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Diagnosing rising damp in the walls of a six bedroom residential apartment in Kumasi, Ghana

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Abstract

This study sought to conduct a diagnosis of the problem of rising damp in the walls of a six bedroom residential apartment in Ghana. In achieving this aim, the study sought to determine the types of soluble salts and their concentrations in the soils and accumulated percentages in the walls over time and whether there exist any linkage between the salts in the walls and those in the ground. The results showed that the main salts predominant in the walls of the building were magnesium sulphate, magnesium chloride, sodium sulphate, and sodium chlorides. Sodium nitrates, sodium chlorides, sodium sulphates, magnesium chloride, magnesium nitrate, magnesium sulphate, potassium chloride, potassium nitrate and potassium sulphate salts were also present in the soil samples collected from the boreholes. Thus sodium sulphate, magnesium sulphate, sodium chloride and magnesium chloride salts found in the soil were also found in the walls, establishing a linkage between the salts found in the ground and that found in the walls and therefore confirming the presence of rising dampness. The results is of value and significance since knowing the types of salts present in an affected building will lead to the adoption of appropriate treatment mechanisms to address the problem.

Keywords: Dampness; Rising damp; Salt attack; Residential buildings

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1. Introduction

Buildings by their very nature are composites of different materials and forms of construction each having its own specific performance characteristics (Watts et al*.,* 2001). The demands placed on a building or an element of its construction by occupants and users relate to its location and siting, climatic and environmental conditions, the manner in which it is used, current and past levels of damage, deterioration and decay, etc. (Watts et al*.,* 2001). Despite the lasting qualities of buildings, all buildings be it old or modern types of construction, are susceptible to natural and man-made mechanisms of deterioration (Noy and Douglas, 2005; Watts et al*.,* 2001; Hollis, 2000; Massari and Massari, 1985).

Among these deterioration is moisture or dampness, the most frequent and dangerous,which contributes more than 50% of all known building failures (Halim et al*.,* 2012; Watts et al*.,* 2001). Accumulation of moisture or dampness in buildings or components of a building leads to physical, biological or chemical deterioration of the building or its materials (Haverinen-Shaughnessy, 2007). Researchers in the past have identified the causes of dampness in buildings to include plumbing leakages, rain water penetration, condensation and rising dampness (Halim and Halim, 2010; Riley and Cotgrave, 2005; Burkinshaw and Parrett, 2004; Ahmed and Abdul Rahman, 2010; Mbachu, 1999). Of all the causes of dampness, rising damp is considered the most challenging (Ahmad and Abdul Rahman, 2010). This is because it was once very common in older buildings, particularly those constructed without damp proof courses, but it is now becoming a common issue with modern types of construction as well (Rirsch and Zhang, 2010).

Ground water contains soluble salts, and when rising damp occurs in the walls of a building, these salts move with the water up the wall and are left behind as the water evaporates. Also, the moisture from rising damp dissolves the existing salts in building materials and these are left behind upon evaporation of the moisture (Ahmad and Abdul Rahman, 2010). Burkinshaw (2012, p.1) stated that "Rising damp is a strange phenomenon because even experts in dampness issues do not agree on exactly what it is, and some even deny its existence". For instance Parrett (2011, p.16) stated that "The presence of chloride and nitrate salts could be found in a number of different sources that come into contact with buildings. What remained unknown was the concentrations of those salts when they have passed through various building materials in the built environment over differing lengths of time". Parrett (2011, p.16) further reported that "To help determine whether dampness has risen vertically in a wall by capillarity from a source of moisture in the ground (soil) or due to a failed, missing or bridged DPC, etc. more research was needed into different salt groups and their concentrations that become manifest in different building elements triggered by dampness and various contaminates". Also, a renowned damp consultant, Burkinshaw suggested that more research was needed to confirm and clarify whether the presence of ground salts in walls of buildings is an indication of rising dampness or not (Burkinshaw, 2012).

The problem of dampness has existed for over 2000 years, even in the times of the Israelites. The problem has also assumed alarming dimensions in public and private buildings in Ghana for many years (Agyekum et al*.,* 2013). Dampness in Ghanaian buildings is normally associated with symptoms such as hygroscopic salts or surface efflorescence, decayed skirting, mold growth, etc. (Agyekum et al*.,* 2013). Dampness has also gained roots and its impacts on the health of occupants have been reported (Asamoah et al*.,* 2012).

Dampness in most of the buildings in Ghana results from design deficiencies, poor quality workmanship, non-inclusion of professionals during construction, etc. (Agyekum et al*.,* 2014). Knowing the root cause of the problem will lead to appropriate interventions to address it. This study therefore sought to conduct a diagnosis of the problem of rising dampness in the walls of a six bedroom residential apartment with the view of identifying the root cause.

2. Literature review

2.1. Rising damp

2.1.1. Phenomenon and definitions of rising damp

Rising damp is common in buildings around the world and it plays a major role in the decay of masonry buildings (Halim et al*.,* 2012; Ahmad and Abdul Rahman, 2010; Hetreed, 2008; Burkinshaw and Parrett, 2004). It results from porous masonry sucking up water from the ground. The water rises up the wall, about one metre or more high and often deposits a horizontal 'tide mark' (Halim et al*.,* 2012; Ahmad and Abdul Rahman, 2010; Hetreed, 2008; Trotman et al*.,* 2007; Burkinshaw and Parrett, 2004).

A number of published articles have been dedicated to defining the phenomenon of rising damp in addition to the provision of an in-depth understanding of the mechanisms involved. According to Oxley and Gobert (2011), 'rising dampness results from the capillary flow of water from the ground'. Melville and Gordon (1998) described rising dampness as 'ground water reaching the foot of a wall which tends to rise in the walling material and continues to do so due to capillary action to varying degrees of intensity'. According to Burkinshaw and Parrett (2004), rising damp is said to have occurred when water rises upwards through the pores of masonries, cracks in buildings, or the floors of buildings, with the water being sourced from the ground. Trotman et al*.* (2004) defined rising damp as 'the upward transfer of moisture in a porous material due to capillary action'. Alfano et al*.* (2006) also defined rising damp as 'the upward vertical flow of water through a permeable wall structure'. In another study by Trotman (2007) the issue of rising damp was not defined but it was demonstrated as walls that stand in water or saturated soils. This infers that a low level penetration damp could also be rising damp. Rising damp usually presents itself by salty brownish-yellow patches of plaster/decor just above skirting board height (Burkinshaw, 2012).

2.1.2. Review of related studies on rising damp and salt attack

Rising damp has been recognized as a perennial and ubiquitous problem in masonry buildings (Zhang, n.d). There have been well reported cases of different aspects of rising damp such as health and safety hazards, economic implications, fundamental research on its nature, experimental investigation, techniques and product development for combating rising damp and case study of ordinary and heritage buildings (Burkinshaw, 2012; Halim et al*.,* 2012; Ahmad and Abdul Rahman, 2010; Burkinshaw, 2010; Hamid and Ngah, 2010; Young, 2008; Trotman, 2007; Bucea et al*.*, 2005; Borrelli, 1999; Arnold, 1982; Zhang, n.d). Extensive studies have also been carried out in Malaysia, Europe and Australia on rising damp (Ahmad and Rahman, 2010; Hamid and Ngah, 2010; Burkinshaw, 2010; Young, 2008, Young, 2007; Burkinshaw and Parrett, 2004).

In the latter part of the 19th Century, the subject of rising dampness and public health became important to researchers (Zhang, n.d.). The Architect Thomas Worthington described rising damp in his 1892 essay, and recommended that a damp proof course (DPC) should be used to disconnect the whole of the foundations from the superstructure. In a detailed study undertaken by the British Research Establishment (BRE), the moisture contents of a total of ninety-four 100 year old properties in the Cardiff Bay area were measured (Harrison and Trotman, 2002). Rising damp was reported to occur if the moisture content was above 5% and it was found that 54% of the properties suffered from rising damp at heights of 0.3m above the floor level (Zhang, n.d). In a study by Trotman et al. (2004), it was reported that soluble salts were drawn up into the structures affected by rising damp and became deposited in the walls. When the water evaporated, the salt solution became more concentrated at the surface and crystallized out of solution, blocked the pores, reduced evaporation and raised the height of the level of dampness. In Greece, Maravelaki-Kalaitzaki et al*.* (2005) revealed that the main reasons for deterioration of construction materials were attributed to salt crystallization, water and the movement of salt solutions through walls by capillarity. Moreno et al*.* (2006), undertook a detailed study of salt damage on a 16th -17th Century church building. Masonry samples were drilled at different heights and locations of the building to determine the salt damages on those samples. From their study it was concluded that rising damp had introduced salts into the building. The World Health Organization in 2009 also revealed that in Europe 10-50% of indoor environments is associated with dampness and rising damp was reported as the main cause of the moisture problem.

Salts normally present in buildings are either present in the masonry at the time of construction or are absorbed from the atmosphere or ground water during the life of the building (Abu Bakar et al*.*, 2011; Jordan, 2001). Salt will crystallize at different heights on walls with rising damp depending on their solubility (Charola, 2000; Arnold and Zehnder, 1985). Arnold (1982) synthesized this distribution from a careful analysis and observation of many damp structures. It was realized that salts distributed within the walls of the building depended on the mixtures of the different salt groups present and their origins. Steiger et al*.* (1997) thoroughly analysed the northern façade of a former convent in northern Bavaria and other monuments and identified the presence of nitrate, potassium, magnesium, chlorides and sodium to be associated with rising dampness. The zone of maximum enrichment, around 2-3m from the ground reflected the capillary rise height. Normally, sulphates are present in many bricks, stones, Portland cement and in some groundwater and are formed in masonry from sulphur dioxide and sulphurous acid in the atmosphere (Abu Bakar et al*.*, 2011).

Different types of soluble salts cause damages to masonry walls. The most common building damaging salts consist of anions-sulphates, chlorides and nitrates (Perry and Duffy, 1997). Also, sodium chloride, carbonates, nitrates and sulphates of calcium, magnesium, potassium, sodium sulphate and magnesium chlorides are damaging (Ahmad and Abdul Rahman, 2010; Department of Environment and Natural Resources of the City of Adelaide, 1997). These salts after they build up in the plaster and on brick surfaces over a period will attract moisture from the atmosphere (Ahmad and Abdul Rahman, 2010) and result in plaster peel off in a belt. The causes of decay and deterioration of buildings are influenced by the existence and movement of water and damaging salts (Espinosa et al*.,* 2008; Rijniers et al*.,* 2005; Buchwald and Kaps, 2000).

Ahmad and Abdul Rahman (2010) identified salt attack and rising damp to be among the possible problems that deteriorate buildings. In a preliminary survey of 5,800 residential buildings in Ghana, Agyekum et al*.* (2013) identified rising damp usually associated with surface efflorescence to be the lead source of dampness in most of the residential buildings surveyed. The survey triggered this current study aimed at conducting a diagnosis of rising damp and seeking to determine the general characteristics of the soils in the location, identifying the types of soluble salts and their concentrations in the soils and in the walls over time, and determining whether the salts located in the walls originated from the ground or otherwise.

2.1.3. Damaging salt concentrations in masonry

Very few countries in the world have threshold values for damaging ions in masonry (Ottosen et al*.,* 2007). In Austria a standard ÖNORM 3355-1 (Dehumidification of masonry-Building Diagnostics and Planning Principles) prescribes threshold values solely related to anions (thus, Chlorides, sulphates and nitrates). This standards have been used in several European countries like Austria, Germany, Denmark, etc. and the threshold values outlined in the ÖNORM 3355-1 are generally considered to be on the safe side (Ottosen et al*.,* 2007). Because at present there is no threshold value for salt content in masonry in Ghana, the Austrian ÖNORM 3355-1, a worldwide standard was used as a benchmark in this current work as it is the only available source of threshold values for ionic concentrations in masonry walls (Ottosen et al*.,* 2007). The standard suggests limits for unproblematic (no risk) ion contents, ion contents which in each case have to be considered in relation to restoration need and problematic ion concentrations where active salt removal is advised (Ottosen et al*.,* 2007). Table 1 shows the threshold values for anions proposed by ÖNORM 3355-1.

Table 1. Threshold values for anions

Problematic content (wt%)	Individual evaluation (wt%)	Unproblematic content (wt%)	Anion
> 0.10	0.03-0.10	< 0.03	Chloride
> 0.15	0.05-0.15	< 0.05	Nitrate
> 0.25	0.10-0.25	< 0.10	Sulphate

Sources (Ottosen et al., 2007)

Based on the ÖNORM 3355-1 standard and other related literature on similar studies, a percentage of total ions exceeding 0.020% for all the ions (cations and anions) identified in this current study will be considered unsafe (Ahmad and Abdul Rahman, 2010; Hamid and Ngha, 2010; Ottosen et al*.,* 2007; Borrelli, 1999).

3. Materials and methods

The study adopted methods which have been used in previous studies (Burkinshaw, 2012; Ahmad and Abdul Rahman, 2010; Hamid and Ngah, 2010; Burkinshaw and Parrett, 2004; Borelli, 1999; BS 5930, 1999). Both primary and secondary data were collected. The secondary data included reports and maps from the Soils and Geological Divisions of the Building and Roads Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR), Ghana. The secondary sources helped in determining the location of the selected building site, vegetation and climate of the area, geological settings, etc.

3.1. Sampling of soil

The ground investigations was carried out in accordance with BS 5930 (1999) “Code of Practice for Site Investigations”, and involved desk study, walk-over survey, cable percussion drilling and soil samples collection. The walk-over survey was undertaken to assess the site, determine the drainage condition of the site and its environs and to enable prudent areas to be located for the boreholes

Two boreholes were drilled using DANDO 2000 cable percussion drill rig. The building under study was a huge 6-bedroom single storey apartment situated on a slopy ground. The investigation of the ground in this locality required a deeper soil samples than can be excavated by trial pitting to enable the presumed soil conditions to be obtained. A detailed site investigation involving deep boreholes is always a necessity for huge structures to enable soil conditions to be obtained (American Socierty of Civil Engineers, ASCE, 1976; 1974). The boreholes were drilled to depths of 11m each. The drilled boreholes enabled the study of the soil profile, recovery of soil samples for laboratory testing and observation of the ground water. Disturbed samples were taken at 1m interval to the final depth in each borehole. These samples were taken from the clay cutter, a cutting device attached to the drilling machine, and preserved in plastic bags and clearly labeled for laboratory tests at the Geotechnical Engineering Laboratory of BRRI of the CSIR.

3.2. Sampling of mortar

The equipment and materials used to obtain the mortar samples included cordless drills, sharp tungsten carbide drill bits, 35mm camera film cases for holding samples, plastic resealable sample bags, sharp 65mm bolster, small piece of card for collecting dust, PCE MMK1 universal moisture meter with deep probes, rule, note pad and labels.

Four different types of mortar samples were taken at 300 mm heights intervals up to the height of visible damp (i.e 300mm, 600mm, 900mm and 1.2m) to provide information about water soluble salts distributions in the walls (Burkinshaw and Parrett, 2004). An extra sample was collected about 1.5 m above the height of visible damp to act as control. In all, fifteen different samples of mortar three at each height were drilled at depths of 0-25 mm, 25-50 mm and 50-75 mm into the walls. Mortar samples collected at depths of between 10 mm and 80 mm is recommended (Burkinshaw, 2012).

3.3. Analyzing samples

The soil samples were sent to the Geotechnical Laboratory at the BRRI of the CSIR where tests were conducted in accordance with BS 1377 (1990). Laboratory tests conducted on the soil samples included moisture content, particle size distribution and Atteberg limits. The determination of the moisture contents were by the gravimetric or oven-dry method whilst the partical size distribution carried out was in two different parts, sieve analysis (to determine the percentage of individual grain sizes present in the soil samples) and sedimentation analysis. The Atterberg limit was conducted to determine the presence or otherwise of clay minerals in the soil deposits.

Mortar and soil samples were also sent to the Chemical Laboratory of the Department of Chemistry at the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana, for ion chromatography tests. Equipment used in the analysis included Ion Chromatography (Metrohm 861 Advanced Compact IC), mechanical shaker, 100 ml measuring cylinder, satorious extend analytical balance, centrifuge tubes (15 ml and 50 ml), wash bottles and volumetric flasks (2000 ml, 1000 ml, 100 ml). Ahmad and Abdul Rahman (2010, p. 11) stated that “The ion chromatography is a type of liquid chromatography that uses ion exchange resin to separate atomic or molecular ions based on their interaction with the resin. Its greatest utility is for analysis of anions and cations for which there are no other rapid analytical methods available”. Conductivity detectors were used to analyse the mortar samples in aqueous form in parts-per-million (ppm) for common anoins such as Fluoride (F^-), chloride (Cl^-), Bromide (Br^-), Nitrite (NO_2^-), Nitrate (NO_3^-), Phosphate (PO_4^{2-}) and Sulphate (SO_4^{2-}), and cations such as Sodium (Na^+), Ammonium (NH_4^+), Potassium (K^+), Calcium (Ca^{2+}) and Magnesium (Mg^{2+}).

4. Results and discussions

4.1. General characteristics of the soil in the location

The geotechnical information on the building site showed that the soils consist predominantly of loose to dense sand with various percentages of clay, silt and some gravel. This soil type exist from the top surface to about 10 m below ground surface. The average moisture content of the soil is about 19.7% and vary with depth (Figure 1a), and the plasticity index ranges from 50.8% to 60.5%. The plasticity chart indicates that the soils have high plasticity since majority of the samples fell above the A-line (Figure 1b). Ground water was not encountered in any of the boreholes drilled to a depth of 11.0 m each. Ground water elevation followed the topography of the land surface and existed below the depth of 11.0 m.

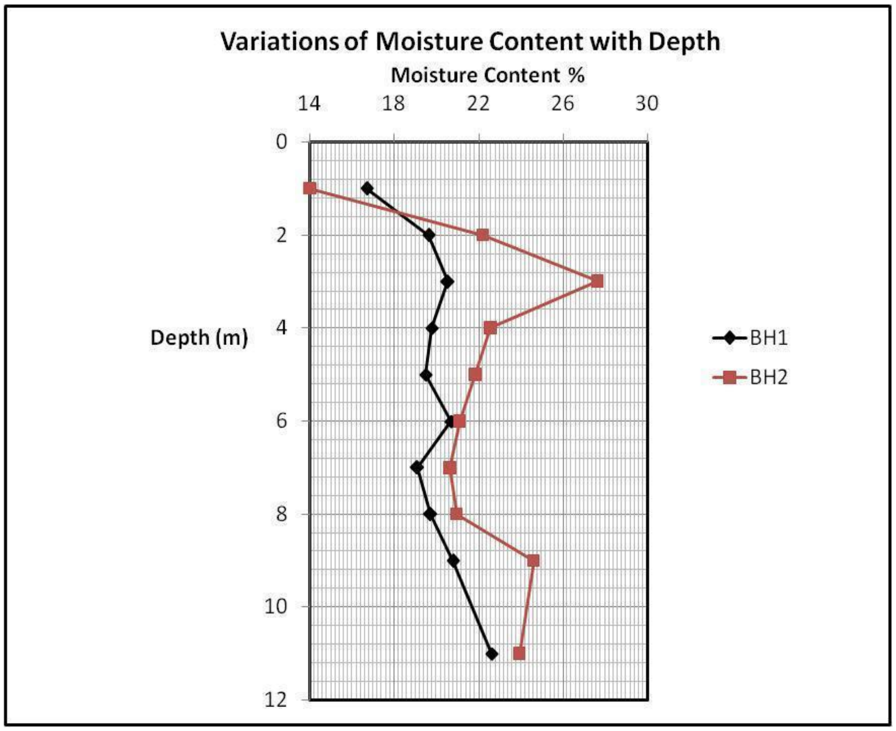

Figure 1a. Variations of moisture contents with depth

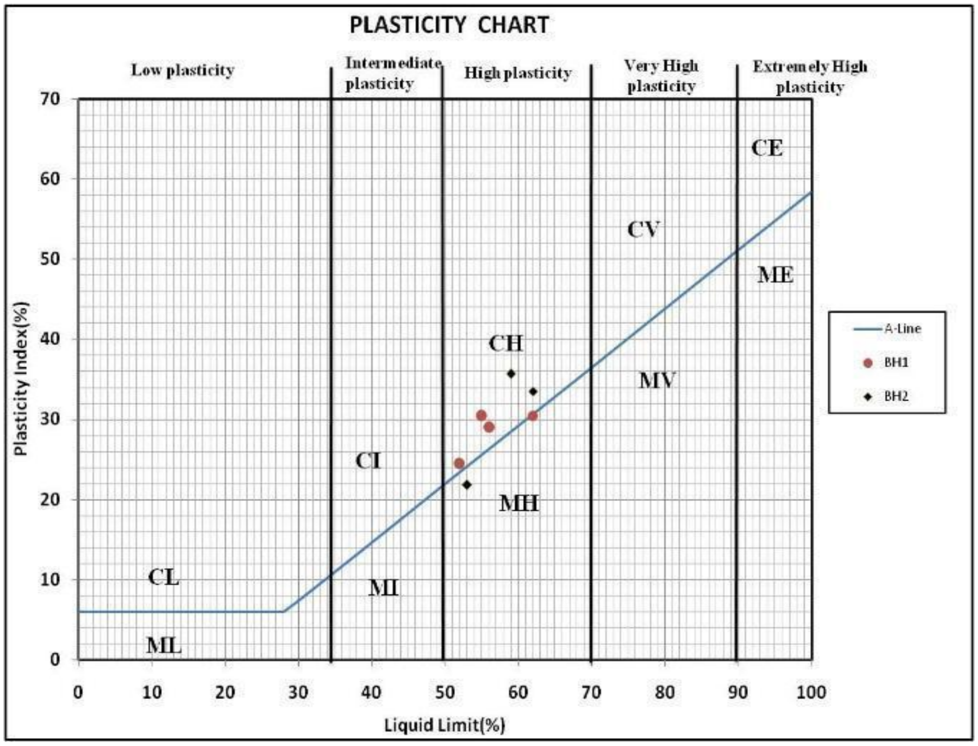

Figure 1b. Plasticity Chart showing positions of soil samples and their plasticity index

4.2. Salts and moisture content analysis of mortar samples

The results obtained for moisture and ionic contents of the mortar samples are presented in Tables 2, 3 and 4 for samples taken from depth 0-25, 25-50 and 50-75 mm respectively. Figures 2, 3 and 4 show graphical representations of the relationship between height of mortar samples, percentage ionic concentration and moisture content of samples.

The results from Table 2 and Figure 2 show that Mg^{2+} is the most predominant ion in the mortar samples followed by Na^+, K^+ and Ca^{2+} in that order. Percentage concentrations of these ions appear to increase with increasing height of mortar sample. The anions, SO_4^{2-} and Cl^- are also present in varying concentrations. At the depth of 0-25 mm (at various heights), Mg^{2+} and Na^+ were identified as the most predominant cations and SO_4^{2-} and Cl^- the most predominant anions. Thus sodium sulphate (Na_2SO_4), magnesium sulphate ($MgSO_4$), sodium chloride (NaCl) and magnesium chloride ($MgCl_2$) appear to be the most abundant salts present at a depth of 0-25 mm in the walls.The above results imply that at the maximum height of visible damp, most of the water in the soluble salts evaporate leaving behind efflorescent salts.

The results presented in Table 3 and Figure 3 show that Magnesium is the most predominant ion in the mortar sample followed by Na^+, K^+ and Ca^{2+} in that order. Percentage concentrations also appear to increase with increasing height of mortar samples. Sulphate and Chloride ions are also identified in varying concentrations in the mortar samples. Moisture contents also decreased with increasing height of mortar samples. The results generally show that Mg^{2+} and Na^+ are the most predominant cations and sulphates and chlorides the most predominant anions in the walls. Thus $MgSO_4$, $MgCl_2$, Na_2SO_4 and NaCl appear to be the most abundant salts present at a depth of 25 mm to 50 mm.

Table 4 and Figure 4 show a similar trend as those from Tables 2 and 3 and Figures 2 and 3. Thus at the depth of 50 mm to 75 mm, $MgSO_4$, $MgCl_2$, Na_2SO_4 and NaCl are abundant in the mortar samples.

The results (Tables 2, 3 and 4) show that most of the salts from mortar samples are highly concentrated on the wall surface (depth 0-25 mm) than at depths 25-50 mm and 50-75mm. This trend can be attributed to the fact that crystallisation which takes place near the surface of affected walls depends on evaporation which is also dependent on environmental conditions (Lubelli et al*.,* 2006; Snethlage and Wendler, 1997; Lewin, 1978). Also the magnitude of the crystallization pressure depends partly on the kind of salt involved, the size and shape of the capillary pore system and the relative humidity of the surrounding climate (2008; Benavente et al., 2007; Van et al., 2007; Steiger, 2005; La Iglesia et al*.,* 1997). The distance of salt precipitations from the surface of walls is mainly dependent on the pore size distribution. According to Benavente et al*.* (2007), when salts crystallise in masonries they result in an increase in volume of the masonry, which further generates internal stresses within the pores of that masonry. This finding corroborates literature. Pel et al*.* (2003) reported that high salt concentrations were encountered at the surface of fired clay brick walls as compared to the inner parts of the material. The crystallization of soluble salts in porous materials can generate pressures inside the pores sufficient to exceed the tensile strength and result in material damage. Cracks in walls and increased costs of maintening walls are among the impacts of salt crystallisation (Espinosa et al*.,* 2008; Benavente et al*.,* 2003; La Iglesia et al*.,* 1997).

Salts consist of a combination of positively (cations) and negatively (anions) charged ions, provided there is a balance between these ions (Young, 2008). In the formation of salts, not all possible combinations of cations and anions are very soluble and hence damaging (Young, 2008). The amount of salts required to cause damage depends on the types of salts, the nature and condition of the masonry and the cohesive strength of the material (Ahmad and Abdul Rahman, 2010). Ground water contains soluble salts and when rising damp occurs in the walls of a building these salts move with the water up the wall and are left behind as the water evaporates. Also, the moisture from rising damp dissolves the existing salts in building materials and these are left behind upon evaporation of the moisture (Ahmad and Abdul Rahman, 2010; Young, 2008).

According to Perry and Duffy (1997), the most common damaging salts found in buildings consist of sulphates, chlorides and nitrates. The salt analysis of the mortar samples in the current study also show that $MgSO_4$, Na_2SO_4, $MgCl_2$ and NaCl are the most predominant salts present. Throughout the entire depths and heights of the walls the concentrations of these salts exceed the acceptable safe limit of 0.020% (Ahmad and Abdul Rahman, 2010; Hamid and Ngah, 2010; Ottosen et al*.*, 2007; Borrelli, 1999) and so are liable to cause severe deterioration in the walls. Calcium sulphate, potassium sulphate, potassium chloride, and calcium chloride salts were all present in appreciable quantities in the mortar samples (Tables 2, 3 and 4). The findings from this study therefore agree with the literature.

Bucea et al*.* (2005) found that deterioration of walls of buildings were due to salt crystallization on both concrete exposed to sulphate solution and mortar exposed to either sulphate or chloride solutions. In a study by Bucea et al*.* (2005), deterioration of masonry caused by salt crystallization was due to the presence of sodium sulphate or the combined effects of sodium and magnesium sulphates or sodium chlorides. Young (2008) however, reported that not all salts that exist in moisture will cause damages to buildings. The most dangerous of these salts are sodium sulphates and magnesium chlorides which attract and absorb water (Young, 2008). A chemical analysis of efflorescence salts carried out by Merrigan (1986) revealed that sodium sulphate and potassium sulphate salts constituted about 90% of the main soluble salts identified with buildings in Southern California. Ibrahim et al*.* (2011) tried to determine the effect of sodium sulphate and sodium chloride solutions on the moisture movement of fired clay masonry walls. The study identified that soluble salt attack, especially sodium sulphate solution, resulted in the expansion of the masonry walls which significantly influenced the deterioration of the mortar joints. The rates of failure depended on the types and concentrations of soluble salt (Ibrahim et al*.*, 2011).

Results from the control samples drilled at the height of 1.5 m above the height of visible damp are also presented in Tables 2 to 4 and Figures 2 to 4 respectively. At the various depths, Mg^{2+} is found to be the most abundant cation and SO_2^{2-} the most abundant anion, all with concentrations above the acceptable safe limit of 0.020% (Ahmad and Abdul Rahman, 2010; Hamid and Ngah, 2010; Ottosen et al*.*, 2007). The concentrations of these ions are, however, lower than the concentrations found in the mortar samples from the lower height. The concentration of these two ions in the control samples could be attributed to the soil (fine aggregate) and cement used in the mixing of the mortar and moulding of the blocks (Ahmad and Abdul Rahman, 2010; Hamid and Ngah, 2010).

Hamid and Ngah (2010) assessed the level of dampness in higher institution buildings in Malaysia and attributed the presence of the nitrate salts to plumbing leakages from the toilets and the presence of high concetrations of the sulphate ions were also attributed to the materials used in the construction (bricks, mortar, plaster) and the soil. Ahmad and Abdul Rahman (2010), also found the soil to have contributed to magnesium salts present in walls of surveyed buildings. Sulphate is normally present in many bricks, screed, blocks, stones, Portland cements and in some groundwater,and it is one of the salt types most frequently considered destructive for masonry materials (Binda and Molina, 1990). They are formed from sulphur dioxide and sulphorous acid in the atmosphere (Jordan, 2001).

4.3. Salts analysis of soil samples

Table 5 shows percentages of ionic concentration at various depths of soils on the building site. The ion test conducted on soil samples from the two bore holes show that there are higher percentages of Na^+ (0.327%) ions than these two cations, Mg^{2+} (0.043%) and K^+ (0.025). The Na^+, Mg^{2+}, and K^+ deposits in the soil samples were found to be above the acceptable safe limits of 0.020% (Ahmad and Abdul Rahman, 2010; Hamid and Ngah, 2010; Ottosen et al., 2007).

The results also show that, the highest concentrations of anions in the samples are Cl^-, NO_3^-, and SO_4^{2-} in that order. There are high percentages of Cl^- ions in the boreholes than NO_3^-, and SO_4^{2-} ions.

The presence of K^+ and Mg^{2+} ions in the soil may be attributed to the use of commercial fertilizers, animal manures, municipal sewage sludges, soil organic matter, run-off from areas where salt products have been used, and irrigation water that is high in dissolved salts (Ahmad and Abdul Rahman, 2010; Young, 2008; Gartley, n.d).

The results point to the conclusion thatthere exist different salt types in the soil (NaCl, $NaNO_3$, Na_2SO_4, $MgCl_2$, $MgNO_3$, $MgSO_4$, KCl, KNO_3 and K_2SO_4). In borehole 1, sodium chlorides (NaCl), sodium nitrate ($NaNO_3$) and sodium sulphates (Na_2SO_4) formed the predominant salts in the soil samples collected. In borehole 2, NaCl, Na_2SO_4, $MgCl_2$ and $MgSO_4$ were the predominant salts in samples collected.

Figure 5 shows a graphical representation of the relationship between the most abundant ions and their total concentrations in the soils. Figure 5 also shows that the most predominant cations in the two boreholes were Na^+, Mg^{2+} and K^+, all with concentrations above acceptable safe limits of 0.020% (Ahmad and Abdul Rahman, 2010; Hamid and Ngah, 2010; Ottosen et al., 2007). Chlorides (Cl^-), NO_3^- and SO_4^{2-} are the most predominat ions that constitute anions in the two boreholes, with concentrations also above acceptable safe limits of 0.02% in the boreholes (ÖNORM 3355-1, 2011; Ahmad and Abdul Rahman, 2010; Hamid and Ngah, 2010; Ottosen et al., 2007).

4.4. Linkage between the salts in the mortar samples and that in the soil

Whereas $MgSO_4$, $MgCl_2$, Na_2SO_4 and NaCl salts were predominant in the mortar samples, NaCl, $NaNO_3$, Na_2SO_4, $MgCl_2$, $MgNO_3$, $MgSO_4$, KCl, KNO_3 and K_2SO_4 were predominat in the soil samples. This finding shows that

$MgSO_4$, $MgCl_2$, Na_2SO_4 and NaCl salts present in the mortar samples from the wall are also present in the soil samples, but in different concentrations (Table 6).

Studies have shown that some of these salts are more damaging than others and the contribution of each salt to the deterioration of materials in walls differ. For instance, Na_2SO_4 and $MgSO_4$ are more damaging and cause more extensive decay in masonry than KNO_3, K_2SO_4, NaCl and $NaNO_3$ salts (Lawrence, 2013; De Clercq, 2008).

Table 6 summarizes the predominant ions and their concentrations in soil and mortar samples. Sodium (Na^+), a cation was predominant in the soil than mortar samples. The presence of the Na^+ ion in the walls could be attributed to the wicking of ground water by the masonry. This is because the bearing soil contained considerable percentage of this ion than the mortar samples from the wall. Magnesium (Mg^{2+}) and K^+ ions, also cations were present in both soil and mortar samples but predominant in the mortar samples. Magnesium ion is very common in soils. However, its predominance in the mortar samples could be attributed to two main reasons. Thus, the possibility of its abundance in the soil (fine aggregates) used in the preparation of mortar or the many years of active dampness caused large quantities to accumulate within the walls. Potassium ions are also normally found in soils and electrolysis of chlorides and hydroxides (Ahmad and Abdul Rahman, 2010).

Chlorides (Cl^-), NO_3^- and SO_4^{2-}, all anions were also present in both mortar and soil samples. Chlorides (Cl^-) and NO_3^- were predominant in the soil than mortar samples. These salts normally originate from de-icing salts (Arnold and Zhender, 1985), sea spray and storage of perishable food. The nitrates could have originated from conversion of animals stools biodegradability of greeneries and it is the most traditional ions found in dwellings (Arnold and Zhender, 1985). Sulphate (SO_4^{2-}), predominant in the mortar samples could have been deposited there partly by ground water and partly by the cement content in the mortar. This is because sulphate ion is normally found in ground water as well as Portland cement (Ibrahim et al*.,* 2011).

5. Conclusion

This study sought to conduct a diagnosis of rising damp in the walls of a six bedroom residential apartment. Results from the geotechnical survey of the building site found the soils in the area to consist predominantly of loose to dense sand with various percentages of clay, silt and gravel. The average moisture content of the soil was about 19.7% and increased with depth, with plasticity index ranging from 50.8% to 60.5%.The main salts that were predominant in the walls of the building were $MgSO_4$, $MgCl_2$, Na_2SO_4 and NaCl. Sodium chloride (NaCl), $NaNO_3$, Na_2SO_4, $MgCl_2$, $MgNO_3$, $MgSO_4$, KCl, KNO_3 and K_2SO_4 salts were present in the soil samples collected from the boreholes. Thus sodium sulphate, magnesium sulphate, sodium chloride and magnesium chloride salts found in the soil were also found in the walls, establishing a linkage between the salts found in the ground and that found in the walls and therefore confirming the presence of rising dampness. The study recommends more research to be carried out on buildings located within different geographical locations. More laboratory tests and scientific analyses on salts should be carried out to have a better understanding of how to handle the problem of rising damp and salt attacks.

Table 2. Summary of results from moisture and ionic contents of samples for depth 0-25 mm

HEIGHT OF SAMPLE	**CATION**					**ANION**							**% Moisture content**
	Na^+	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	PO_4^{2-}	SO_4^{2-}	F^-	Cl^-	Br^-	NO_2^-	NO_3^-	
300mm	0.032	0	0.012	0.011	0.146	0	0.031	0.005	0.011	0	0	0	6.168
600mm	0.051	0	0.022	0.018	0.127	0	0.023	0.001	0.022	0	0	0.005	6.228
900mm	0.041	0	0.020	0.015	0.158	0	0.028	0.005	0.013	0	0	0	5.249
1200mm	0.047	0	0.024	0.037	0.289	0	0.160	0.003	0.016	0	0	0.006	3.404
Control	0.012	0	0.010	0.011	0.035	0	0.040	0.000	0.008	0	0	0.005	0.374
% TOTAL OF IONS	**0.183**	**0**	**0.088**	**0.092**	**0.755**	**0**	**0.282**	**0.014**	**0.070**	**0**	**0**	**0.016**	
	2nd	**5th**	**4th**	**3rd**	**1st**	**7th**	**1st**	**4th**	**2nd**	**5th**	**6th**	**3rd**	

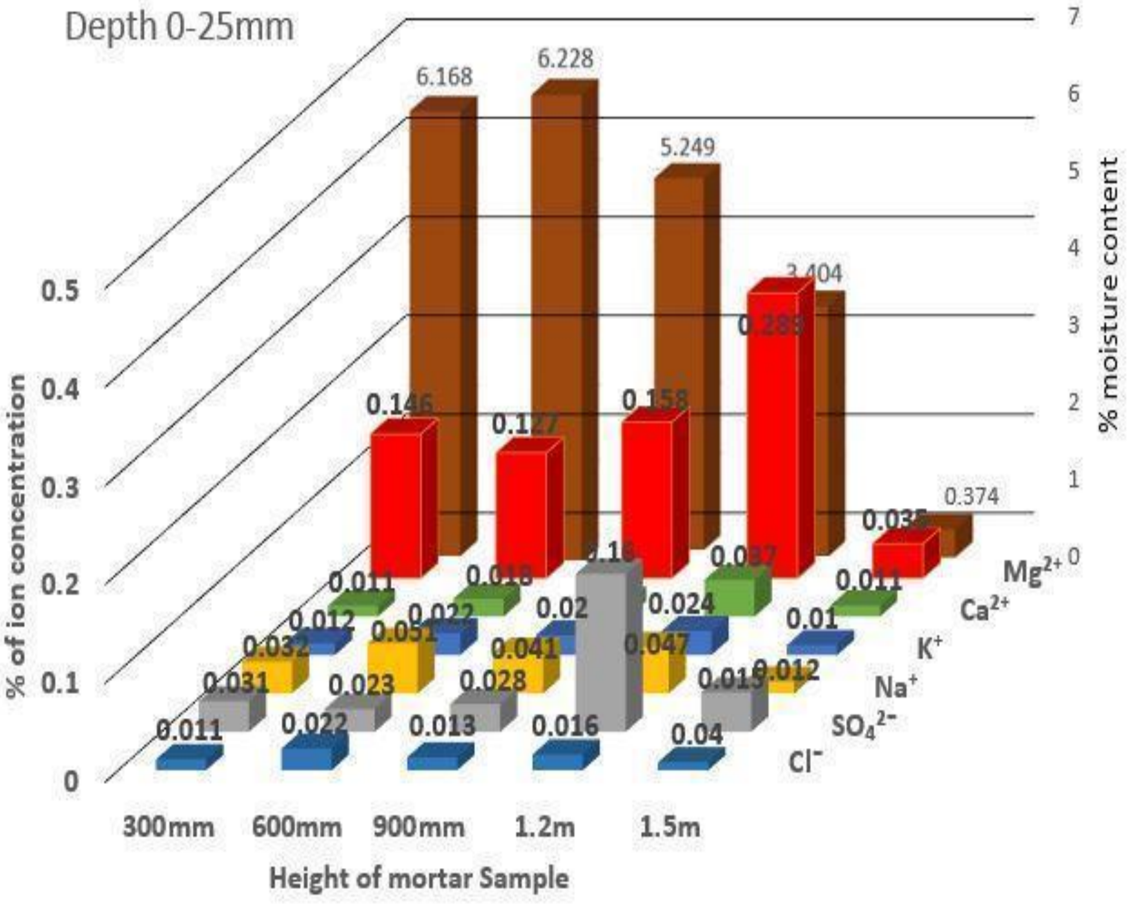

Figure 2. Relationship between height of mortar samples, percentage ionic concentration and moisture content of sample (0-25mm)

Table 3. Summary of results from moisture and ionic contents of samples for depth 25-50 mm

HEIGHT OF SAMPLE	**CATION**					**ANION**							**% Moisture content**
	Na^+	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	PO_4^{2-}	SO_4^{2-}	F^-	Cl^-	Br^-	NO_2^-	NO_3^-	
300mm	0.037	0	0.011	0.012	0.142	0	0.032	0.001	0.015	0	0	0	7.169
600mm	0.039	0	0.031	0.018	0.130	0	0.005	0	0.002	0	0	0	7.043
900mm	0.038	0	0.013	0.011	0.193	0	0.020	0.002	0.016	0	0	0.004	5.361
1200mm	0.051	0	0.020	0.037	0.221	0	0.173	0.001	0.010	0	0	0.006	3.450
control	0.014	0	0.010	0.018	0.032	0.011	0.021	0.001	0.017	0	0	0.007	0.610
% TOTAL OF IONS	**0.179**	**0**	**0.085**	**0.096**	**0.718**	**0.011**	**0.251**	**0.005**	**0.060**	**0**	**0**	**0.017**	
	2nd	**5th**	**4th**	**3rd**	**1st**	**5th**	**1st**	**3rd**	**2nd**	**6th**	**7th**	**4th**	

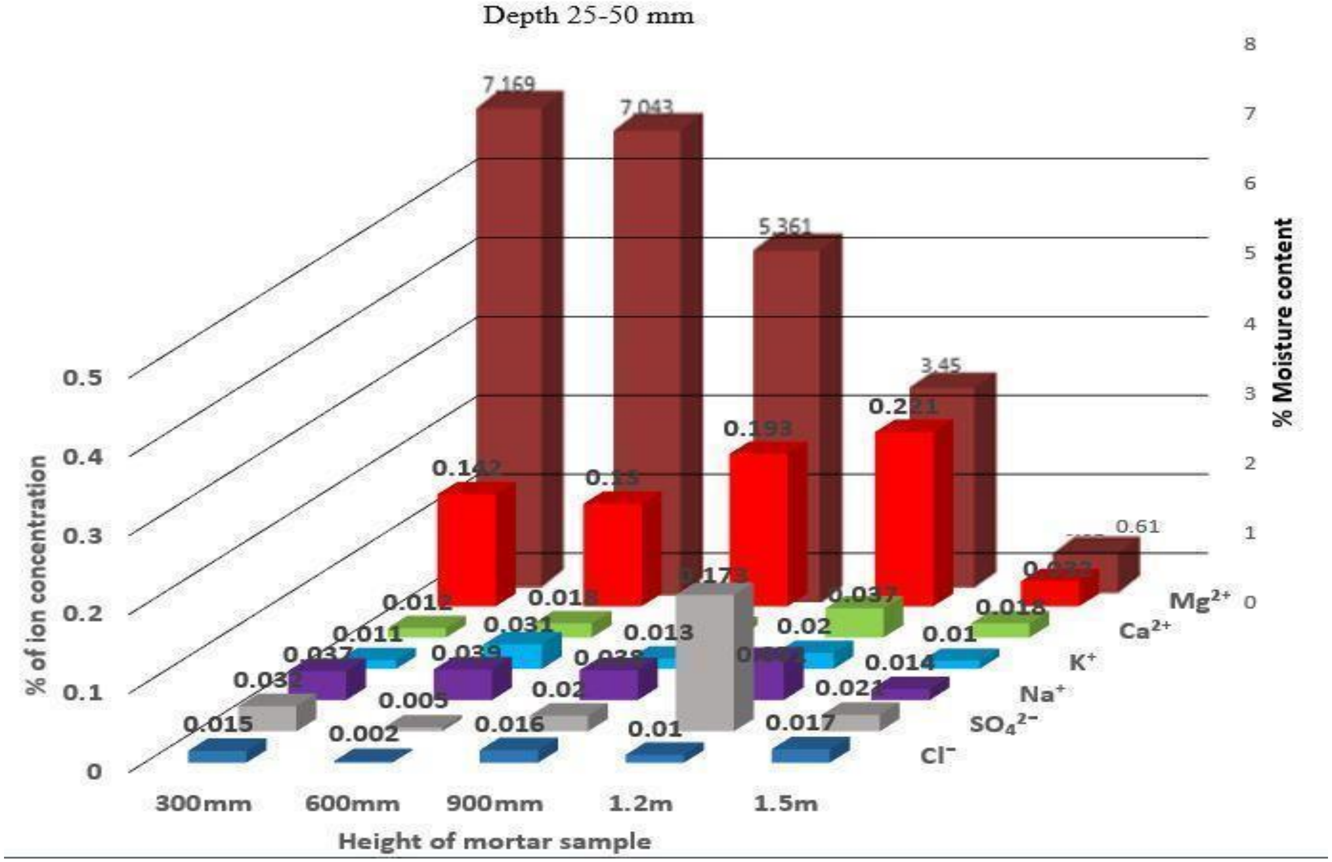

Figure 3. Relationship between height of mortar samples, percentage ionic concentration and moisture content of sample (23-50mm)

Table 4. Summary of results from moisture and ionic contents of samples for depth 50-75 mm

HEIGHT OF SAMPLE	**CATION**					**ANION**							% Moisture content
	Na^+	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	PO_4^{2-}	SO_4^{2-}	F^-	Cl^-	Br^-	NO_2^-	NO_3^-	
300 mm	0.032	0	0.017	0.019	0.120	0	0.024	0.001	0.023	0	0	0.004	7.588
600 mm	0.049	0	0.038	0.026	0.136	0	0.021	0.005	0.027	0	0	0	8.565
900 mm	0.044	0	0.024	0.022	0.193	0	0.006	0	0.005	0	0	0	5.412
1200 mm	0.047	0	0.016	0.032	0.176	0.010	0.181	0.010	0.010	0	0	0.006	3.284
Control	0.017	0	0.019	0.007	0.046	0	0.023	0.002	0.013	0	0	0.006	0.381
% TOTAL OF IONS	**0.189**	**0**	**0.114**	**0.106**	**0.671**	**0.010**	**0.255**	**0.018**	**0.078**	**0**	**0**	**0.016**	
	2nd	**5th**	**3rd**	**4th**	**1st**	**5th**	**1st**	**3rd**	**2nd**	**6th**	**7th**	**4th**	

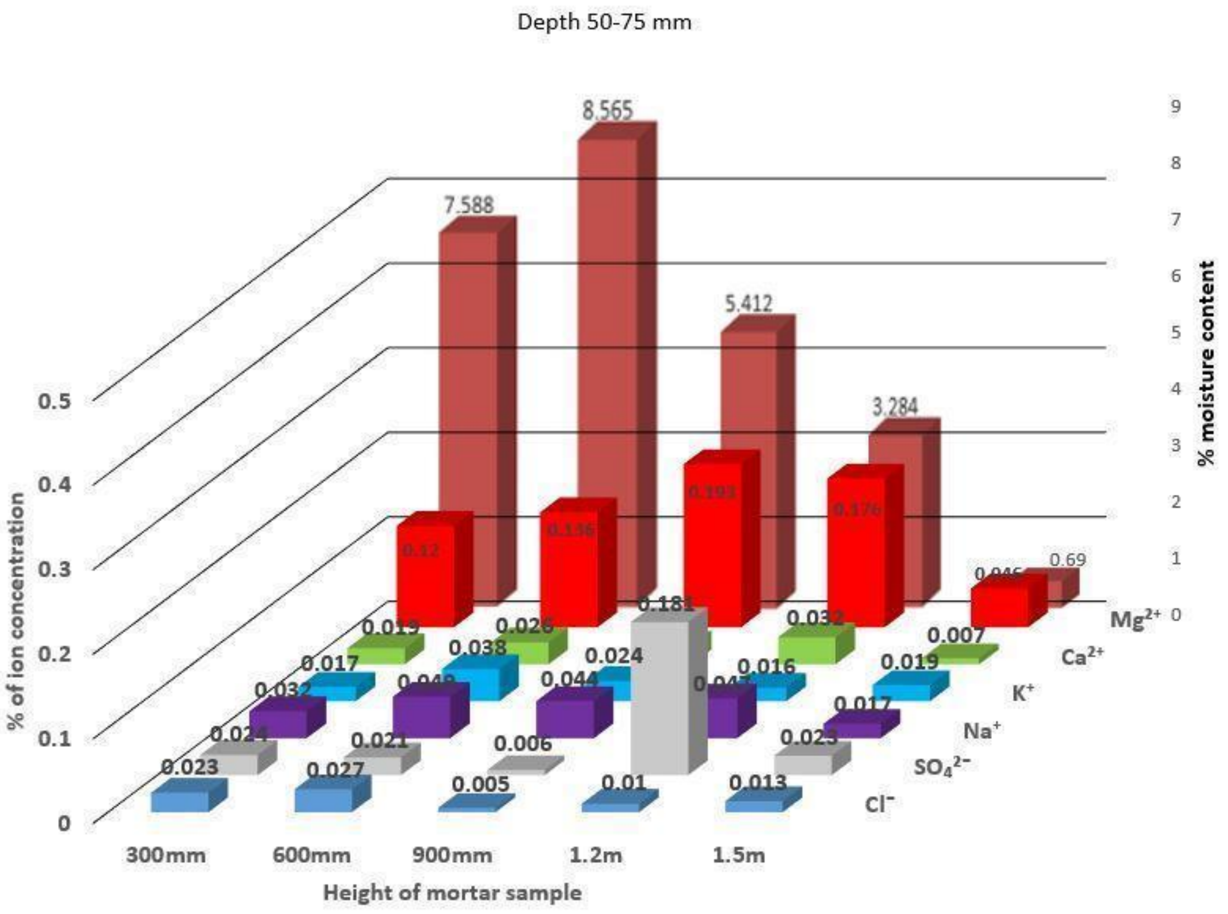

Figure 4. Relationship between height of mortar samples, percentage ionic concentration and moisture content of sample (50-75mm)

Table 5. Percentage ionic concentrations in soil samples

BOREHOLE DEPTH	**CATION**					**ANION**						
	Na^+	**NH_4^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**PO_4^{2-}**	**SO_4^{2-}**	**Cl^-**	**F^-**	**Br^-**	**NO_2^-**	**NO_3^-**
BOREHOLE 1												
0.45-1m	0.039	0.004	0.001	0.000	0.003	0.000	0.016	0.010	0.000	0.000	0.000	0.018
1-2m	0.036	0.000	0.001	0.000	0.006	0.000	0.011	0.020	0.001	0.000	0.000	0.015
2-3m	0.033	0.000	0.001	0.000	0.004	0.000	0.012	0.012	0.000	0.000	0.000	0.012
3-4m	0.024	0.000	0.000	0.000	0.003	0.000	0.010	0.010	0.000	0.000	0.000	0.012
4-5m	0.034	0.003	0.002	0.000	0.003	0.000	0.010	0.017	0.000	0.000	0.000	0.015
5-6m	0.032	0.000	0.003	0.000	0.003	0.000	0.011	0.011	0.001	0.000	0.000	0.012
6-7m	0.041	0.000	0.014	0.000	0.004	0.000	0.013	0.017	0.000	0.000	0.000	0.012
7-8m	0.028	0.005	0.001	0.000	0.004	0.000	0.012	0.017	0.000	0.000	0.000	0.011
8-9m	0.029	0.002	0.001	0.000	0.005	0.000	0.009	0.014	0.000	0.000	0.000	0.012
9-10m	0.031	0.000	0.001	0.000	0.008	0.000	0.011	0.016	0.000	0.000	0.000	0.011
%CONCENTRATION	**0.327**	**0.014**	**0.025**	**0.000**	**0.043**	**0.000**	**0.115**	**0.144**	**0.003**	**0.000**	**0.000**	**0.130**
	1st	**4th**	**3rd**	**5th**	**2nd**	**5th**	**3rd**	**1st**	**4th**	**6th**	**7th**	**2nd**
BOREHOLE 2												
0.45-1m	0.031	0.006	0.006	0.000	0.005	0.000	0.011	0.016	0.000	0.000	0.000	0.004
1-2m	0.028	0.000	0.008	0.000	0.007	0.000	0.009	0.014	0.000	0.000	0.000	0.004
2-3m	0.028	0.000	0.000	0.000	0.002	0.000	0.014	0.010	0.000	0.000	0.000	0.004
3-4m	0.008	0.000	0.001	0.000	0.105	0.000	0.010	0.013	0.000	0.000	0.000	0.004
4-5m	0.026	0.001	0.001	0.000	0.003	0.000	0.011	0.013	0.000	0.000	0.000	0.004
5-6m	0.031	0.000	0.001	0.000	0.004	0.000	0.012	0.007	0.000	0.000	0.000	0.004
6-7m	0.030	0.003	0.001	0.000	0.004	0.000	0.013	0.011	0.000	0.000	0.000	0.004
7-8m	0.031	0.000	0.004	0.000	0.008	0.000	0.010	0.014	0.000	0.000	0.000	0.004
8-9m	0.027	0.000	0.002	0.000	0.006	0.000	0.010	0.012	0.000	0.000	0.000	0.004
9-10m	0.027	0.000	0.000	0.000	0.012	0.000	0.010	0.010	0.000	0.000	0.000	0.004
%CONCENTRATION	**0.267**	**0.010**	**0.024**	**0.000**	**0.156**	**0.000**	**0.120**	**0.120**	**0.000**	**0.000**	**0.000**	**0.040**
	1st	**4th**	**3rd**	**5th**	**2nd**	**4th**	**1st**	**1st**	**5th**	**6th**	**7th**	**3rd**

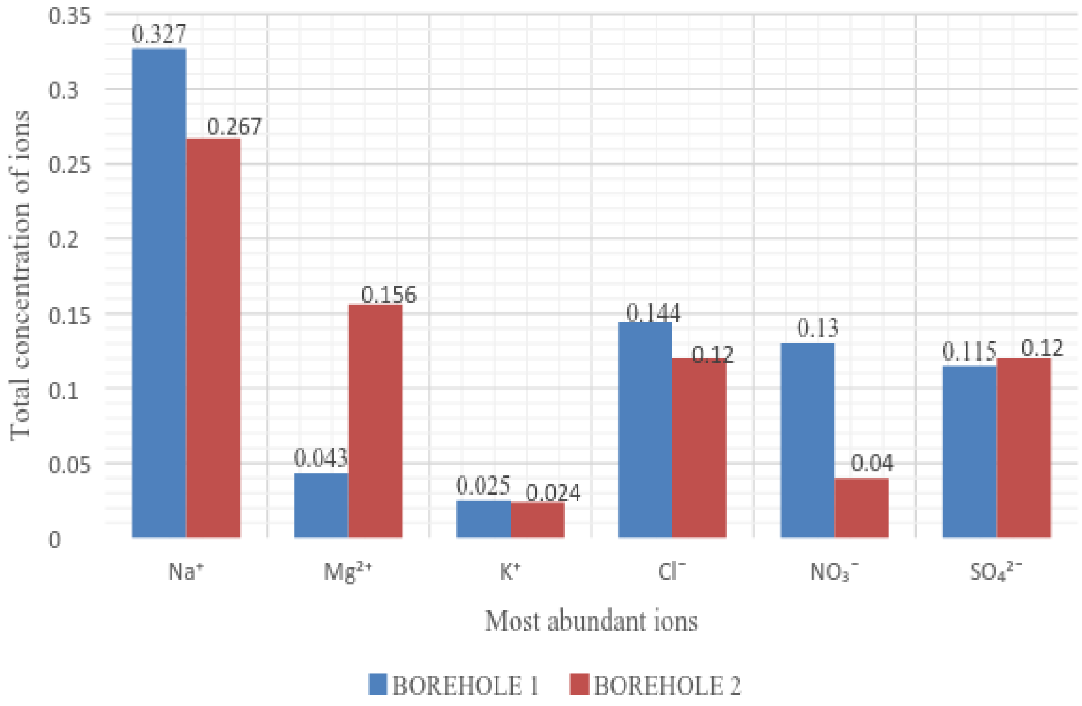

Figure 5. Most abundant ions and their concentrations in the soils

Table 6. Summary of predominant ions and their concentrations in soil and mortar samples

Type of ion	**Soil samples**		**Mortar samples**		
			Depth of mortar samples		
	Borehole 1	**Borehole 2**	**0-25 mm**	**25-50 mm**	**50-75 mm**
Cl^-	0.144*	0.120*	0.070	0.060	0.078
NO_3^-	0.130*	0.040*	0.016	0.017	0.016
SO_4^{2-}	0.115	0.120	0.282*	0.251*	0.255*
Na^+	0.327*	0.267*	0.183	0.179	0.189
K^+	0.025	0.024	0.088*	0.085*	0.114*
Mg^{2+}	0.043	0.156	0.755*	0.718*	0.671*

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