ORIGINAL ARTICLES

Assessment of Soil Salinity on Grand Bahama Island Post-Hurricane Dorian

Danica Stubbs 0009-0005-8862-759X
Aaliyah Adderley 0009-0007-9337-2856
Clare Bowen-O'Connor 0000-0002-1988-9546
Carlton Watson 0000-0002-2101-399X
Williamson Gustave 0000-0001-6934-5689
University of The Bahamas

Abstract

Saltwater intrusion into land is becoming more of a problem as sea levels rise across the globe. The Bahamas is highly susceptible to extreme weather events and climate change because the islands are low-lying and located in the Atlantic hurricane belt. Hurricane Dorian (2019) had a devastating impact on Grand Bahama Island: producing heavy rains of up to 30-40 cm and storm surges of about 8 m. The objective of this study was to analyse the soil salinity status in Wellfields 1 and 6 on the island of Grand Bahama to determine if the salinity had decreased in the three years following Hurricane Dorian. As expected, the study found that by 2022, soil salinity in the wellfields had decreased compared to levels recorded in the year after Hurricane Dorian. Soil analysis completed in October 2022 illustrated that soil salinity averaged 475.5 mg/kg for both Wellfield 1 and Wellfield 6 on the island of Grand Bahama.

DOI: https://doi.org/10.15362/ijbs.v29i1.507

Introduction

Soil salinity is a significant problem in agriculture worldwide; when a build-up of salts in soil layers exceeds a threshold, crop productivity is negatively impacted (Rengasamy, 2010). Soil salinity is the total concentration of soluble salts in soil solutions, consisting of dissolvable salts expressed as electrical conductivity (EC). Excessive salt ions such as sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), sulphates (SO_4^{2-}), and chlorides (Cl^-) inhibit a plant's function and growth (Stavi et al., 2021). Salinity interferes with plant biological uptake of nutrients and water, which intrudes on the physiological functions necessary for their development. Therefore, salinization can contribute to land degradation and threaten soil health (Butcher et al., 2016). Increased soil salinity causes a variety of issues, including a decrease in biodiversity, lower agricultural yields, desertification, and contamination of water supplies (Zaman et al., 2018).

There are many causes of soil salinization. Although rain includes only trace amounts of salt, it can cause salt to accumulate in the soil over time. Another source of salt is wind-transported material from soil or lake surfaces. Other contributors to soil layer salinization are the application of soluble fertilizers and soil additives, poor irrigation water quality, and rising shallow saline groundwater levels (Rengasamy, 2010). The most prevalent source of salt accumulation is plant evapotranspiration, which increases salt concentration with depth through the root zone and salt accumulation below the root zone (Corwin & Scudiero, 2019). Especially of concern to the Bahamas is saltwater incursion, which is becoming more of an issue worldwide as sea levels rise.

Grand Bahama and Abaco were the two major islands of The Bahamas affected by Hurricane Dorian. Hurricane Dorian's eye passed over Grand Bahama on September 2, 2019, as a Category 5 hurricane at 2 km/hr. The Bahamas Department of Meteorology (https://met.gov.bs/) reported that the storm surges and flooding caused severe damage, particularly on the island's eastern side (Deopersad et al., 2020, p. 14). "Damage resulted from high winds and storm surge and was exacerbated by poor construction practices and communities and infrastructure located in vulnerable areas" (Deopersad et al., 2020, p. 15). Hurricane Dorian produced heavy rains of 0.92 m and storm surges of about 6.1–7.6 m, both of which contributed to major flooding and high levels of saltwater intrusion (Deopersad et al., 2020, p. 14). Flooding began on the northern side of Grand Bahama, following the trajectory of the hurricane toward the southern side of the island (Deopersad et al., 2020, p. 14). The eastern side of Grand Bahama experienced particularly severe damage to many small settlements and its forested areas (Deopersad et al., 2020, p. 35).

The Types of Soil Salinity

Dryland salinity, also known as primary salinity, refers to salt accumulation caused by the high salt content of the parent material or groundwater (Hailu & Mehari, 2021). Butcher et al. (2016) claim that the spontaneous deposition of soluble salts in soil arises from the capillary rise in saline parent material or saline groundwater, resulting in dryland salinity. Dryland salinity occurs in discharge locations when water escapes from groundwater to the soil surface (Rengasamy, 2010). Salt-affected soils may occur from natural salt-containing irrigation water, a significant quantity of salt in the soil, and a high groundwater table level (Hailu & Mehari, 2021). Usually, the groundwater dissolves salt embedded in the soil's rock, causing the salty water to reach the soil surface and evaporate, resulting in higher salinity (Zaman et al., 2018).

Irrigation salinity, also known as secondary salinity, is anthropogenic. It is caused by the salts deposited by irrigation water accumulated within the root zone due to low leaching (Rengasamy, 2010). Rengasamy (2010) notes that irrigation salinity is produced by the build-up of salts using low-quality irrigation water. Hailu and Mehari (2021) further noted that secondary salinity is caused by human factors such as improper irrigation with salty water or inadequate drainage, improper usage of fertilizers, incorrect irrigation, management systems, and industrial use driven by population growth and socioeconomic factors.

Classifications of Salt-affected Soils

Saline soils have an excessive amount of soluble salt that can be quantified based on the type of soil and their interference with the development of most crops. These soils are often well-structured, permeable soils and are non-sodic soils because they contain enough solubility to inhibit the growth of most agricultural plants (Hailu & Mehari, 2021). The chemical properties of saline soils are primarily governed by the types and quantities of salts that control the soil solution's osmotic pressure (Hailu & Mehari, 2021). Additionally, saline soils can be identified by their pH levels which are usually lower than 8.5 (Zaman et al., 2018).

Sodic soils affect crop yields because they contain excessive exchangeable sodium (Hailu & Mehari, 2021). Moreover, they are poorly organized with scattered clays in the topsoil and are characterized by colloidal clay dispersion. This can affect permeability and infiltration rates, causing difficulty in tilling and penetrating systematic parts of plants (Hailu & Mehari, 2021). Sodic soil pH levels range between 8.5 and 10 due to the limited amounts of insoluble carbonates (Hailu & Mehari, 2021; Zaman et al., 2018).

Saline-sodic soils have a high presence of soluble salts and exchangeable sodium that interfere with most agricultural plant growth and production (Hailu & Mehari, 2021). These soils are also well-structured and permeable just like all of the other salt-affected soils. The pH levels of saline-sodic soils are usually lower or more than 8.5 (Zaman et al., 2018); however, Hailu and Mehari (2021) state that the pH level is less than 8.5 under excess salt conditions.

Seawater Intrusion

Seawater intrusion is the most common cause of soil salinity in coastal areas. Coastal regions are more susceptible to seawater intrusion because of their proximity to the ocean (Stavi et al., 2021; Zaman et al., 2018). Thiam et al. (2021) demonstrated salt accumulation in coastal areas was caused by seawater intrusion.

Monitoring Soil Salinity

Soil salinity is considered an essential parameter because it reflects if the soil is sustainable for growing crops (Zaman et al., 2018). Notably, the Western Australia State Salinity Council (2000) required a salinity monitoring strategy to be included in every agricultural project that involved irrigation water with salinity constituents. Thus, a method for monitoring salinity in the soil must be devised to track salinity changes, particularly in the root-zone soil (Zaman et al., 2018). Moreover, monitoring soil salinity allows farmers to track changes on a season-to-season basis, thereby having a guide as to when the land will be capable of producing crops (McLeod et al., 2010). This is especially important after a natural disaster strikes the landscape because many factors may have affected the soil (McLeod et al., 2010).

Numerous research studies have been conducted on soil salinity worldwide in countries such as India, New Zealand, and Turkey. However, there has not been enough research done on the soil salinity of The Bahamas despite its occurrence as a result of hurricanes. This study was conducted in areas of Grand Bahama Island, which is the second most populated island in the Commonwealth of The Bahamas. Located among the northern islands of The Bahamas, Grand Bahama is bordered by the Atlantic Ocean and approximately 100 km from the United States, just east of Florida. Previous articles about Hurricane Dorian and its impact on the island focused more on the structural impact on groundwater but not specifically on soil salinity (Welsh et al., 2022; McKenzie et al., 2023). The main objective of this study was to analyse the soil salinity status in Wellfield 1 (W1) and Wellfield 6 (W6) on the island of Grand Bahama to determine if the salinity status had decreased three years after Hurricane Dorian. It was expected that immediately after the impact of Hurricane Dorian the levels of soil salinity would have been significantly high; however, as of 2022, there should be a slight decrease. The research questions for this study were: (a) Was there an increase or decrease of soil salinity in both W1 and W6 between the years 2020 and 2022?; (b) Which wellfield had a greater decrease of soil salinity on the island?; and (c) What conditions present in the soil could lead to a possible decrease in soil salinity?

Materials and Methods

Study Site

This research study was conducted on the island of Grand Bahama. There are six wellfields that provide drinking water supplies and irrigation for most of the population on the island. The privately-owned Grand Bahama Utility Company, (https://grandbahamautility.com/) manages the six wellfields, the four main ones being W1, W3, W4, and W6 (Welsh et al., 2022).

Before Hurricane Dorian, some of the wellfield water sources were used to supply other islands of The Bahamas. In addition, 95% of the water supply for Grand Bahama came from both W6 and W1. Lack of monitoring of both wellfields, therefore, can have a negative effect on residents' health as they depend on their groundwater wells for household water with 35% of the water extracted from W1 and 60% from W6 (Welsh et al., 2022, p. 46).

The largest wellfield on the island is W6, which can be found in the northeastern portion of western Grand Bahama, an area that consists of unpaved roads and pine forests. W1 is also found in the western Grand Bahama but is located in the northwestern region within an urban area, which consists of residential homes and pine forests.

Field Sampling

Soil samples were collected from W1 and W6 in June 2022, three years after Hurricane Dorian. Soil samples were compared to data presented by Dokou et al. (2020). A total of 19 samples were collected for this study. On June 6, 2022, 4 samples were collected from W1. On June 7, 2022, 15 samples were collected from W6. The depth at which soils had to be collected ranged from 7-21 cm. Samples were collected from a wide range of sites due to the physical state of the environment. Some areas were rocky with little to no presence of soil from 0-6 cm. The start depth for the W6-120 site began at 10 cm and ended at 13 cm to avoid rocks at the surface. The start depth for the W6-124 site was 16.5 cm and ended at 19.5 cm. Site W6-7 also had rocky surface, so the start depth was 13 cm and ended at 17 cm.

Soil Analysis for Salinity, Electrical Conductivity, and Total Dissolved Solids

Soil samples collected were analysed in a laboratory at University of The Bahamas where they were stored at room temperature of 25 °C. Each sample was passed through a 5 mm sieve to ensure any residue or rock debris was removed. To obtain soil salinity data, electrical conductivity (EC) data is commonly used because EC1:5 (a ratio of 1 part soil to 5 parts distilled water) is less connected to plant response in soils of varying textures. This is because EC is more related to the soluble salt content of the soil solution (McLeod et al., 2010). Following Blakemore et al.'s (1987) method, data were collected using a 1:2 ratio, 1 part soil and 2 parts water. Utilizing an approximate 1 to 3 ratio, 20 mL of soil and 60 mL of distilled water were added to a beaker. The solution was stirred by hand for 1 min at 15-min intervals. Results were then recorded using a probe meter which provided digital recordings. An EZ-9909 water quality testing meter (5 In 1 Function Water Quality Testing Meter) tested for electrical conductivity measured in microsSiemens per cm (µS/cm), total dissolved solids and salinity in both parts per million (ppm) and percentage. The accuracy of total dissolved solids and electrical conductivity is ± 2% of the reading. Salinity accuracy is 0.01%–5% (± 0.1%) and 5.1%–25% (± 1%) of the readings from the meter.

Soil Analysis for Nutrients Present

A Lamotte soil testing kit (Model STH-14 https://lamotte.com/products/soil/) was used to measure the pH of the soil and the presence of nitrate nitrogen, nitrite nitrogen, phosphorus, and potassium. Following the instructions of the Lamotte soil testing kit, a single soil extract was made for nitrate nitrogen, nitrite nitrogen, phosphorus, and potassium. An extraction tube was filled with a universal extracting solution to a 14 mL line, followed by eight levels of soil sample using a 0.5 g spoon. The tube was capped and shaken by hand for one min. Due to the high concentration of carbon dioxide in the soil samples, each tube was swirled by hand for at least 30 s to allow for ventilation of the soil mixture. Filter paper and plastic funnels were used to filter the soil suspension into a second tubule.

A pipette of 1 mL of the general soil extract was transferred to a large depression on a spot plate to determine nitrate nitrogen. 10 drops of the nitrate reagent provided with the kit were also added to the depression. Then, using a 0.5 g spoon, one level measure of nitrate reagent 2 powder, was also added to the spot plate and stirred with a clean rod. After standing for five min to allow for full-colour development, the sample colour was matched with the Nitrate Nitrogen Colour Chart provided with the soil testing kit. To obtain a nitrite nitrogen reading, a similar procedure was followed where a pipet transferred the soil extract onto a depression on the spot plate and adding one drop of nitrite nitrogen reagent 1 and reagent 2 to the depression and mixed with a rod. After waiting for one min, the sample colour was matched to a colour standard on a nitrite nitrogen chart.

Phosphorus measurements were also determined by using a transfer pipet to fill a phosphorous B tube with the soil extract. Then six drops of phosphorus reagent 2 were added to the tube and shaken until fully mixed. Next, one phosphorus test tablet was placed in the tube and shaken until it completely dissolved. Once the tablet dissolved, the solution colour was immediately compared to the phosphorus colour chart.

Following excess soil extraction, potassium (potash) measurements were also obtained. The general soil extract was transferred to the lower line of the Potash A tube. One potassium B tablet was added to the tube and shaken until dissolved. Potassium reagent C was also added until the solution had reached the upper line of the Potash A tube and swirled. An empty Potash B tube was placed on white plexiglass with a solid black line down the middle. Then, using a transfer pipet, solution from the Potash A tube was allowed to slowly drip down the tube. This step lasted until the black line below the tube had disappeared.

Soil pH was measured by filling a test tube with approximately one-third of the soil and demineralized water to at least 1.5 cm from the top. Then, five drops of soil flocculating agent were added to the tube and shaken. The mixture was set aside to allow all contents to settle before proceeding to the next step. One mL of the clear solution above the soil was transferred to a large depression on the spot plate. Two drops of the duplex indicator were added to the spot plate, stirred, and compared against the duplex colour chart. Then, a range indicator and appropriate chart were chosen to perform a more precise pH test and two drops were added to the spot plate. The results were then compared to the appropriate colour chart.

Soil analysis for the presence of organic matter

The presence of organic matter in soil was obtained utilizing the (Heiri et al., 2001) basic loss on ignition method. Soil samples were placed in a drying oven (Fisher Scientific Isotemp Oven) at 105 °C for 24 hr. After 24 hr, the samples were placed in crucibles and measured to obtain their weight. Next, soils were placed in a muffle furnace (SH Scientific Muffle Furnace, 2016 version) at 550 °C for three hr. At the three-hour mark, crucibles were removed, and the weight was measured on a scale.

Statistical Analyses

Statistical analyses were carried out using Microsoft Excel software (Ver. 16.77). The data is presented as mean ± variance. The ArcGIS software was used to generate the heat maps.

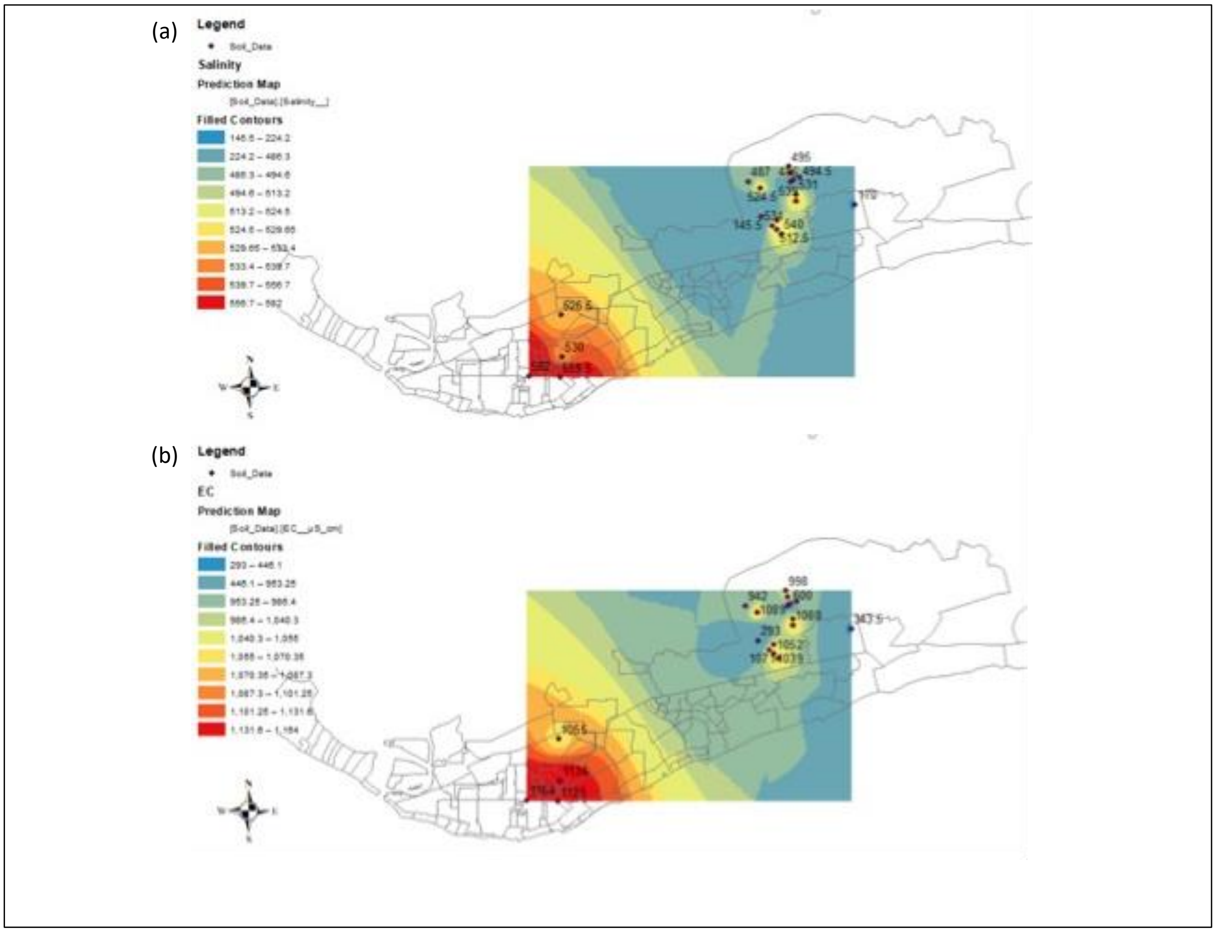
Results and Discussion

Soil Status for 2022

Soil analyses completed in October 2022 illustrated that soil salinity averaged 475.5 mg/kg and 0.04% for both W1 and W6 on the island of Grand Bahama. The salinity of W1 averaged 549.5 mg/kg and 0.05%, while W6 measured approximately 455.8 mg/kg and 0.04%. Results show that salinity levels on W6 are slightly lower than the average for W1. Figure 1(a) shows a map of Grand Bahama with the soil salinity status for 2022. This indicates high levels of salinity on W1 ranged between 529.65–582 mg/kg. In addition, W6 had levels of salinity that ranged from 145.5–540 mg/kg. Furthermore, the heat map that represents the soil status for total dissolved solids (TDS) in Grand Bahama's W1 and W6 shows similar readings of soil salinity data. The average total dissolved solids of W1 and W6 is approximately 477.7 mg/kg, which is only 2.2 mg/kg higher than the average salinity of both wellfields. The average TDS of W1 is 557.38 mg/kg and W6 is 456.47 mg/kg. Since the majority of dissolved solids are normally composed of inorganic ions, which are the building blocks of salts, TDS and salinity levels are closely connected. As a result, increasing salinity is comparable to increasing TDS (Maliki et al., 2020).

The electrical conductivity (EC) of soils on W1 and W6 was also composed in a heat map as shown in Figure 1(b). The capacity of soil to transmit an electrical current is determined by its EC. However, the unit in which EC is measured is different from salinity and TDS. Electrical conductivity is usually recorded as microSiemens per cm (µS/cm). The average EC for both W1 and W6 on the island of Grand Bahama is 958.63 µS/cm. W1 averaged 1120 µS/cm and W6 averaged 915.6 µS/cm, which was a difference of approximately 204.4 µS/cm. The heat map for the EC does resemble that of both salinity and TDS. The legend for this image differs as W1 ranged between 1055–1164 µS/cm with the colour shades of yellow, orange, and red whereas W6 ranged between 293–1089 µS/cm with colour shades of blue, yellow, and green. Additionally, like the salinity and TDS map, the software used to generate the data read the space between W1 and W6 as coordinate points, making it difficult to see the correct colours of W6 based on the legend. Since salts improve a solution's capacity to conduct electricity, a high EC value denotes a high salinity level.

Figure 1 *Soil Status on Grand Bahama Wellfield 1 and Wellfield 6 for 2022*



Note: Wellfield 1 has shades of orange and red, while Wellfield 6 is shaded blue, green, and yellow.

The pH of a solution is measured on a scale from 0 to 14, where 0–7 represents the acidic range and 7–14 represents the basic range. A pH of 7 is classified as neutral (Alam et al, 2020; Iersel, 2020). Since pH has an impact on the micronutrient availability in the growth media, it is significant. The slightly acidic pH range between 5.4 and 6.0 is ideal for most crops. Some plants, however, prefer a pH that is a little bit higher or lower (Alam et al, 2020; Iersel, 2020). Calcium carbonate is indicated by a pH between 7.3 and 8.5, and a saturated extract with large amounts of neutral soluble salts would have a high electrical conductivity. Electrical conductivity is often poor, and a pH of more than 8.5 suggests the presence of considerable levels of exchangeable CO_3 (Alam et al, 2020). The soil pH of both W1 and W6 on the island of Grand Bahama ranged from 7.6 to 8.6. Given this pH, it can be inferred that high levels of EC are the result of calcium carbonate within the soils.

Organic matter is an essential component of soil quality and the environment as it provides essential nutrients for plants and microorganisms and impacts physical, chemical, and biological processes. The incorporation of organic elements can affect the soil's strength, porosity, aggregation, and bulk density, as well as the amount and transmission of water, air, and heat in the soil (Wichern et al., 2020). The chemical characteristics of soils are also influenced by organic materials. Nutrients such as nitrogen, phosphorus, and sulphur are released into the mineral nutrient pool during the breakdown of organic waste and help to raise crop output. The average organic matter for W1 is 6.99% and 7.03% for W6.

Nitrate and nitrite nitrogen were both detected in the soil samples obtained from W1 and W6. The average nitrate-nitrogen levels for both W1 and W6 were 40.26 mg/kg. W1 had an average of 60 mg/kg and W6 was about 35 mg/kg. As it pertained to nitrite-nitrogen, the average for both wellfields was 1 mg/kg. However, for some sites, nitrite-nitrogen was undetectable based on the specific method used. Research suggests that nitrite levels in soils are typically low, less than 0.1 mg/kg NO_2-N, and they hardly ever rise over 50 mg/kg NO_2-N of soil (Cleemput & Samater, 1995).

Moreover, based on the procedure followed, potassium levels were undetectable for all sites on W1 and W6. The research concludes that potassium deficits can appear in soils that test in the adequate range of a pH under 5.8, are overloaded with Ca^{2+} ions, or lack oxygen (“Why the Potassium Deficiency”, 2018, para. 3). This makes it more difficult for potassium to bind below pH 5.8 because H^+ ions start to occupy cation exchange sites (“Why the Potassium Deficiency”, 2018).

Additionally, phosphorus levels in the soils of wellfields ranged as low as 0 mg/kg and as high as 43.75 mg/kg. The ideal range of phosphorus is between 25-50 mg/kg. The nutrient phosphorous typically limits crop productivity as it can restrict plant growth and reduce yield and quality. Although phosphorus is present in sufficient amounts in most soils, the quantity of phosphorous that is immediately available is constrained due to the slow mineralization of this nutrient.

Comparison of Soil Status between 2020 and 2022

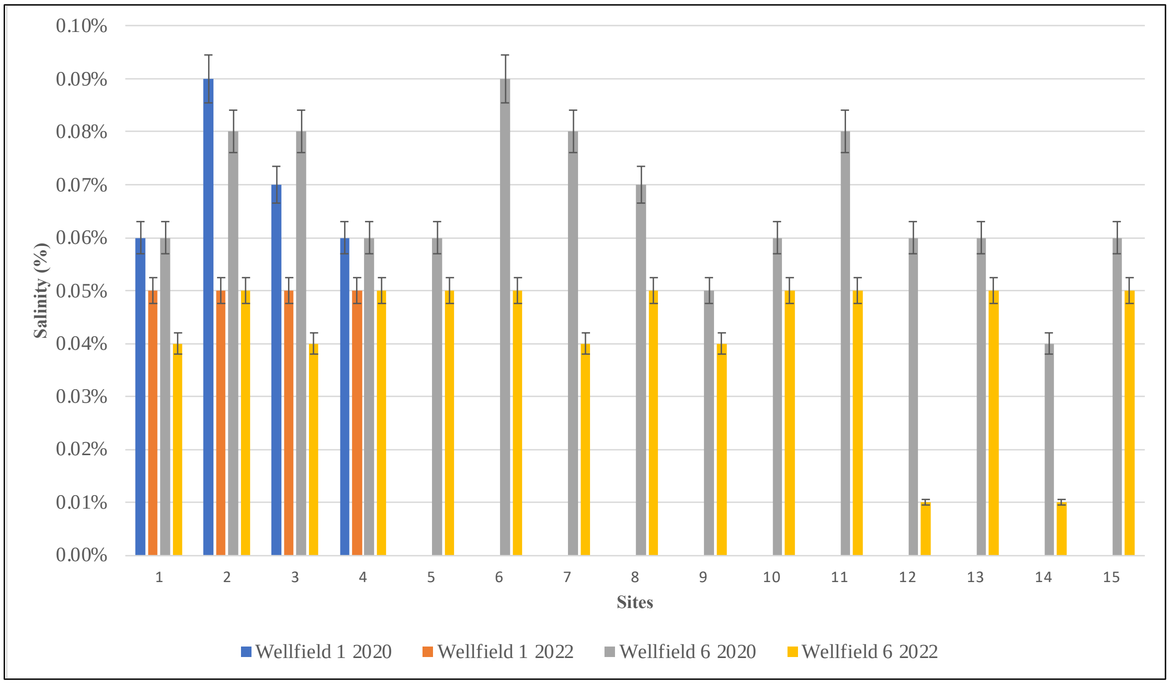
The research team did not have access to soil samples from Grand Bahama collected pre-Dorian. Therefore, this study compared data between 2020 and 2022. Data from 2020 was obtained from a study published by Dokou et al. (2020), where the researchers analysed both W1 and W6. Figure 2 illustrates that W1’s soil salinity varied between a low of 0.06% and 0.09% in 2020. However, in 2022, soil salinity levels averaged 0.05%. Salinity status for W6 varied between a low of 0.04% and a high of 0.09% in 2020 and, in 2022, the lowest salinity level was 0.01% while the highest was 0.05%. These results demonstrate that soil salinity levels on W1 and W6 are gradually decreasing as time passes.

Many factors may contribute to the decrease of soil salinity in both wellfields on the island of Grand Bahama. Organic matter amendments are known to alleviate the effects of salt on soil microbes, favouring microbial activity and nutrient cycling as a result (Wichern et al., 2020; Luedeling et al., 2005). The presence of organic matter such as livestock manure and composts can increase soil’s organic concentration and improve the soil macro-aggregation process. This process reduces salt accumulation in the surface soil layer by increasing the leaching capacity of salts from the rhizosphere and decreasing evaporation rates (Stavi et al., 2021). In addition, high levels of nitrogen increase nitrification rates and added organic matter tends to lower soil salinity statuses.

Some researchers suggest that it can take decades for soil salinity to be restored after negative impacts like a hurricane (Keim et al. 2019). Soil salinity restoration will be delayed due to factors such as climate change, sea level rise, and poor drainage.

The Bahamas and other countries are experiencing many negative impacts due to climate change. Regarding soil salinity, evapotranspiration is increased by climate change, which causes water to evaporate from the soil and increase the salinity levels (Khamidov et al. 2022). On the other hand, there are many interventions that can be used to aid in the restoration of soil salinity levels. Some of these strategies include salt flushing, chemical remediation, irrigation schemes, and phytoremediation (Keim et al. 2019).

Figure 2 *Comparison of Salinity between 2020-2022 for Wellfield 1 and Wellfield 6*



Conclusion

Organic matter present in the soil possibly aided in the decrease of soil salinity between 2020 and 2022. However, research studies suggest that restoration of soil salinity after the impact of hurricanes can take up to two decades. Restoration of salinity levels in soil on Grand Bahama will take a few more years before returning to pre-Hurricane Dorian levels. Researchers must continue to monitor soil salinity levels on Grand Bahama Island because the majority of the residents depend on groundwater for drinking water. If salinity levels are not monitored closely in W1 and W6, it may have a negative effect on the groundwater systems and on the lives and health of residents.

It is important to note that even though the soil was collected in July, during a relatively rainy period, this did not impact the result as the overall aim was to analyse the trend of salinity over time. Studying the impact of weathering factors on soil salinity can provide a better understanding of why salinity levels take a long period to normalise. Additionally, further studies can be completed to determine which factors have delayed the restoration of soil salinity in the wellfields studied. Researchers can also monitor whether the soil salinity is restored to the recommended levels. Future studies can also determine which strategies and interventions can be used to help maintain soil salinity levels on the island.

References

Alam, S. I., Hammoda, H., Khan, F., Al Enazi, R., & Goktepe, I. (2020). Electrical conductivity, pH, organic matter and texture of selected soils around the Qatar University campus. *Research in Agriculture Livestock and Fisheries*, 7, 403–409. https://doi.org/10.3329/ralf.v7i3.51359

Blakemore, L. C., Searle, P. L., & Daly, B. K. (1987). Methods for chemical analysis of soils. *New Zealand Soil Bureau Scientific Report*, 80. Landcare Research. https://doi.org/10.7931/DL1-SBSR-10A

Butcher, K., Wick, A. F., DeSutter, T., Chatterjee, A., & Harmon, J. (2016). Soil salinity: A threat to global food security. *Agronomy Journal*, *108*(6), 2189-2200. https://doi.org/10.2134/agronj2016.06.0368

Cleemput, O., & Samater, A. (1995). Nitrite in soils: Accumulation and role in the formation of gaseous N compounds. *Nutrient Cycling in Agroecosystems, 45,* 81–89. https://doi.org/10.1007/BF00749884

Corwin, D. L., & Scudiero, E. (2019). Review of soil salinity assessment for agriculture across multiple scales using proximal and/or remote sensors. *Advances in Agronomy, 158*, 1-130. https://doi.org/10.1016/bs.agron.2019.07.001

Deopersad, C., Persaud, C., Chakalall, Y., Bello, O., Masson, M., Perroni, A., Carrera-Marquis, D., Fontes de Meira, L., Gonzales, C., Peralta, L., Skerette, N., Marcano, B., Pantin, M., Vivas, G., Espiga, C., Allen, E., Ruiz, E., Ibarra, F., Espiga, F., … Nelson, M. (2020). *Assessment of the effects and impacts of Hurricane Dorian in the Bahamas*. Inter-American Development Bank. https://doi.org/10.18235/0002582

Dokou, Z., Nikolopoulos, E., Mazzoni, N., Moxey, A., & Baghdadi, L. A. (2022, May 1). *Grand Bahama groundwater and soil salinity dataset*. Zenodo. https://zenodo.org/record/6509571#.Y2vk4i1w1pS

Hailu, B., & Mehari, H. (2021). Impacts of soil salinity/sodicity on soil-water relations and plant growth in dry land areas: A review. *Journal of Natural Sciences Research*, *12*(3), 1–10. https://doi.org/ 10.7176/JNSR/12-3-01

Heiri, O., Lotter, A. F., & Lemeke, G. (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology, 25*(1), 101–110. https://doi.org/10.1023/A:1008119611481

Iersel, M. V. (2020). EC and pH: What is it and why does it matter? The University of Georgia. https://hortphys.uga.edu/hortphys/files/2020/03/EC-and-pH.pdf

Keim, R. F., Lemon, M. G. T., & Oakman, E. C. (2019). Posthurricane salinity in an impounded coastal wetland (Bayou Sauvage, Louisiana, U.S.A.). Journal of Coastal Research, 35(5), 1003-1009. https://doi.org/10.2112/JCOASTRES-D-18-00088.1

Khamidov, M., Ishchanov, J., Hamidov, A., Donmez, C., & Djumaboev, K. (2022). Assessment of soil salinity changes under the climate change in the Khorezm Region, Uzbekistan. *International Journal of Environmental Research and Public Health, 19*(14), 8794. https://doi.org/10.3390/ijerph19148794

Luedeling, E., Nagieb, M., Wichern, F., Brandt, M., Deurer, M., & Buerkert, A. (2005). Drainage, salt leaching and physico-chemical properties of irrigated man-made terrace soils in a mountain oasis of northern Oman. *Geoderma, 125*, 273–285. https://doi.org/10.1016/j.geoderma.2004.09.003

Maliki, A. A. A., Chabuk, A., Sultan, M.A., Hashim, B. M., Hussain, H. M., & Al-Ansari, N. (2020). Estimation of total dissolved solids in water bodies by spectral indices case study: Shatt al-Arab River. *Water Air Soil Pollution, 231*, 482. https://doi.org/10.1007/s11270-020-04844-z

McKenzie, Z., Kumler, M. P., Ma, R., Williams, K., & Hayes, W. K. (2023). Eyes from the sky: Application of satellite-based indices to assess vegetation casualty on Grand Bahama Island one year post-Hurricane Dorian. *Remote Sensing Applications: Society and Environment*, *32*, 101044. https://doi.org/10.1016/j.rsase.2023.101044

McLeod, M. K., Slavich, P. G., Irhas, Y., Moore, N., Rachman, A., Ali, N., Iskandar, T., Hunt, C., & Caniago, C. (2010). Soil salinity in Aceh after the December 2004 Indian Ocean tsunami. *Agricultural Water Management, 97*(5), 605–613. https://doi.org/10.1016/j.agwat.2009.10.014

Rengasamy, P. (2010). Soil processes affecting crop production in salt-affected soils. *Functional Plant Biology, 37*(7), 613–620. https://doi.org/10.1071/FP09249

State Salinity Council. (2000). *Natural resource management in Western Australia: The salinity strategy*. Government of Western Australia.

Stavi, I., Thevs, N., & Priori, S. (2021). Soil salinity and sodicity in drylands: A review of causes, effects, monitoring, and restoration measures. *Frontiers in Environmental Science, 9*, 330. https://doi.org/10.3389/fenvs.2021.712831

Thiam, S., Villamor, G. B., Faye, L. C., Bienvenue Sène, J. H., Diwediga, B., & Kyei-Baffour, N. (2021). Monitoring land use and soil salinity changes in coastal landscape: A case study from Senegal. *Environmental Monitoring and Assessment, 193*(5), 1–18. https://doi.org/10.1007/s10661-021-08958-7

Welsh, K., Bowen-O'Connor, C., Stephens, M., Dokou, Z., Imig, A., Mackey, T., Moxey, A., Nikolopoulos, E., Rein, A., Turner, A., Williams, A., Al Baghdadi, L., Bowleg, J., Leite Chaves, H., Davis, A., Guberman, G., Hanek, D., Klausner, S., Medlev, D., … Wilchcombe, R. (2022). Potable water and terrestrial resources on Grand Bahama post-Hurricane Dorian: Opportunities for climate resilience. *International Journal of Bahamian Studies*, *28*, 43-66. https://doi.org/10.15362/ijbs.v28i0.467

Why the potassium deficiency in my crop? (2018). *Insight FS*. https://www.insightfs.com/Products-Services/Resource-Center/Resource-Detail/why-the-potassium-deficiency-in-my-crop

Wichern, F., Islam, M. R., Hemkemeyer, M., Watson, C., & Joergensen, R. G. (2020). Organic amendments alleviate salinity effects on soil microorganisms and mineralisation processes in aerobic and anaerobic paddy rice soils. *Frontiers in Sustainable Food Systems, 4*. https://doi.org/10.3389/fsufs.2020.00030

Zaman, M., Shahid, S. A., & Heng, L. (2018). *Guideline for salinity assessment, mitigation, and adaptation using nuclear and related techniques*. Springer Open. https://library.oapen.org/bitstream/id/fa591144-4b76-41b4-a297-791b27c51720/1007237.pdf