotechnical engineer, the change in volume is the one of important property of soil. In general, the change in volume of soil mass occurs either due to a change in moisture content or a change in effective stress. For understanding the mechanism of volume change, the relationship between clay mineralogy and moisture content is a major concern. The soils in which volume change occurs due to variation in their moisture content are termed "swelling soils". Several investigations have been conducted to understand the mechanism of change in the volume of soil with moisture variations. Despite this, various studies show that even at the presence of a small quantity of contaminants can also cause significant influence on volume change in expansive as well as non-expansive soils. The unexpected heaving due to the interaction of contaminants is a slow and time-dependent process. The interaction of contaminants that causes heaving in soil may or may not cause any change in the mineralogical composition of the soil. The heaving in soil due to two chemical contaminants, i.e., acid and alkali, draws the attention of numerous researchers as it involves complex chemical reactions between soil and contaminant. The interaction of these contaminants with soil occurs either through natural processes (acid rain, acid rock drainage) or through anthropogenic processes (leakage, spillage, handling etc.) (Gratchev and Towhata, 2011). However, the contamination effect on the properties of soil is more prominent in the case of anthropogenic processes as compared to natural processes. During the production or use of these chemicals, they encounter storage, handling, spillage and leakage problems. The serious effect of the ingression of these chemicals into the foundation soil for any of these reasons has been studied by various researchers. The study shows that the frequent infiltration of acid and alkali solutions into the foundation soil leads to vigorous heaving that results in movement of the foundation, upliftment of pavement and floor, and differential settlement in the structure built on it. Extensive investigation has been carried out which provides a useful insight into the significantly altered geotechnical properties of soil due to the physicochemical reactions that take place during the interaction between clay minerals and chemical contaminants. Past studies reveal that the alkali or acid interaction leads to the active decomposition of clayey minerals and results in heavily hydrate neogenic formation of increased volume. The alteration in the soil properties depends upon the shape and size of particles, mineral structure, type of bond between the particles, cation exchange capacity, specific surface area of soil, etc. Out of these, the heaving in soil due to alkali interaction occurs in a more complex manner and at a slower rate. Thus, the alkali solution has become an important contaminant that can severely alter the behaviour of soil. As a result, it became necessary to investigate soil contamination in order to gain a better understanding of the alkali-induced heaving mechanism and to devise a preventative measure to control heaving.

## 1.2 Source of Alkali Contamination

In India, one of the most diversified industries is the chemical industry, with over 80,000 products. India is the sixth largest producer of chemicals in the world and the fourth largest in Asia. Among all the major chemical industries, alkali chemicals share a maximum percentage of about 69% of the total production. The production of alkali chemicals has increased from 6.49 to 7.78 million metric tonnes in the last decade as shown in Fig. 1.1. Sodium hydroxide is the most versatile alkali that is used in many industries in their manufacturing processes, such as paper and pulp industries, soap and detergent industries, petroleum industries, textile industries, alumina industries and others. The large growth in the textile and alumina industries is likely to drive the overall demand for sodium hydroxide in India. According to the World Bureau of Metal Statistics, the production of aluminium has doubled to approximately 3.55 million metric tonnes in the last decade. The production of such a huge quantity of aluminium consumes about 19% of the total volume of sodium hydroxide manufactured. While chemical industries use

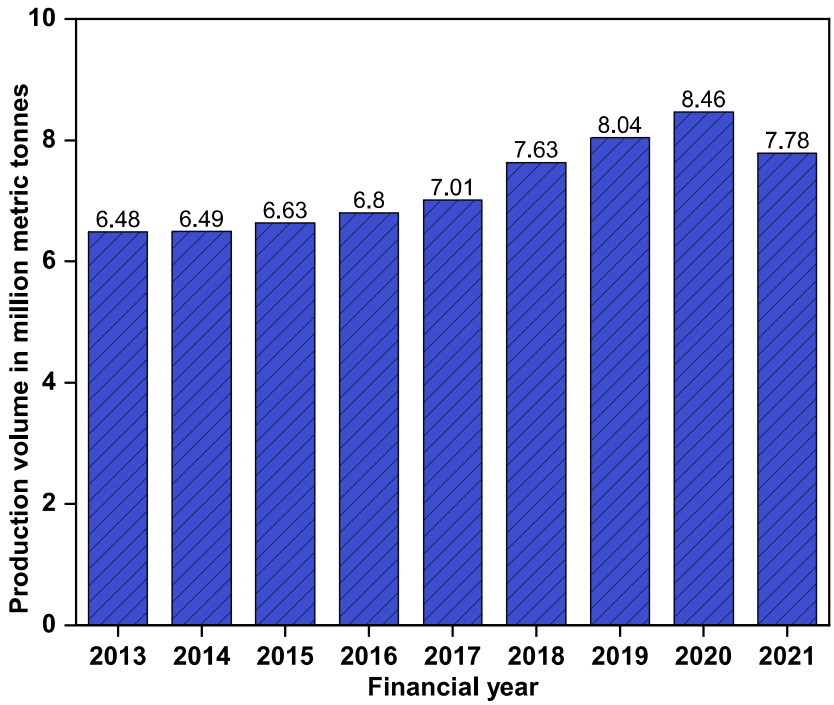


Figure 1.1: Production volume of alkali chemicals in India from financial year 2013 to 2021(Source, www.statista.com)

the most NaOH (31%), textile industries, paper and pulp industries, soap and detergent industries, and other industries use 15%, 15%, 11%, and 9%, respectively. The use of different percentages (by volume) of NaOH solution in different industries reported by CHEMANALYST (www.chemanalyst.com) for the financial year 2021 is shown in Fig. 1.2. Alkali is used either in liquid form or as solid pellets or flakes. Sodium hydroxide is mostly used in liquid form because it is easy to handle, store, and pump within the industry; however, the storage and transportation of sodium hydroxide solid pellets require an airtight container, which is expensive. During the pumping and storage of sodium hydroxide, some amount of sodium hydroxide solution gets leaked or spilt into the foundation soil due to improper or inadequate process of handling. The leakage of alkali solution leads to unexpected heaving in soil resulting in substructure failure.

## 1.3 Field Incidents of Alkali Contamination

Several interesting case studies came into the frame with remarkable deformations in the structures because of the accidental spillage of alkalies onto the ground. Sokolovich

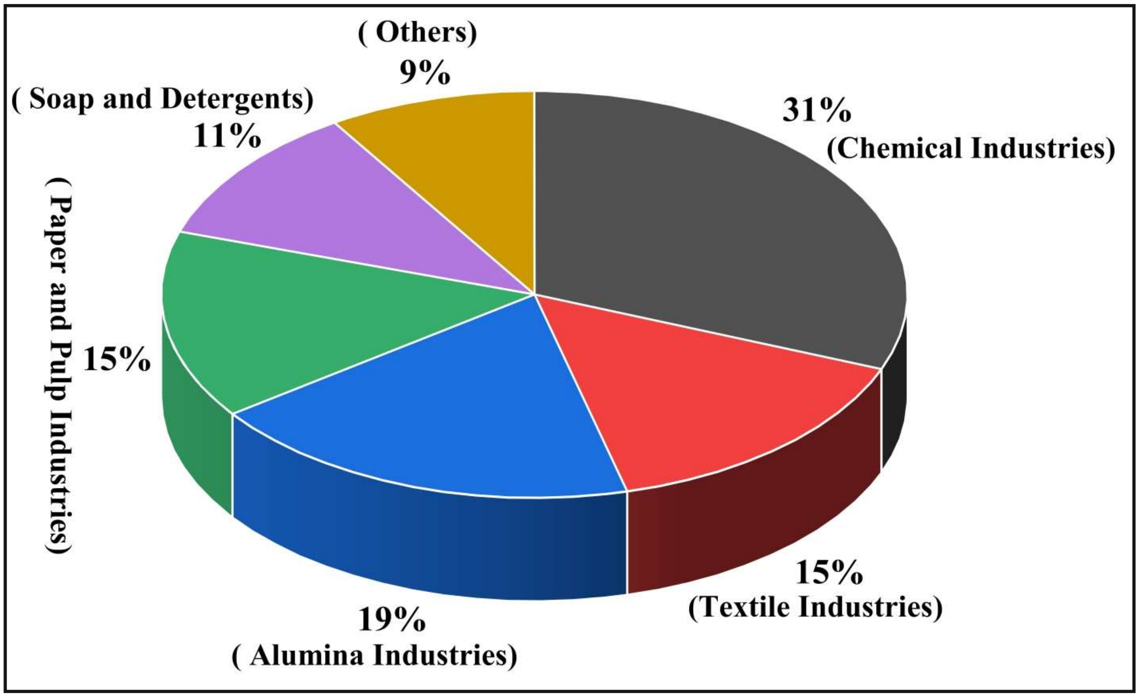


Figure 1.2: Consumption of different percentages (by volume) of NaOH solution in varying industries (source: CHEMANALYST)

and Troitskii (1976) reported the heaving of sand due to leakage of NaOH, $NH_4Cl$, and soda solutions into the subsoil for 5-year period of the Krasnopresensk sugar refinery in Moscow. Kabanov et al. (1977) investigated the swelling and deformations of soils in various aluminium plants in Uralsk due to leakage of alkali solutions. Kumapley and Ishola (1985) presented the structural damage of buildings in an industrial complex in Tema, Ghana. The investigators found that accidental leakage of highly concentrated caustic soda solution from cracked drains lead to the damage. Sibley and Vadgama (1986) reported the damage to the floor and misalignment of some columns and beams due to ground heave after interaction with alkali solution at the K-Unit plant, within the area of Imperial Chemical Industries. Rao and Rao (1994) revealed that the seepage of alkali solution causes heaving in foundation soil after the loss of cementitious iron oxide coatings. Sinha et al. (2003) reported the results of investigations on the effect of seepage of caustic soda, due to spillage of liquid caustic soda during the operation of an alumina plant, on the bearing capacity of foundation rock. The structural distortion in an alumina extraction plant in Karnataka, India has been reported by Sivapullaiah et al. (2004) due to the heaving of foundation soil induced by prolonged alkali contamination. Kumar et al. (2019)

Figure 1.3: Leakage of alkali solution during unloading in an aluminium plant

reported the differential heaving distress in the foundation and columns due to heaving in foundation soil after contamination with caustic liquor resulting from the process of manufacturing Alumina at Hindalco Industries Limited, Renukoot, India. Based on these case studies, several researchers draw their attention towards the mechanism involved in alkali-induced heaving.The leakage of alkali into the ground during unloading activity and subsequent heaving of the ground below the boundary wall of railway platform due to alkali-soil interaction have been shown in the Fig. 1.3 and Fig. 1.4 respectively.

## 1.4 Impact of Alkali Contamination

The adverse effect of alkali contamination on alteration of soil bheaviour, geotechnical characteristics, morphologies as well as mineralogical specification are studied by numerous researchers. This alteration can severely affect the geotechnical properties of soil.

Figure 1.4: Heaving in wall of railway platform of aluminium plant due to alkali interaction

Investigation of the impact of alkali contamination on the engineering properties of soil has been a mainstream topic of research over a long period of time. The influence of alkali contamination on the geotechnical properties of soil such as Atterberg limits, hydraulic conductivity, compaction characteristics, unconfined compressive strength, shear strength parameters and heaving behaviour was reported by different literature. The studies show that the geotechnical properties of the soil get compromised due to alkali contamination. The alkali contamination causes a reduction in shear strength, creates a collapsible soil Skeleton, increase compressibility and heaving behaviour, changes physicochemical properties and reduces plasticity index. Deterioration of these geotechnical properties of soil will ultimately impact the serviceability and reliability of structures. The impact of alkali on different properties of soil are shown in flow chart in Fig. 1.5. Over the last three decades, significant research has been performed to analyse the effect of alkali contamination on the soil due to accidental leakage and spillage of sodium hydroxide solution leads to failure of the structure. The interaction of sodium hydroxide solution results in the formation of a hydrated salt crystal, causing heaving in soil. Such a large number of structure failure incidents due to alkali interaction becomes more challenging for most researchers. In some cases, it has been reported that the repairing cost of the structure is

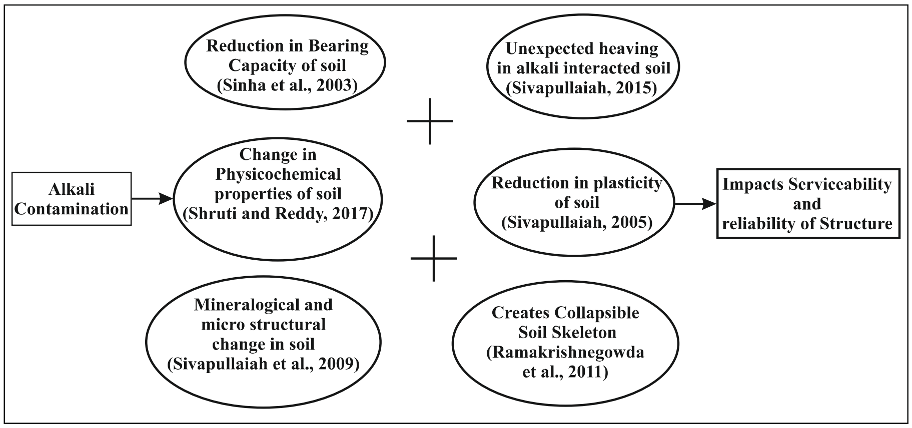


Figure 1.5: Impact of alkali contamination on soil

more than the construction cost of the structure (Isaev et al., 1995; Izbash et al., 1989). These structural failures have necessitated a better understanding of soil behaviour under changing and extreme environmental conditions. The researchers mentioned that the heaving in soil due to alkali interaction is a function of several important factors, such as chemical composition and concentration of the pore fluid, pH of the medium, type and degree of electrolyte dissociation, chemicomineralogical composition and exchange capacity, etc. Further, it was also established that changes in soil volume are not only due to moisture variation but also due to active decomposition under highly alkaline conditions, leading to new formations in pore space. Thus, it became important to control the damage caused by alkali contamination. The present study bridges mineralogical changes and morphological changes to identify and characterize the effect of the reaction product by soil alkali interaction. To control the adverse effects of alkali on soil, studies are conducted with salts such as KCl, $MgCl_2$, $FeCl_3$.

## 1.5 Mitigation Techniques

Various innovative techniques, such as special foundations, anchor piling, soil nailing, and moisture barrier, have been developed to mitigate these problems. Besides, an altogether different technique, the utilisation of some pozzolanic industrial waste such as (fly ash and GGBFS), in controlling the heaving in soil due to alkali interaction, has shown a great achievement. The addition of these pozzolanic waste materials not only enhances the geotechnical properties of soil but also provides a safer way of disposal of these waste by-products. In the past several studied has been done to utilize such huge quantity of these waste material in different geotechnical engineering activities which includes embankment construction, used as a filling material for retaining walls, land filling, road construction, bridge construction, filling of valleys and so on. Despite these, the utility of different chemical stabilisers has also been studied for the improvement in the geotechnical properties of soil. The main advantage of the use of these chemicals is that they can be used with or without any other chemicals or additives. These chemicals act as an activator, which accelerates their effectiveness in improving the geotechnical properties of soil. Some of the chemicals can be used alone to enhance the properties of soil. The use of different additives and chemicals depends upon the type of soil and the geotechnical properties that are to be improved. Thus, it is very important to have detailed information about the chemicals and waste products. These additives can be mixed in situ or ex situ depending upon the type of additives, equipment used, and the degree of improvement in geotechnical properties to be achieved. Electrokinetic method is one of the techniques for in-situ stabilization of soil can be used with different additives. This technique has used for last five decades for removal of excess water, rapid consolidation of low permeable soil, improving the bearing capacity of soil. This method is best suitable for in situ condition and when the removal of soil is not feasible from the ground. This technique uses electric field for the stabilization of soil.

## 1.6 Motivation of Study

The heaving behaviour of soil due to alkali contamination has received a great deal of attention by several researchers (Chavali et al., 2017; Reddy et al., 2017; Sivapullaiah, 2015; Sivapullaiah et al., 2007), there are still a few cases where more information and understanding is required. In comparison to the quite large number of studies conducted on the heaving behaviour of soil due to alkali contamination, there are very few studies related to effect of different concentration of alkali solution. Therefore, the effect of alkali contamination on the geotechnical properties along with the heaving behaviour and its stabilization using different additives required a much-needed attention. The alkali contamination affects the quality of large land area of different industries results in failure of large number of structures. For the effective reclamation of the alkali contaminated soil, an effort has been made to conduct a comprehensive study on the heaving behaviour of soil and also impact of alkali contamination on its geotechnical properties (such as index and strength properties). Furthermore, a sustainable and in situ technique has been developed to control the effect of alkali contamination in such a soil.

## 1.7 Research Objectives

The research gap in the available literature is explained in preceding section which provides the motivation for taking up the present research. The primary objectives of the present research are as follows:

- To study the effect of alkali contamination on the geotechnical properties of soil.
- To evaluate the alkali induced heaving in oedometer and large scale electrokinetic (EK) models.
- To study the stabilising effect of industrial waste by-products in controlling the alkali induced heaving as well as on geotechnical properties of uninteracted soil and alkali interacted soil.
- To assess the effect of chemical stabilizers in controlling the alkali induced heaving and also these chemicals were used as electrolytic solution to enhance the geotechnical properties of alkali interacted soil through bench scale EK model.

## 1.8 Thesis Outline

The research conducted to accomplish the above-stated goals is presented in seven different chapters. The board content of various chapters of the thesis are as follows:

**Chapter 1** address the effect of alkali contamination on the soil and highlights key objective of present thesis in detail. It discusses the different case studies of the failure of structure in different industries due to alkali contamination. The different mitigation techniques to control the heaving in soil due to alkali contamination and utilization of different waste materials and chemicals for various engineering applications.

**Chapter 2** provides a discussion on detailed literature review on soil heaving caused by alkali contamination. The focus is drawn on the influence of alkali contamination on the physical and chemical properties of soil. Following that, an in-depth discussion of various techniques employed to improve the geotechnical properties of soil has been brought out.

**Chapter 3** outlines the details of materials and methodologies used in the present study. The characteristics of soil, waste materials and chemicals are discussed in detail. Preparation methods of alkali solution of different concentrations in the laboratory are also discussed. A brief discussion on the preparation of soil samples and the procedure of various geotechnical tests along with the XRF, XRD and SEM analysis are also mentioned in this chapter. The fabrication details of large-scale and bench-scale electrokinetic models are explained.

**Chapter 4** elucidates the effect of different concentrations of alkali solution on the geotechnical properties of soil by performing a series of experiments. The main focus is to investigate the percentage of heaving in the large-scale electrokinetic models inundated with alkali solution.

**Chapter 5** in this chapter an attempt has been made to explore the efficiency of GGBFS and alccofine to control the heaving in the soil after alkali interaction. The importance of pozzolanic reactivity of these waste materials to stabilise the alkali interacted soil has been also studied.

**Chapter 6** provides a discussion on the potentiality of three different chemical stabilizers to stabilise the alkali-interacted soil. The ingression of a different combination of chemicals was carried out through an electrokinetic process in a bench-scale electrokinetic model.

**Chapter 7** summarizes key conclusions based on test result are presented in various chapters along with the major conclusions. The limitations of present research and its future scope are also presented in this chapter.