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Effects of Climate Change on Salt Production a Systematic Review

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Abstract

High evaporation rates are associated with salt production, with climatic factors significantly influencing the volume of salt yielded within a given area over a season or year. The erratic rainfall patterns resulting from climate change have adversely affected global salt production, consequently impacting the income of communities reliant on this industry. A review of the literature has limited information on the association between climatic conditions and salt production, particularly in sub-Saharan Africa. To address the gap in research, this systematic review explores the climatic conditions conducive to high salt production levels and assesses the ramifications of climate change and variability in the salt sector. Despite limited existing literature on this topic from Africa, this review aims to consolidate insights from relevant studies to inform strategic decision-making in sub-Saharan Africa. This systematic review was conducted using the PRISMA guidelines. Academic databases were searched for studies that focus on climate change and salt production. Over 2000 articles were identified and reviewed. After applying screening and eligibility criteria, 18 studies meeting the inclusion and exclusion criteria were retained and utilized for the review. The majority of the 18 articles primarily discussed the correlation between high temperatures and favorable evaporation rates, resulting in increased salt production volumes across various salt mining locations examined. The studies analyzed the climatic factors that help in the high volume of salt production and any intervention to help sustain the high volume of salt production. We recommend high-quality research in the sub-regions and a detailed meta-analysis of the impact of climate change on salt production to inform policy making.

1. INTRODUCTION

Climate change is a global phenomenon characterized by increases in the severity of extreme weather events. In the last several decades, these changes have affected everyone globally. The severity extends from humans to animals (livestock) and the environment. In 2013, a report from the international conference of the Inter-governmental Panel on Climate Change (IPCC), widely recognized climate change as one of the greatest threats that currently confront everyone in the world, especially people living in developing countries [1, 2]. It has been reported that sub-Saharan Africa has equally been affected by devastating and fluctuating climate change issues. The direct and indirect consequences of these prolonged droughts have been published elsewhere [3, 4] and shown to affect people living in poorer and drier regions of the sub-region. Farmers who rely on consistent rainfall for agriculture were affected by the drastic and prolonged changes in temperature and rainfall patterns [5, 6]. The Sub-Sahara Africa (SSA) is one of the most susceptible regions to global climate change. The inhabitants of SSA were mostly affected by these severe droughts, flooding, etc. which have an impact on their health status too. With these alarming problems, climate change cannot be separated from the intensification and increased frequency of climatic hazards worldwide such as storms, drought, and flooding. Together with indirect effects including food and water insecurity and increased air pollution, climate change is having a detrimental impact on the social and environmental determinants of human health [7].

The term ‘climate change’ may be defined as a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years [8]. Climate change may also be described as long-term shift in the climate of a specific location, region, or geographical sub-region. The shift is measured by changes in features associated with average weather, such as temperature, wind patterns, and precipitation [9]. For most people, the expression – ‘climate change’ means the alteration of the world’s climate that’s caused by humans, through the burning of fossil fuel, clearing of forests, and other anthropogenic practices that increase the concentration of greenhouse gases in the atmosphere [10]. This is in line with the official definition by the United Nations Framework Convention on Climate Change (UNFCCC) that climate change is the change that can be attributed directly or indirectly to human activity that contaminates the composition of the global atmosphere in addition to the natural variability of the climate observed. In talking about the debates in the media space among the state actors regarding the anthropogenic nature of climate change, the IPCC reported with 95% certainty that human activity is the primary cause [11], leading to a consensus that it is “marked by human influence”[12].

For example, it is unequivocal that human influence has warmed the atmosphere, ocean and land. Global mean sea level increased by 0.20 m between 1901 and 2018. The average rate of sea level rise was 1.3 mm per year between 1901 and 1971, increasing to 1.9 mm per year between 1971 and 2006, and further increasing to 3.7 mm per year between 2006 and 2018. Human influence was very likely the main driver of these increases since at least 1971 [13]. The extreme weather events characterized by climate change include the following: excessive drought, severe storms, flooding, sea level rise, and unpredictable rainfall patterns. This unpredictability or fluctuations in rainfall figures across the world has a direct impact on the increases in global temperatures [14]. The consequences of the profound weather events have adverse effects on sectors which depend directly on the land, vegetation and the atmosphere for production as in agricultural activities [15].

At the recent 2023 IPCC conference, it was highlighted that climate change has led to widespread adverse effects and associated losses and damages, disproportionately impacting various systems, regions, and sectors. Economic repercussions of climate change have been evident in sectors highly exposed to climatic variations, including agriculture, forestry, fisheries, energy, and tourism. The consequences extend to individual livelihoods, encompassing the destruction of homes and infrastructure, loss of property and income, compromised human health and food security, and adverse effects on gender and social equity [16].

Another sector that suffers from the weather events is salt production. Salt production is a derivative of favorable temperature and rainfall patterns. As reported by Quashie and Aggey [17], a successful salt mining depends on the favorable temperature and rainfall of a geographical area. As a result, any unfavorable weather condition is a potential risk to salt mining. According to Roland and others [18], climate variability presents a major threat to the sustainability of such sectors and the overall implication on the livelihoods of the communities that rely on the said resources. The cataclysmic impact of climate change has covered industrialization and productivity, as in the case of salt mining/production. Salt production has long been a significant source of employment worldwide, particularly for individuals residing in coastal regions. Salt is very important in domestic and industrial use, to the extent that any decline in its production is a matter of concern to everyone. Scientists and researchers have published papers that enumerate some determinants of high and low level of salt production as determined by climatic elements.

A comprehensive review of literature on salt production and its relationship with climate change reveals two distinct categories: quantitative and qualitative studies. In the quantitative literature [18–23] researchers have consistently reported a correlation between rising temperatures and increased salt production. Conversely, higher levels of rainfall have been linked to a decrease in salt production. On the other hand, qualitative studies [24–29] support the quantitative findings, highlighting that excessively hot climatic conditions were directly associated to higher salt production volumes.

However, the reviews of articles on salt production and climate change lack a systematic review and results reveal inconsistencies in their conclusions. To fill this gap, we set up to collate, document similarities and dissimilarities in the literature on salt production and climate change and its impact on salt production by conducting a systematic review and meta-analysis. This work will highlight climate change and its devastating effects on salt production in different geographical locations including the sub-Saharan, Africa by comparing and contrasting conclusions from the published literature. Additionally, we will summarize the implications on livelihoods and any future projections. We will discuss qualitative and quantitative literature on salt farmers and how climate change affects their work and health.

2. MATERIALS AND METHOD

Search Strategy:

The authors consulted several resources and databases for this manuscript preparation. Our searched manuscripts were from Google Scholar, PubMed, Bielefeld Academic Search Engine (BASE) and Directory of Open Access Journals (DOAJ) electronic databases. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [30] guidelines during the collation and analysis of the manuscripts. Two researchers independently screened literatures and

completed data extraction. The two authors cross-checked results of the extraction and a third author adjudicate results after disagreement. We included full-text studies in the English language which were published between 1st January 2001 and 30th June 2024. This timeframe was selected to derive a good number of articles to work with and to get the most current reports on the field. The main keywords for manuscripts search from these databases were climate change, salt production, climate variability, temperature, and rainfall. Additionally, an expanded keywords includes salt pond, wind, solar radiation, wetland and environmental changes.

Inclusion and exclusion criteria:

The following Joanna Briggs Institute (JBI) inclusion criteria recommended for systematic reviews [31] was used to select appropriate manuscripts for this study. The manuscripts were from countries including India, Indonesia, Australia, Thailand, Bangladesh, Ghana, and other countries. We included only full-text studies conducted and published on climate change and salt production. Studies were included if they reported the impact of climate change on salt production and excluded studies if they reported only on climate change and not salt production. We run searches for these keywords from the above databases and shortlisted the resulting manuscripts for further evaluation. We evaluated the manuscripts by reviewing the title, abstracts, and sections of the manuscripts. In the evaluation process, first, we review the shortlisted titles to identify whether the titles of the manuscripts contained at least one keyword. If so, the abstract of a manuscript is further evaluated if it has at least one keyword. After we review the abstract and several sections of the manuscript, we included manuscripts in the study if it has several keywords and describes the outcome of climate change on salt production, otherwise it is excluded. Additionally, manuscripts based on only one keyword on climate change or studies that link climate change to crop production analysis and socioeconomic issues were excluded. Dissertations, unpublished manuscripts were also excluded.

Figure 1 shows the PRISMA flow diagram with number of included and excluded studies. A total of 2184 records were identified through the PubMed, DOAJ, BASE and Google Scholar databases. Following de-duplication and an initial title and abstract screening process, 68 articles were retrieved. Subsequent screening with specified eligibility criteria retrieved 18 articles for full text-review.

Table 1
Articles Used in the Systematic Review on Climate change and Salt Production.

Article	Author (Year)	Title
1	*Bhat et al* (2015)	Impact of climate variability on salt production in Sambhar Lake, a ramsar wetland of Rajasthan, India
2	*Kurniawam & Zulham* (2020)	Salt farmer's adaptation strategies facing climate change (case study in Paty Regency).
3	*Helmi & Sasaoka* (2018)	Dealing with socioeconomic and climate-related uncertainties in small scale salt producers in rural Sampang, Indonesia.
4	*Roland et al* (2019)	Impact of climate variability on salt production in Ghana; a case study of Songor salt project.
5	*Hossain et al* (2006)	An analysis of economic and environmental issues associated with sea salt production in Bangladesh and Thailand coast.
6	*Austen et al* (2009)	Climate change impact on water and salt balances: an assessment of the impact of climate change on catchment salt and water balances in the Murray-Darling Basin, Australia.
7	*Amrih Halil* (2019)	The impact of season changes to salt productivity in Pangenan Sub-district, Cirebon Regency in 2013 and 2014.
8	*Norma B. Muyot et al (2022)*	Constraints and challenges of salt farming in Occidental Mindoro, Philippines.
9	*Yani et al* (2019)	Environmental and social policy analysis of traditional salt production in Jeneponto Regency, Indonesia.
10	*Mahasin et al* (2017)	Ecological mapping for the development of salt production centers in Indonesia during the Dutch colonial era.
11	*Nirwansyah and Braun* (2020)	High tide event and its impact upon solar salt production area in Cirebon, West Java, Indonesia.
12	*Affam and Asamoah* (2011)	Economic potential of salt mining in Ghana towards the oil find.
13	*Mahabror (*2021)	Study of the weather parameters effect on the maduris salt production.
14	*Mani et al* (2012)	Community solar salt production in Goa, India
15	*Bramawanto et al* (2022)	The effect of ENSO and IOD climate variability on salt production in Nusa Tenggara islands.
16	*Saulong et al (2023)*	The salt industry in Occidental Mindoro: Improving the production.
17	*Montojo et al (2024)*	Status of the salt industry in the Philippines: production, challenges, and opportunities.
18	*Tran et al (2022)*	Livelihood of salt farmers in the context of environmental changes in Can Gio district, Vietnam.

3. METHODS FOR DATA EXTRACTION

There were two main methods used for data or result extraction in this section: The quantitative and qualitative research. Other strategies include mixed methods.

Quantitative Evidence

Quantitative research on salt production and climate change is limited. Bhat and others [19] researched salt mining in the Sambhar Lake region of India and found an association between an increase in temperature with high volume of salt

production. Thus, they reported 1℃ rises in temperature during the Samhbar region is associated with an increase of 1.363 tons of salt production in the Samhbar region based on the analysis of data from the Samhbar Salt Limited, a salt production company in the Samhbar region of India. On the contrary, when the Samhbar region saw a 1 mm increase in rainfall, it was associated with 0.78 tons decrease in salt production volume in the Samhbar region in the state of Rajasthan, India. Similarly, Helmi and Sasaoka [20], reported that at least 2950 metric tons of salt dissolved in flood water because of excessive rainfall just before salt harvesting time (Badan Nasional Penanggulangan Bencana (BPBD), 2013) in rural areas in the Sampang region of Indonesia. It is important to note that according to this report, the average rainfall is relatively low in Sampang, but rain during the salt season is always fatal for salt production and the livelihoods of the inhabitants. Additionally, Kurniawam and Zulham [22] reported in 2010 that extreme rainfall in the study area caused the importation of salt, as there was zero production in Indonesia that year. A report by Austin and others [32] shows that reduction in salt production continues to increase over time due to flooding of the catchment area. They projected that by 2030, salt yield reduction is estimated to be up to 880kg/ha/year resulting in a reduction of salt yield of up to 17% by 2070 due to frequent rainfall. A focus group discussion (FGD) in 2015 explained that excess rainfall and salt price fluctuation ranked first among uncertainty events in salt production practices because unpredicted rains have the strongest impact on their salt production [20].

Most authors [19–23, 28] reported an association between higher temperature and higher yield of salt production but Roland and others' [18] findings were contradictory to this assertion. They asserted that an increase in temperature is associated with a decrease in salt production while an increase in rainfall relates to increases in salt production. Their results revealed that a 1-degree Celsius increase in temperature is associated with a decrease of 0.488 metric tons of salt production and vice versa. However, a 1mm increase in rainfall increases salt production by about 0.142 metric tons and vice versa. The above authors were quick to admit that increasing temperature can equally be a good opportunity for an increase in salt production as proclaimed by other researchers. They reiterated that their findings aren't statistically significant but present an important concern for the salt industry and the communities that depend on salt production for livelihood. They estimated that about 51.4% of the annual salt production decrease in the Songor Salt Project, Ghana is accounted for by climate variability (temperature and rainfall).

Qualitative Evidence

In other analyses, a review of qualitative papers suggests that excessive rains leading to flooding make it impossible to produce salt. Prolong and excessive rains during the rainy season were detrimental to salt farming as salt ponds become flooded. Hossain and others [24] reported that the extended rainy season has a direct devastating effect on the livelihoods of salt farmers resulting in poor economic returns. Additionally, flooding of the salt beds has an indirect effect due to a decrease in employment of salt farmers and loss of income. As a result, salt farmers devise alternative ways of livelihood. For example, some salt farmers turn flooded salt ponds into fish farming ponds. Kurniawam and Zulham [22] reported that these salt farmers adapt by producing fish using the same salt ponds during the wet climatic periods in order to maintain their livelihood. With flooding of salt ponds, salt becomes a scarce commodity resulting in prices of the limited supply going up. Specifically, the authors reported that during that year, salt prices rose to about three times the previous years. Thus, Rp200-250 per kg of salt was the price before 2015 and before the rainy season in 2015. However, prices rose to Rp500 per kg when the rains came and flooded the salt ponds. Subsequent years of persistent rain exacerbated salt prices as prices were quoted as high as about Rp4000-16000 per kg in 2017.

They [22] reported that salt farmers along low-lying coastal areas in Indonesia have more extended and dryer summer now than before. They also experience frequent rainfalls during the rainy season with high tides that affect (decrease) salt production. The frequent rains were usually associated with strong winds, high tides, and flooding of the coastal areas (sea-level rise). This rise in sea levels leads directly to sedimentation. Thus, the salt ponds for the salt farmers become flooded with sediments and seawater leading to an unfavorable salt mining condition. Hence, they adapt to other economic activities like aquaculture during that time.

Data Extraction

In our analysis, the study authors gathered a diverse range of data, including both quantitative and qualitative information from the manuscripts. The climate-related data were obtained from each country's meteorological agencies. Conversely, data for salt yield and production estimates were retrieved from companies engaged in salt production within each specific geographic region. The results from the manuscript analysis, based on data from various countries, overwhelmingly indicate a negative impact of climate change on salt production. The articles presented in Table 1 predominantly focus on examining the effects of climate change on salt production in several countries, with a notable emphasis on Indonesia (7 articles), Philippines (3 articles), Ghana (2 articles), India (2 articles), and single article each for Australia, Vietnam, Thailand, and Bangladesh.

These articles consider various climatic elements, including temperature, precipitation, sunshine, wind, and relative humidity. It's worth noting that some articles used alternative names or synonyms for these climatic elements. Additionally, some studies [21, 29, 23] incorporate unique variables such as wet season, dry season, rainy days, La Niña, El Niño, flooding, landslides, and evaporation rates. Data collection methods vary among the studies, with some employing a combination of both quantitative and qualitative approaches. Visual representations, such as bar charts for annual salt production volume and rainfall figures, were utilized to convey the distribution of the data. Line graphs were employed for temperature, ENSO, La Niña, and salt production volume illustrations. Similarly, Austin and others [32] employed map shading to illustrate climate and revegetation areas.

4. DATA ANALYSIS

We analyzed the result sections for all the manuscripts included in Table 1 for Section four of this paper. The evaluated manuscripts used three thematic study designs methods for the study findings. These include quantitative, qualitative, and mixed methods. The study designs established a relationship between the total volume of salt production within a year or salt season and the climate variables (amount of rainfall, temperature changes). The statistical methods implemented for the analyses of the studies included multiple linear regression and the Pearson Product Moment correlation methods for the quantitative and a narrative essay format for reporting the findings of the qualitative papers. The mixed method used focus group discussions and interviews to support figures derived from the climatic element [rainfall/temperature] and salt production data.

Bhat et al. [19] and Roland et al. [18] used multiple linear regression models to establish a relationship between the total volume of salt production as a function of the temperature and rainfall within the salt mining area. Thus, the total volume of salt production was a function of temperature and rainfall and can be expressed mathematically as: $Y = \phi\,(U,\ V)$ where $Y = total\ salt\ volume,\ U = Average\ Rainfall,\ V = average\ temperature,\ and\ \phi\ = a\ monotone\ function$. The above authors [19] and [18] fit a multiple linear regression model to evaluate the relationship between total salt production volume as a function of the explanatory variables: temperature and rainfall. Although these authors fit similar statistical models to their respective data, their conclusions contradict each other's findings. The results from their models were not statistically significant. That is, Bhat et al [19] concluded that a unit temperature rise corresponds to an increase in total salt production and vice versa, while a rise in rainfall results in a decrease in total salt production. The study results used data from the Sambhar Salt Ltd Company, which operates in Rajasthan, India, during the 2005–2013 salt mining seasons. Similarly, Roland et al [18] also used climatic data from 1980–2010 and salt production data from 1996–2014 in the Ada Songor salt project located in Ghana for their regression analysis. It is unclear whether the authors used data corresponding to the overlapped dates. They reported that a rise in temperature translates to a decrease in total salt production and vice versa, while an increase in rainfall results in an increase in salt production. The conclusion from Roland and others [18] analysis is contrary to the findings from Bhat and others [19]. Perhaps because the results were not statistically significant according to their data. They also reported that climate changes (temperature and rainfall) can account for 51.4% of changes in total salt production volume.

Similarly, Halil [21] employs the Pearson Product Moment (PPM) correlation analysis to establish an association between total salt production volume and changes in seasonal variables. The seasonal variable was the number of dry months within each year. Halil [21] analyzed total salt productivity volume between 2013 and 2014 and correlates the yield with the number of rainy days within each year with seasonal variables. The results indicate that salt productivity in 2014 increased 2-fold due to more dry months (four dry months) compared to only two dry months in 2013. The author posited from the results that there was a significant association between total salt production volume and seasonal changes (number of dry months and rainy days). The correlation coefficient for the association between total salt production volume and changes in the seasonal variable (dry months) was (r) counting of 0.368. The Pearson correlation coefficient value of 0.368 was compared with the r-table value of 0.320, showing that 0.368 > 0.320 with a p-value less than a 5% significance level. The author concluded by confirming that there was an effect of dry months in 2013 and 2014 on total salt productivity in Australia. In other words, the drier the months in one year, the higher the total salt production volume. This result was confirmed by the interviews with salt farmers, who noted that the number of bags of salt harvested varied with seasonal changes. In a study conducted by Mahabror [23], the research aimed to evaluate the influence of different weather parameters on the production of salt in the year 2019. The study adopted a quantitative approach, primarily employing correlation analysis. The primary objective was to establish the association between the rate of evaporation and four specific weather parameters: air temperature (correlation coefficient, r = 0.964), relative humidity (r = -0.985), sunshine duration (r = 0.987), and wind speed (r = 0.622). The findings of this study underscored the significant influence of the above mentioned weather parameters on the evaporation rate of saltwater. It was concluded that the process of salt production, particularly when using the evaporation technique, exhibits a strong dependence on climate and weather conditions. Analysis of the data collected from July to October 2019 revealed specific ranges for the weather parameters: air temperature (ranging from 27.42 to 29.08 degrees Celsius), sunshine duration (between 9.71 and 10.40 hours per day), wind speed (ranging from 3.68 to 4.19 meters per second), and relative humidity (between 68% and 73%). Importantly, these parameters were found to be favorable factors associated with salt production. A noteworthy observation, as depicted in their study, revealed a steady increase in total salt production during the period from July to October. This increase exhibited a progressive trend, with salt production quantities for each month as follows: July (2385 kg), August (6525 kg), September (12546 kg), and October, which recorded the highest total production at 15939 kg. This trend clearly established that salt production is markedly influenced by dry weather conditions, with October standing out as the driest month and consequently, the month with the highest salt production yields.

We also analyzed qualitative manuscripts for this study. Kurniawam and Zulham's [22] study was on the alternative approach salt farmers use in the Paty Regency of Indonesia when climatic variables were unfavorable for salt production. The authors reported that salt farmers produced less salt due to heavy rainfall and a lack of sunlight during the years in which the study was conducted. However, during the years with high dry season, total salt production volume rose in Indonesia, and salt markets were full of salt. With over-abundance of salt during these years, the salt farmers divert their attention away from producing salt in the rainy season because of poor returns on salt farming. The salt farmers then concluded that in the rainy season, they convert their salt ponds into fishponds and then secure a proper warehouse to store the already harvested salt. The activities of the salt farmers support the assertion that higher temperature leads to higher total salt production volume, and higher rainfall leads to lesser salt production. A study reported by Helmi and Sasaoka [20] from rural Sampang in Indonesia, the second-largest salt production area had similar findings. This study examined the climatic changes and other uncertain events that have been faced by salt producers regarding the frequency and impact of salt production.

As observed in the study by Helmi and Sasaoka [20], It illustrates that all interviewees perceived excess rainfall as detrimental to the volume of salt production. They reported that high rainfall in 2013 resulted in flooding that dissolved the salt formation in some salt mining areas. And that rain during the salt season was always fatal for salt production because it affected the density of saltwater resulting in low salt yield. Salt producers produce only 7820 metric tons of salt in a previous year, 2010 because of the prolonged rainy season in that region compared to an average of 50,000 metric tons in a good year. A focus group discussion said that the 'fluctuation of salt prices and unpredicted rains have the strongest

impact on their salt production' [20]. An interviewee stated "During the rainy season, usually I cultured shrimp and fish in the pond. But the result is usually not as much compared to the salt yield, because many of the fish either died, were swept away by floods, or were stolen. Usually, in the rainy season, nobody watches the ponds so sometimes people poach the fish." MK (Interview, May 22, 2016). These testimonies pointed to the assertion that a season of high rainfall resulted in low salt production volume and vice versa. In Mahasin et al [27], salt production in Indonesia was generally influenced by rainfall patterns. A rainfall average below 60mm/month within a specific timeframe could serve as a forecasting tool for salt production. Illustrations of Mahasin's study [27] showed the correlation between rainfall and salt production in 1936–1940. That is the higher the rainfall, the lesser the salt production volume during the salt mining season and vice versa. Other qualitative papers quoted losses in monetary terms for the years with heavy rainfall seasons. For example, Nirwansyah and Braun [33] reported that tidal flood occurrence due to high rainfall affected large scale salt production sector negatively that year. Thus, tidal flooding caused a total loss of €48.69 million in salt production resulting from low production. Bramawanto and others [29] summarized their findings on the association between ENSO and IOD (which causes rainfall) and salt production. During La Nina, rainfall patterns and rainy days increase by interfering with salt production volume. When rainfall pattern and the number of rainy days increase, the salinity, quality, and evaporation rate within the salt ponds decrease. For example, when El Nino and IOD occurred in 2015 it increased the dry season thereby increasing salt production. But in 2016, when La Nina and negative IOD was experienced leading to the wet season, salt production decreased in Nusa Tenggara Island of Indonesia.

The result from Affam and Asamoah's [25] study was an overview of the salt industry in Ghana with market analysis and problems faced by the industry. With decreased rainfall patterns in Ghana, the conditions for producing artisanal salt (artisanal salt winning is by evaporation of sea water in which there is virtually no human intervention) were better along the coast (west to east). The analysis of climatic factors like temperature, rainfall pattern, etc., for areas of salt production appears favorable. The work of Austen and others [32] investigated the impact of climate change and revegetation on the salt resource in the Murray Darling Basin of Australia. They concluded that climate change will yield a higher salt production volume in the arid western parts of the basin but a decrease in the remaining areas by 2030. Salt yield volume reduction was expected to increase over the coming years. The overall production decreased in salt yield for the catchment area is significantly dependent on the rainfall patterns of the surrounding area.

Similarly, Hossain and others [24] reported several negative impacts of extended rainy season on sea salt production volume. The extended rainy season halts salt production activities early because salt beds become flooded resulting in poor economic return to the salt farmers. Another study also supported the fact that high rainfall leads to lower salt production as reported in coastal Bangladesh and Thailand. Moreover, Yani and others [28] examined the local and regional policies, weather conditions, and environmental issues that inhibit salt production in the Jeneponto Regency of Indonesia. Yani and others's [28] report showed that the success of salt production depends on weather conditions and the conditions of the salt ponds. When rainfall is high, the salinity of the seawater decreases, and the sodium chloride (NaCl) level becomes low and cannot be deemed raw salt water for sea salt production. A higher-than-expected rainfall pattern in an area was unsuitable for salt mining. Hence there existed limited areas of salt production which resulted in less salt yield of the season.

Further analysis of similar studies conducted in Philippines highlighted one significant issue: Interviews with salt farmers and members of the top salt-producing municipalities reveal that climate change and unpredictable weather patterns were major constraints facing the salt industry. These interviews identified multiple factors contributing to the decline in domestic salt production, with climate change posing a long-term threat to the industry [34–36]. Similarly, salt farmers in Vietnam reported that salt production is highly sensitive to natural variations, with erratic rainfall being a primary risk factor that adversely affects their livelihoods [37]. Among the eighteen articles listed in Table 1, seventeen agree that increased temperatures generally lead to higher salt production.

5. DISCUSSION

We examined peer-reviewed climate-change related published papers on the effect of climate variability on salt production across the world. Both quantitative and qualitative methods were employed for the analysis of the connection between salt production volume and climate variability. Consistent climate variables consist of the amount of rainfall within the year or during salt production season, temperature changes (high versus low temperatures), El Nino, La Nina, and humidity. The climate variables were intricately intertwined with each other. Thus, a temperature rise suggests a corresponding decrease in rainfall volume and an increase in salt production volume. In other words, a rise in rainfall volume during the year of salt mining season translates into low temperature and high humidity leading to low levels of salt production volume. El Nino and La Nina were two climate events that occur every two to seven years and affect temperature and rainfall patterns. Much rainfall and high temperatures increase the humidity in the air which affects the output of salt production. In other words, low humidity was associated with high temperature and high salt production volume.

Qualitative Findings

The qualitative findings revealed that salt production was influenced by environmental and weather conditions. Flooding, for instance, hampers salt production as it caused the salt to melt rather than evaporate. Abundant rainfall leads to flooding and reduced sunshine, limiting the land available for salt production. Essentially, any weather element or environmental phenomenon that reduces the rate of evaporation can result in decreased salt production.

Quantitative Findings

Quantitative studies used mathematical models to understand the relationship between climate variables and salt production. They formulated regression equations with multiple independent variables, such as temperature and rainfall, influencing total salt production volume. These models demonstrated that higher temperatures were associated with factors like wind velocity, solar radiation, and prolonged sunshine, increased rate of evaporation, leading to greater volume of salt production. Additionally, some studies employed correlation coefficients to measure the association between salt production and temperature or rainfall.

Limitation:

We would like to acknowledge a limitation in our research, which pertains to the challenge of obtaining consistent data from various manuscripts. Consequently, we were unable to conduct a comprehensive meta-analysis of the quantitative data and articles available. Our review incorporates a relatively small sample of 18 articles, representing only a fraction of the many countries within the sub region. Therefore, it may not be fully representative of the entirety of the sub region and may predominantly reflect the effects observed in the countries included.

The limited number of articles included in our study also reduces its statistical power and increases the risk of potential bias. Furthermore, we encountered difficulties in accessing studies published in languages other than English that could have enriched our analysis but did not meet our inclusion criteria. Consequently, our findings may have limited applicability in regions where English is not the primary language. Publication bias may also be a limiting factor.

Summary and Conclusions

This systematic review compiled evidence from both qualitative and quantitative articles on climate change and salt production across numerous countries. While most studies primarily analyzed the variability in rainfall and temperature, a few considered other elements like sunshine duration, relative humidity, and wind speed. The central focus of some of the papers was on the evaporation rate, with high evaporation rates correlating with increased salt production volume and vice versa. Some authors explored additional weather and climate factors that could positively or negatively affect evaporation rates, including solar radiation, rainy days, and seasonal variations.

The majority of the reviewed papers were qualitative, and their findings generally aligned, emphasizing the impact of temperature on evaporation rates and the influence of excessive rainfall on salt production. Furthermore, these studies used variations in salt production as indicators of climate change, with reduced salt production serving as evidence of climate change in specific regions [19]. Notably, while climate change was not universally regarded as detrimental to salt production, some studies suggested that regions experiencing hot and dry conditions associated with climate change could potentially benefit from increased salt production due to higher evaporation rates [18]. This underscores the complex and context-dependent relationship between climate variables, salt production, and climate change impacts.

Declarations

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Conflict of Interest: All authors declare that there is no conflict of interest in the preparation of this manuscript.

Ethical approval: This systematic review involves the use of publicly available data which have already been published. So, we did not contact any Institutional Review Board.

Clinical Trial Number: Not Applicable.

Inform consent to participate: Not Applicable.

Author contribution statements: All the authors contributed to the contextualization of the topic and its design. Mr Oliver Nortsu and Ezekiel Odonkor worked on the methodology and prepared the figures. Oliver Nortsu and Reuben Adatorwovor wrote the first draft of the manuscript. Reuben Adatorwovor and Albert Allotey did the supervized the writing process. All the authors reviewed the manuscript; they read through the manuscript and gave final approval. With the consent that it should be submitted for peer review.

Data Availability Statement: Not Applicable.

Ethics, Consent to publish/participate: Not Applicable

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Figures

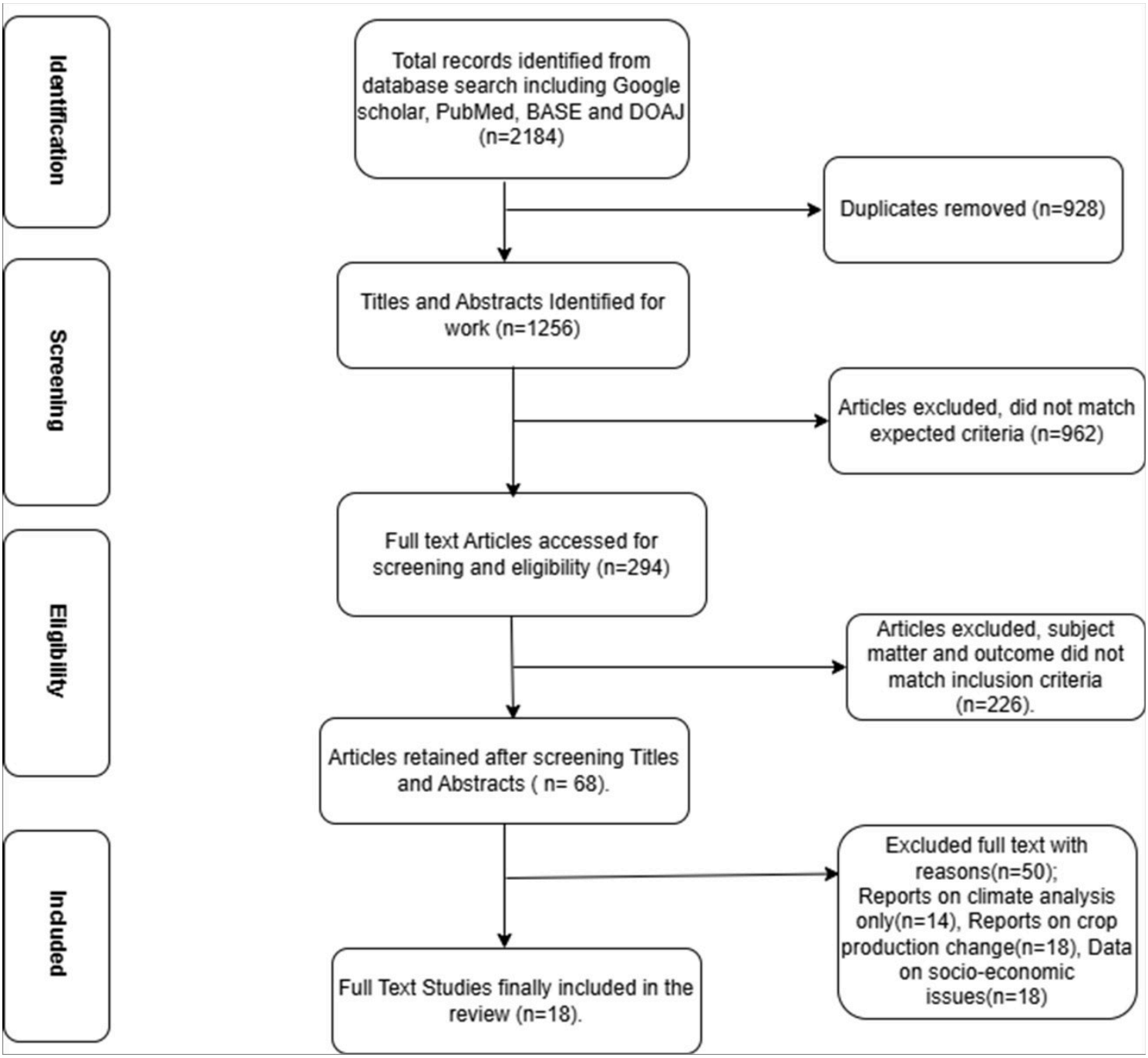


Figure 1

shows the PRISMA flow diagram with number of included and excluded studies. A total of 2184 records were identified through the PubMed, DOAJ, BASE and Google Scholar databases. Following de-duplication and an initial title and abstract screening process, 68 articles were retrieved. Subsequent screening with specified eligibility criteria retrieved 18 articles for full text-review.