Nut Industry in The Central Valley (CA), The Water Crisis And, Groundwater Depletion

by

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Abstract

The market demand for tree nuts such as almonds, walnuts, and pistachios is increasing globally. However, these water-intensive nuts are grown primarily in the dry central valley of California and have been accused of groundwater depletion. Previous studies have focused either on the acreage change or groundwater change due to overdraft. Therefore, groundwater level change has yet to be studied with the change in acreages for nut production, especially after 2014 and post-drought. This study used data from the California Department of Water Resources (DWR) and the Sustainable Groundwater Management Act (SGMA) to analyze the acreage change and its relations with groundwater depletion from 2014 to 2018 and 2018 to spring 2022. The study showed that despite the recent drought of 2012-2016 and the 2014 rising public's concern over the water use by the nuts industry, nut production in the central valley still increased dramatically. This study found significant correlations of [$R^2 = 0.70$] between the increase in nuts acreage and the decrease in groundwater between 2014-2018, indicating the risk of expanding the nut industry amid water shortages.

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Introduction

California Water Systems and Drought

Water in California

Water is an essential commodity: human life – and indeed all life on earth – depends upon it. It is also a critical input to production in many economic sectors. For instance, water is used to extract energy and mineral resources from the earth, refine petroleum and chemicals, mill paper, produce electricity, and maintain fish stocks and habitats for the commercial fishing and tourism sector. It supports innumerable other goods, from semiconductors to food and beverages, and more (USEPA 2012). California's agricultural sector is highly dependent on water. However, much of California has a Mediterranean climate, characterized by warm, dry summers and mild winters (Water Education Foundation n.d.), with little to no yearly precipitation. So, where and how does California manage its water for agricultural production?

California gets its limited water supply from two primary sources: surface water and groundwater. Surface water gathers or travels from the watersheds, such as rivers, lakes, and streams and gets managed as snowmelt runoff stored in reservoirs or using trans basin supplies. For the convenience of water management, California has defined ten major drainage basins. They include the following basins from north to south; North Coast, Sacramento River, North Lahontan, San Francisco Bay, San Joaquin River, Central Coast, Tulare Lake, South Lahontan, South Coast, and Colorado River regions (Water Education Foundation n.d.), shown in Fig 1. Of the ten regions in the state, however, approximately 75% of California's available water supply originates in three hydrologic regions in the northern basins comprising one-third of the state's land area (CNRA 2009). Yet 80% of the demand occurs in the southern two-thirds of the state (Mirchi 2013).

The three hydrological regions in the northern basins include the Sacramento River, San Joaquin River, and Tulare Lake, which comprise the Central Valley (CV) watershed. It is the largest and the most crucial watershed in California due to its contribution to Central Valley agriculture. However, the watershed depends on the Sierra Nevada and Rocky Mountain snowpack for water sources in the state's long dry season when little precipitation falls. In fact, up to 30 percent of California's water supply is from the snowpack, and most of California's hydroelectricity is also generated from the Sierra Nevada snowpack (California Department of Water Resources n.d.). Nonetheless, about 60 percent of precipitation from rain and snow evaporates or is transpired by trees and vegetation (Water Education Foundation, n.d.). In addition, the CV watersheds are draining over a third of the state – 60,000 square miles (160,000 km2) – and producing nearly half the total runoff (Kenneth 1997), a major water challenge to the state's dry south. In addressing the water issues, the state, therefore, built six major systems of aqueducts and massive water projects and infrastructure that redistribute and transport water in California: The State Water Project, the CV Project, several Colorado River delivery systems, the Los Angeles Aqueduct, the Tuolumne River/Hetch Hetchy system, and the Mokelumne Aqueduct (Carle 2016). These water infrastructures are shown in Fig 2.

As Carle (2016) mentions, to create 21st century California, an intricate network has been engineered across the state. The enormous population growth of southern California and the San Francisco Bay Area was only made possible by damming distant rivers, importing their water, and supporting the economy (Carle 2016). In the 1930s, the federal government built the CV Project (CVP) to support the arid but fertile CV and its agricultural economy. Built by the U.S. Bureau of Reclamation, the CVP transports water from Lake Shasta in the north to Bakersfield in the southern San Joaquin Valley (California-Department-of-Water-Resources n.d.). Another infrastructure, California's State Water Project (SWP), was constructed in the 1960s and 1970s to supply water to more than 27 million people and 750,000 acres of farmland. Planned, constructed, and operated by the (Department of Water Resources) DWR, it is one of the world's most extensive systems of dams, reservoirs, power plants, pumping plants, and aqueducts and remains key to California's economy. In addition, the Colorado Aqueduct, built in the 1930s, transports water from the Colorado River to Southern California. It is operated by the Metropolitan Water District of Southern California (MWD) and is the region's primary source of drinking water (California Department of Water Resources n.d.).

Fig 1. Ten Major Basins in California

(Yamasun 2022)

Fig 2. Water infrastructure in California

(DWR 2022)

Climate Change and Drought

Climate change is already impacting water and other resources in California and will continue to do so as the State's population and demand for water increase. As of 2021, California has the highest resident population in the United States, with an estimated 39.24 million people (Statista 2021). Fulfilling the water needs of such a large population and the State's economy, however, has been challenged due to climate change. For instance, the mountain snowpack provides as much as a third of California's water supply by accumulating snow during the wet winters and releasing it slowly during dry springs and summers. However, the temperature increases are already causing decreases in the snowpack as warmer temperatures melt the snow faster and earlier, making it more challenging to store and use water throughout the dry season (California Department of Water Resources n.d.). In addition, most precipitation that falls as rain or snow evaporates before it reaches the reservoirs.

According to California Department of Water Resources (DWR), climate change has further altered and intensified the natural pattern of droughts in California, making them more frequent, longer, and more severe (2015). Their report (DWR 2015) notes that the drought has played a role in shaping California's early history, as the so-called Great Drought in 1863–1864 contributed to the demise of the cattle ranching system, especially in Southern California. Subsequently, three 20th-century droughts were significant from a water supply standpoint—1929–1934, 1976–1977, and 1987–1992 (DWR 2015). More recent multiyear droughts occurred in 2007–2009 and 2012–2016 (California Department of Water Resources 2021). Thus, the State has frequently experienced drought throughout its history as part of a normal climate. The drought of 2012-2016 was also natural, but climate change due to anthropogenic carbon emissions has resulted in temperature and precipitation changes that have enhanced drought conditions. For instance, the drought critically decreased the amount of snowpack in the Sierra

Nevada Mountains, an important water source for irrigation in the CV area (Greene 2021). It caused direct statewide economic losses to agriculture, with approximately $3.8 billion in total for 2014-2016 (Medellin-Azuara et al. 2016). Scientists predict climate change will increase crop-water demands and earlier snowmelt, which could increase the frequency and severity of extreme weather events such as storms, floods, and drought (Lewis et al. 2019).

The decrease in snowpack due to climate change and drought has made the surface water supply inadequate to fulfill the demands of the farms in the CV and the vast surrounding communities. Thus, groundwater has become an alternative source of water. CV agriculture has heavily depended on local groundwater as an invaluable resource. For instance, in normal and dry years, groundwater usually supplies approximately 30% of the State's water supply. However, groundwater meets 60% of the water demand during droughts statewide (Brush et al. 2013). Scientists estimate that by the end of the 21st century, the snowpack will decline by as much as 79.3% (Rhoades et al. 2018), causing the demand for groundwater to increase dramatically. Despite this, nut-growing farmers have already removed groundwater at a rate of 4-5 times greater than the rate at which groundwater can be replenished (Rankin 2014). The problem, thus, has become groundwater overdraft, or aquifer depletion, "in which the amount of water withdrawn by pumping exceeds the amount that recharges a basin" (Keppen and Dutcher 2015).

Central Valley, Nut Industry, and Droughts

Over a third of the vegetables and three-quarters of the country's fruits and nuts are grown in California. In 2020 alone, California's agricultural production (12.5% of all in the United States) generated nearly $50 billion in cash receipts (CDFA 2020). Furthermore, California's agricultural economy supports 1.2 million jobs, including the vital farmworkers who labor to harvest, process, and transport California's agricultural bounty to the consumers of the state, country, and the world (CDFA 2021). Likewise, California is well-known for its diverse agricultural offerings, from meat (beef) to dairy to fruits and nuts. Its agricultural abundance includes more than 400 commodities (CDFA n.d.), of which more than 250 crops are grown in the CV alone and are estimated at $17 billion annually.

One of the primary sources for the state's economy is the export of agricultural products to countries around the world. Top commodities for export include almonds, dairy products, pistachios, walnuts, and wine. For instance, in 2020, California's export of agricultural products to its top 10 export destinations such as the European Union, Canada, China/Hong Kong, Japan, South Korea, Mexico, India, United Arab Emirates, Taiwan, and Turkey – accounted for 68 percent of the 2020 agriculture export value (CDFA Export Data 2020). Due to its high economic value, California, the primary agricultural state of the country and the world's 5th largest agricultural supplier, maintains itself as a critical part of the world's agricultural trade.

The Central Valley

Agricultural production is an integral national security asset, especially in today's uncertain global trade climate since it is essential to have a reliable and accessible domestic food supply. However, there are a limited number of places where suitable climate, soil, and space overlap as they do in the California CV to produce an ideal climate for agriculture (Shires 2017). The CV is unique in its geographical location (Fig 3). The CV, also known as the Great Valley of California, covers about 20,000 square miles and is one of the more notable structural depressions in the world. The valley encompasses all or parts of 19 California counties, including Butte, Colusa, Glenn, Fresno, Kern, Kings, Madera, Merced, Placer, San Joaquin, Sacramento, Shasta, Solano, Stanislaus, Sutter, Tehama, Tulare, Yolo, and Yuba. It averages about 50 miles in width and extends about 400 mi northwest from the Tehachapi Mountains to Redding (USGS n.d.). The Cascade Range bounds it to the north, the Sierra Nevada to the east, the Tehachapi Mountains to the south, and the Coast Ranges and San Francisco Bay to the west (USGS), providing water to its thriving agricultural valleys. The CV can be divided into two large parts which meet in the delta area: the northern one-third, known as the Sacramento Valley, and the southern two-thirds, known as San Joaquin Valley. The combined discharge of the Sacramento and San Joaquin Rivers (USGS 2022) is stored and managed by the state in reservoirs, dams, canals, and aqueducts. The Fig 3 shows the four main regions of the Central Valley from north to south: the Sacramento Valley, Delta & Eastside Streams, San Joaquin Basin, Tulare Basin.

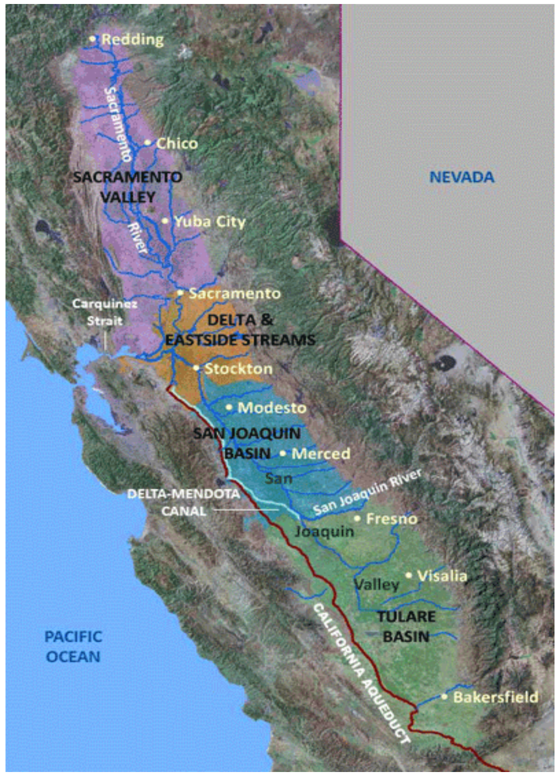


Fig 3. Map of the Central Valley's four major regions (USGS, 2022).

Two significant regions in the CV alone, the Sacramento, and San Joaquin Valley, are suitable for almost all the varieties of agricultural products grown in the CV. For example, the Sacramento Valley is known for two million acres of farmland irrigated by the Sacramento River and its tributaries, along with groundwater (Water Education Foundation 2018). Primary crops grown in the region include almonds, rice, peaches, plums, tomatoes, walnuts, pistachios, and other nuts. Similarly, the primary crops in the San Joaquin Valley include almonds, walnuts, milk, grapes, tomatoes, hay, sugar beets, nuts, cotton, and many other fruits and vegetables (CDFA 2021). Although varieties of crops are grown in these subbasins, only several crops have been able to dominate the valley because of their economic values. According to USDA ERS numbers (USDA 2022), California's top 10 valued commodities for the 2021 crop year are shown in Table 1 below.

Crops	Value (billion $)
i. Dairy Products, Milk	7.57
ii. Grapes	5.23
iii. Almonds	5.03
iv. Cattle and Calves	3.11
v. Strawberries	3.02
vi. Pistachios	2.91
vii. Lettuce	2.03
viii. Tomatoes	1.18
ix. Walnuts	1.02
x. Rice	1.00

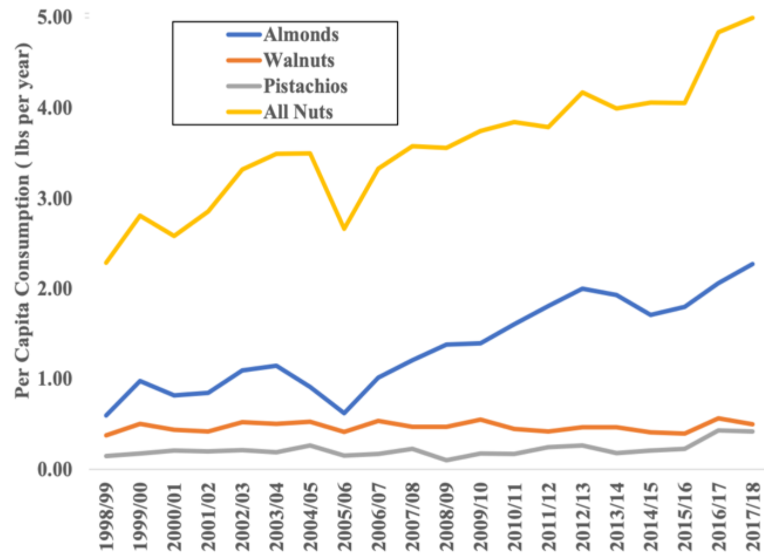
Table 1. California's top 10 valued commodities for 2021

Table 1 displays that the different crops have different economic values. For instance, dairy products, grapes, and almonds have economic values of $7.57, $5.23, and $5.03 billion, respectively. The surprising fact from the table is that almonds, pistachios, and walnuts, the most water-intensive perennial crops, are also in the top 10 list. When we add the almond, pistachio, and walnut values, the total value is approximately $9.00 billion. In other words, the tree nuts in the CV are a $9.00 billion industry, making them the largest industry in the CV. Because California is already battling water stress and shortages due to drought, growing water-intensive crops has become an essential topic of discussion.

The Nut Production in the Central Valley

Nut production in the CV has played an essential role in California Agriculture. Almonds, *Prunus dulcis*, have long been recognized as a source of nutrients in many traditional diets and are increasingly promoted as a healthy snack and ingredient. It is considered a nutritionally important and valuable specialty crop grown in many temperate and sub-tropical regions like the CV for domestic consumption and trade (Yada 2011). Walnuts, *Juglans regia*, grown in the CV at the same time as almonds, are also recognized as energy-rich and part of a heart-healthy diet (Elaine 2002). In California, walnuts account for 99 percent of the commercial U.S. supply and three-quarters of world trade, making it a top commodity crop with high economic value (walnut.org n.d.). Finally, pistachios, *Pistacia vera*, are another tree nut with a wide range of health benefits, including weight loss, lower risk of heart disease, and blood sugar control (CV Ag partners n.d.). It is also America's best-selling snack nut, with global consumption growing at an annual rate of over 8%. The United States remains the largest producer of pistachios in the world, with 98% grown in California (CV Ag partners n.d.).

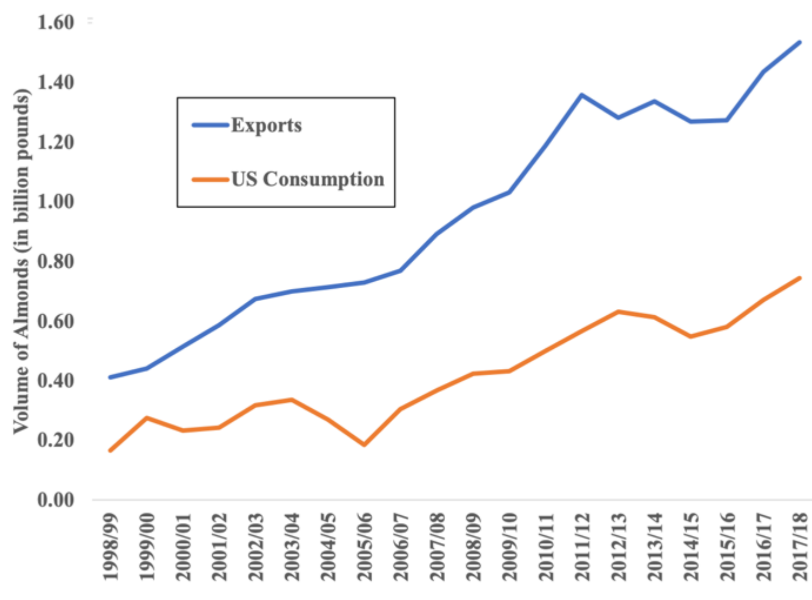
Nut production and consumption have been increasing in the CV because of their rising demand in the global markets and the U.S itself. For instance, Figs 4 and 5 show that the annual U.S. per capita consumption of tree nuts and its exports from 1998/99 to 2018 has been growing steadily. The graph strongly suggests that nut production has been high due to growth in their exports and domestic consumption. Fig 4 shows that from 1998/99 to 2017/18, the volume of almond export (in billions of pounds) increased by ~120% [(1.60 – 0.40)/0.40*100].



Source: USDA ERS Fruit and Tree Nut Yearbook

Fig 4. Annual U.S. Per Capita Consumption of Tree Nuts,

1998/99 to 2017/18 (Summer 2022)



Source: USDA ERS Fruit and Tree Nut Yearbook

Fig 5. Comparison of Annual California Almond Utilization between

Exports and Domestic Consumption, 1998/99-2017/18

Nut Production and Water Issues

In the CV, almonds, pistachios, and walnut acreage have increased, and yields and value began increasing in the 1960s (Udal et al. 2017). For instance, almond cultivation increased from 510k to 870k acres between 1960 and 2000, and in 2000, the CV produced 703 million pounds of almonds. By 2014, production was over 1.8 billion pounds, an almost 260 percent increase since 2000. In 2000, the total value of CV-grown California almonds was $666 million. Fourteen years later, it had increased by 900% to almost $6 billion (Udal et al. 2017). The same story holds for pistachios and walnuts. In 2000, there were 74.6k acres of pistachios producing 243 million pounds with a total value of $245 million. By 2014, acreage nearly tripled to 221k, and the production was more than 514 million pounds, with the total value reaching almost $1.6 billion, a 6.5-fold increase (CDA 2015). For walnuts, acreage steadily increased from 102.9k in 1920 to 200k in 2000. It took nearly 80 years for an increase of almost 100,000 acres. However, from 2000 to 2014, the acreage increased by another 90k. Production more than doubled from 478 million pounds to 1,140 million pounds. During the same period, the total value increase has been dramatic: $286 million to $1.8 billion, a 630 percent increase (CDA 2015).

In 2014, during the height of 2012-2016 California drought, the water use of almonds was widely discussed. Headlines from prominent news sources read “It Takes How Much Water to Grown an Almond?!” (Hamblin 2014), “The Dark Side of Almond Use” (Hauter 2015), “Stop Water Abuse by the Almond and Pistachio Empire” (Park & Lurie 2014), and “Here's the Real Problem with Almonds” (Philpott & Lurie 2015). Furthermore, it was revealed that a single almond requires more than a gallon of water to grow (Udal et al. 2017), as do pistachios and walnuts. Despite knowing the facts, nut farmers used a significant amount of water during the drought. The reason was due to water affordability; the nut farmer could afford the high price of water in spot markets because the nut market was in high demand internationally, leading to an increase in their profits. However, when residential mandates on water conservation began, many argued that farmers of water-intensive crops like almonds should also conserve (Udal et al. 2017). For example, articles from The New York Times and the New Republic argued that exporting almonds was exporting water (Bittman 2015; Hamblin 2014; Park & Lurie 2014; Philpott & Lurie 2015). Therefore, if exporting nuts is exporting water, then the water exports from California are of critical concern to Californians because the State is already facing water shortages.

California has faced criticism from residents and politicians on the water use by the nut industry. Notably, the cases of drying wells have become frequent concerns for the locals whose livelihood has depended on those wells for years. For instance, groundwater overdraft from agricultural wells, usually deeper than the domestic wells, has impacted thousands of domestic wells (Pauloo et al. 2020). In addition, there are indirect consequences of groundwater overdraft, including land subsidence and infrastructure damage, harm to groundwater-dependent ecosystems, and economic losses from a more unreliable water supply (WaterInTheWest n.d). However, groundwater level change has yet to be studied with the change in acreages for nut production, especially after 2014 and post-drought. Studying the relationship between the increase in acreage and the impacts on groundwater level helps to understand whether we should continue growing water-intensive perennial tree nuts, primarily almonds, walnuts, and pistachios. This research paper, therefore, analyzes the relationship between crop acreage and groundwater levels for 2014, 2018, and 2022. It considers 2014 an essential starting year of study due to the rising concerns around droughts and water use by the nut industry. In addition, the SGMA (Sustainable Groundwater Management Act) was signed into law that year. 2018 is another crucial year of the study because the new landmark water conservation legislation was signed into law that year (California Department of Water Resources n.d.). The law primarily focuses on using water more efficiently, strengthening local drought resilience, and improving agricultural water use efficiency and drought planning. Significant is the fact that this 2018 legislation applies to the actions of DWR, the State Water Resources Control Board (State Water Board), and water suppliers. This breakdown of 2018-2022 will be beneficial for understanding the impacts of legislation on water uses over land acreage changes in the nut industry.

Data Analysis

In this project, I used two datasets to study the relationship between crop acreage and groundwater levels for 2014, 2018, and 2022. The first dataset includes the Statewide Crop Mapping, accessed via the California Natural Resource Agency (CNRA) website [https://data.cnra.ca.gov/dataset/statewide-crop-mapping]. The datasets are collected by the Department of Water Resources (DWR) throughout the state which uses this information to develop water use estimates for statewide and regional planning efforts, including water use projections, water use efficiency evaluation, groundwater model development, and water transfers (CNRA 2022). The datasets primarily include the different types of crops grown in the CV using remotely sensed imagery and associated analytical techniques. Datasets were downloaded for the years 2014, 2018, and 2022 in CSV file format from the CNRA website. The second dataset includes the Groundwater Level Changes, accessed via SGMA (Sustainable Groundwater Management Act) data viewer, [https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#gwlevels]. In the SGMA data viewer map services, I selected the datasets for underwater level changes in feet from 2014-2018 and 2018- spring 2022. The datasets were downloaded as shapefiles, later to be used in ArcGIS Pro for the data visualization.

Firstly, the Statewide Crop Mapping datasets were cleaned up, filtered, and analyzed using a data analysis approach, using Python Machine Learning libraries such as Pandas, NumPy, and Matplotlib. The Python libraries mentioned were a good fit for the study due to the large size of the datasets. For instance, each dataset for 2014, 2018, 2022 included massive data entries of > 400,000 each. The goal was to calculate the total acres of land used by these three nuts in the particular counties in a particular year in the Central Valley. I first filtered the data entries and created a data frame for almonds, walnuts, and pistachios by year. For instance, *almonds_2014* would only include almond data entries (i.e., county name, total acres used, etc.) for 2014, *walnuts_2014* would only include walnut data entries, and so on. Next, a dictionary was created within a class *Nuts_calculation*, and a method *get_acres_data*, was used in returning total amount of each nut in particular counties. I wrote the following Python class and method to calculate the total acres of land used by these three nuts in the particular counties in a particular year in the Central Valley (Fig 6).

```python
'''
Name: Anjan Rana Magar
Date_Created: Sun, Nov 6th, 2022
This code is designed to extract the required nuts data including only Almonds, Pistachios and Walnuts!
For the purpose of this project, only acres and the counties data are extracted from 3 datasets of year 2014,2018 and 2022, each having datapoints of >400,000.
'''

# installing pandas package to work on csv file and data sorting!

import pandas as pd


class Nuts_calculate:
    ''' A class that accepts the file and perform specified methods with it!'''

    def __init__(self, csv_file):
        ''' Read csv data and copy the data for backup! '''
        self.csv_file = csv_file
        self.read_data = pd.read_csv(self.csv_file)
        self.copy_data = self.read_data.copy()

    def find_percent_nuts(self, column, nuts_name):
        '''
        nuts_name accepts the name of only one nuts! out of almonds, pistachios and walnuts!
        Here the column is the column that has the data! only accepts one column!
        '''
        self.nuts_name = nuts_name
        self.nut_index_ls = []
        for i, value in enumerate(self.copy_data[column].head(len(self.copy_data))):
            if value == nuts_name:
                self.nut_index_ls.append(i)
        nut_num = len(self.nut_index_ls)
        total_entry = len(self.copy_data)
        self.percent_nuts = (nut_num / total_entry) * 100

        return self.nut_index_ls, self.percent_nuts

    def nuts_percent_info(self):
        ''' Based on whichever nuts is given in the find_percent_nuts, it gives the data back to the user, description! '''
        return f"{self.nuts_name} is {round(self.percent_nuts, 2)} percent out of 100."

    def make_new_df(self):
        ''' Make a new dataframe for a nuts!'''
        new_df = self.copy_data.loc[self.nut_index_ls]
        return new_df

    def drop_column(self, new_data_frame):
        ''' Get rid of unnecessary columns in dataframe!
        I need to revisit this but I am gonna use this for 2014 and 2016 data! '''
        self.new_data_frame = new_data_frame
        self.drop_ls = list(self.new_data_frame.columns)
        self.drop_column = self.new_data_frame.drop(columns=self.drop_ls[4:])
        self.final_df = self.drop_column.drop(columns=self.drop_ls[0])

        return self.final_df

    def get_acres_data(self, new_data_frame):
        ''' get acres based on the new dataframe provided!'''
        self.acre_counts = {}
        self.new_data_frame = new_data_frame
        for i, row in self.new_data_frame.iterrows():
            ''' this works for both 2014 and 2016 but not for 2018 and 2022 datasets! The bug is the
            'County' lowercase and Uppercase COUNTY in 2018 and 2022.which is solved using condition!'''
            if len(self.copy_data) > 400000:
                self.county = row['COUNTY']
                self.acres = row['ACRES']
            else:
                self.county = row['County']
                self.acres = row['Acres']
            try:
                self.acre_counts[self.county] += self.acres
            except KeyError:
                self.acre_counts[self.county] = self.acres

        ''' Organize the data into the datraframe and return it to the user!'''
        self.counties = []
        self.acres = []
        for key, value in self.acre_counts.items():
            self.counties.append(key)
            self.acres.append(round(value, 2))
        self.nut_data = {'County': self.counties, 'Acres': self.acres}
        self.nuts_df = pd.DataFrame(self.nut_data)

        return self.nuts_df.sort_values(by='County')


if __name__ == "__main__":
    main()
```

Fig.6 A python class that returns the total acres of land used

by particular nuts by County

Finally, the changes in the acres of land in each county used by all three nuts were calculated. Firstly, the datasets for the almonds, walnuts, and pistachios for the year 2014 were added to get the total acres used by nuts collectively that year. The same process was followed to calculate the total acres used by all three nuts in particular counties in 2018 and 2022. I wrote the following code to calculate the final change from 2014-2018 and 2018-2022 (Fig 7).

```python
'''
Name: Anjan Rana Magar
Date: Nov 15, 2022
A file that returns the change in total nuts acres by counties and years!'''

import numpy as np
import pandas as pd
import os

''' Reading the total nuts by county for 2014, 2018 and 2022 '''
read_nuts_2014 = pd.read_csv('Total_Nuts_2014_by_Counties_v2.csv')
read_nuts_2018 = pd.read_csv('Total_Nuts_2018_by_Counties_v2.csv')
read_nuts_2022 = pd.read_csv('Total_Nuts_2022_by_Counties_v2.csv')

'''Combine all three data frames and calculate the change! 2014-2018 and 2018-2022
the data is from 2014-2018-2022! '''

new_df_combine = pd.concat([read_nuts_2014, read_nuts_2018, read_nuts_2022], axis=1)
new_df_nuts_change = new_df_combine.drop(columns=[drop_column[0]], axis=0)
new_df_nuts_change.columns = ['County2014', 'Total_Nuts_Acrease_2014', 'County2018', 'Total_Nuts_Acrease_2018',
                              'County2022','Total_Nuts_Acrease_2014']
county_2014 = new_df_nuts_change['County2014'].values.tolist()
county_2018 = new_df_nuts_change['County2018'].values.tolist()
all_acres_2014 = new_df_nuts_change['Total_Nuts_Acrease_2014'].values.tolist()
all_acres_2018 = new_df_nuts_change['Total_Nuts_Acrease_2018'].values.tolist()

''' Calculate change for 2014-2018 '''
change_2014_18 = []
for i, county in enumerate(county_2018):
    try:
        index = county_2014.index(county)
        acres_2018 = all_acres_2018[i]
        acres_2014 = all_acres_2014[index]
        change = acres_2018 - acres_2014
        change_2014_18.append(change)
    except:
        change_2014_18.append('NA')

change_2014_to_18 = pd.DataFrame(list(zip(county_2018, change_2014_18)), columns=['County', 'Change 2014-2018'])
change_2014_to_18 = change_2014_to_18.sort_values(by='County')
''' Save the Change as a new dataframe!'''
# change_2014_to_18.to_csv('change2014-2018-allnuts-production.csv',encoding='utf-8')
''' Similar appraoch is used for the 2018-2022 year! '''
```

Fig. 7 A python file to calculate the change in nuts acreages from 2014-2018 and 2018-2022 by County

I calculated the change in acreage by subtracting the total nuts from 2014 from 2018 and 2018 from 2022, respectively. I then use matplotlib to visualize the results in graphs. In addition, the data was further exported into ArcGIS Pro for the map visualization. The final data from the Statewide Crop Mapping was exported as excel and joined with the county shapefile in ArcGIS Pro using the joining filed 'County' and "Table to Excel" geoprocessing toolbox.

Results

The overall production of almonds, walnuts, and pistachios has gradually increased since 2014

From 2014 to 2018 and again to 2022, total acreage for the three nuts increased in the CV, with almond acreage far exceeding the other two nuts combined. The total acres used by all three nuts combined in 2014 was approximately 1,841,000 (1.84 million acres) and in 2018 was 2, 216,000 (2.22 million acres). The total acres of land used for almond, walnut, and pistachio production in 2014, 2018, and spring of 2022 are given in Fig 8. In 2014, the total acres used by almonds in the CV was 1.13 million, which increased to 1.37 million in 2018, an additional 240,000 acres of land for almonds alone in four years. However, from 2018 to spring 2022, there was an increase of only 31,000 acres of land, only a 3.1% increase from previous years. Although walnuts and pistachios occupy less land in the CV compared to almonds, their acreage experienced a moderate increase from 2014 to 2018 and 2018 to 2022. For instance, between 2014 and 2018, walnut acreage expanded by more than 45,000 acres and an additional 12,000 acres from 2018 to 2022. However, pistachio acreage expanded by 91,000 acres from 2014 to 2018, twice the increase of walnuts and 19,000 acres from 2018-2022. In sum, production for all three nuts added a total of approximately 375,000 acres of land between 2014 and 2018 and another approximately 62,500 acres between 2018 and 2022. The total increase of acreage from 2014 to 2022 was roughly 438,000 acres.

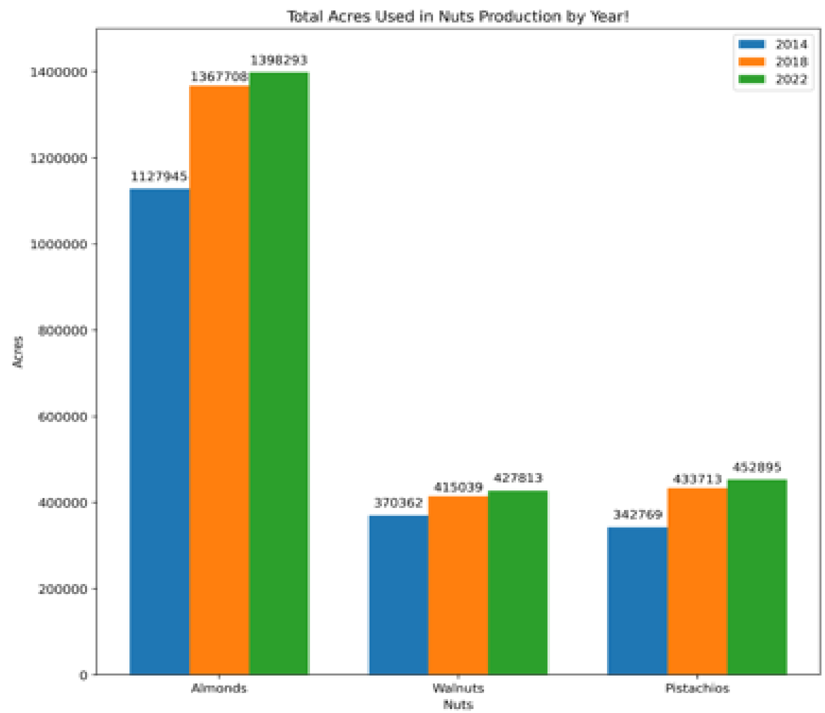


Fig 8. Total Acres of Land used for three nuts production in year 2014, 2018, and spring 2022 in the Central Valley

During the time analyzed, nut acreage increased much quicker from 2014 to 2018 than from the later time period 2018 to 2022. Fig 9 provides the county-level acreage changes under nut production from 2014 to2022. The change in acreage from 2014 to 2018 shows that all nineteen counties in the CV added significant land for nut production, with an average increase of ~ 20,000 acres. Kerns, Kings, Madera, Merced, San Joaquin, Stanislaus, Tulare, and Yolo added more than 20,000 acres, while Colusa, Glenn, Tehama, and Solano, had an increase of land of more than 10,000. Butte, Yuba, Sutter, Placer, and Sacramento had a slight increase of acreage under nut production of around 1000 acres, with the increase in Shasta amounting to just 100 acres. However, Fresno County added more than 80,000 acres of land during this period, four times the average. The acreages changes from 2018 to 2022 were ten times less, with an average increase of only 2000 acres as shown in Fig 10. Again, Fresno County added the most acres from 2018 to 2022, i.e., around 13,000. Kings, Kerns, Shasta, Solano, Sutter, and Tehama counties had acreage increases of more than 2000. However, Shasta County added 38 times more acreage from 2018 to 2022 period (i.e., 148 acres) than in 2014 to 2018, (i.e., 5782 acres). Nonetheless some counties, such as Butte, Madera, and Merced, lost up to 250 acres of land under nut production.

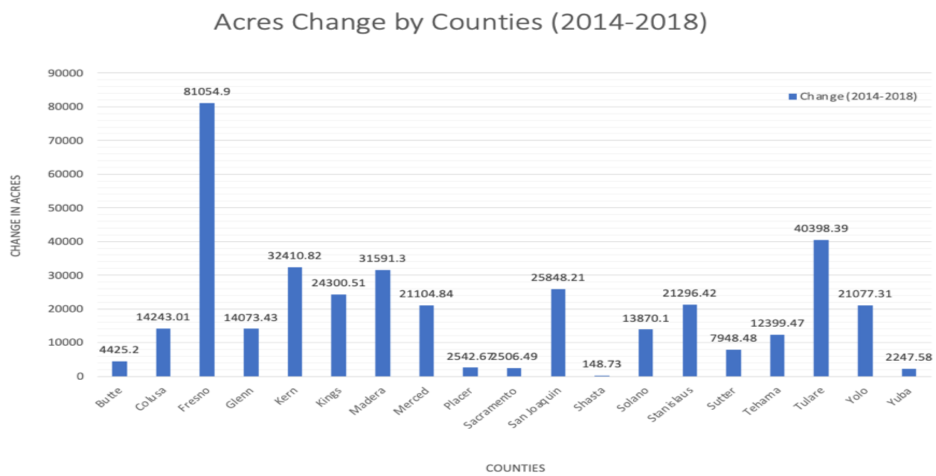


Fig 9. Change in Acreage by county from 2014 to2018

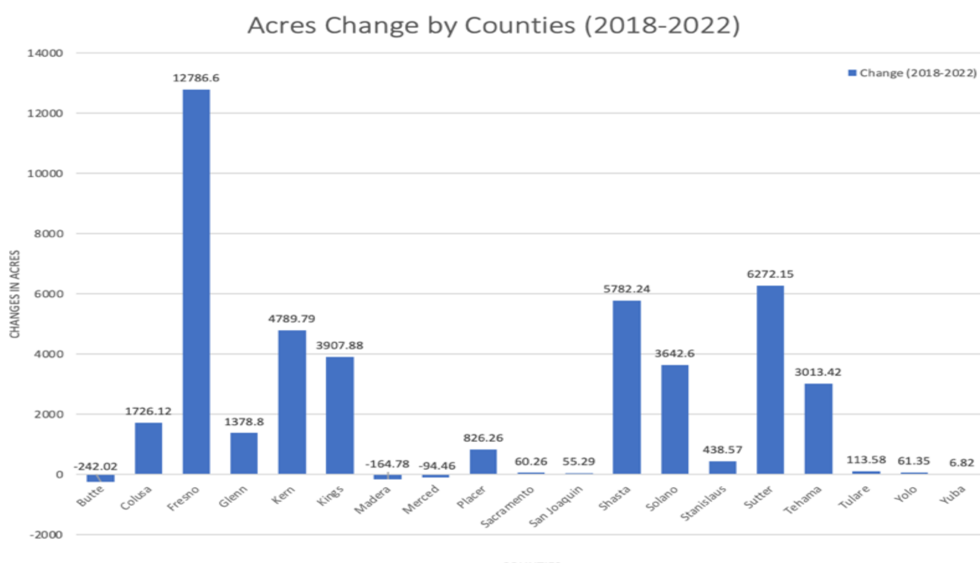


Fig 10. Change in Acreage by county from 2018 to 2022

The groundwater levels are decreasing since 2014

Both parts of the CV, the Sacramento Valley in the north and the San Joaquin Valley in the south, had a similar distribution of wells reporting increases and decreases in groundwater level, respectively, from 2014 to 2018. However, between 2018 and 2022, almost all wells reported a groundwater level decrease in the entire CV. The groundwater change from 2014 to 2018 shows that Sacramento Valley had a more significant number of wells reporting an increase in groundwater level by 1 and 10 ft. The map in (Fig 11) displays those counties. The counties with a significant increase in groundwater levels include Yuba, Sacramento, Placer, Sutter, and Butte. However, the groundwater change during the same period shows that the southern part of the CV, the San Joaquin valley, had a more significant number of wells reporting a decrease in groundwater level by 2.5 to 10 ft. The counties in or close to this valley with a decrease in groundwater level include Kings, Kerns, Bakersfield, Tulare, and Fresno.

From 2018 to 2022, almost all the counties experienced a drastic decrease in groundwater levels. Fig 12 shows the Sacramento and the San Joaquin Valleys, with most wells reporting a decrease in groundwater less than 2.5 and 10 ft. Compared to 2014-2018, the counties in the north, including Tehama, Glenn, Butte, Colusa, Sutter, Yuba, and Yolo, showed a drastic decrease in groundwater level. Nonetheless, the counties in the San Joaquin Valley, especially Fresno, Kings, Tulare, Kern, Merced, and Stanislaus, showed even larger decrease in the groundwater level.

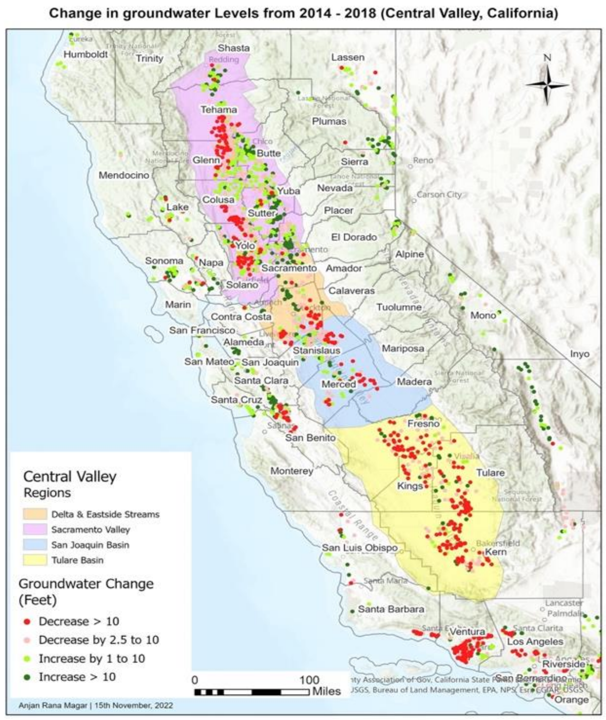


Fig 11. Groundwater level change from 2014 −2018 in the CV

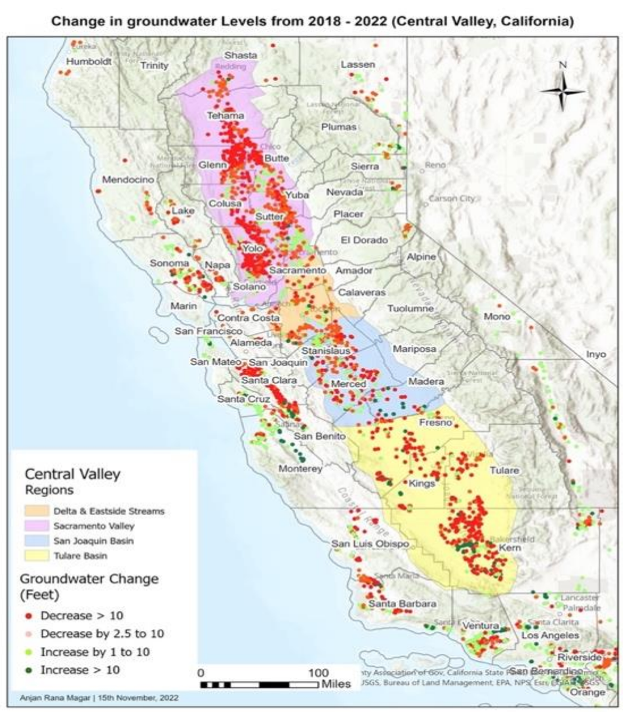


Fig 12. Groundwater level change from 2018 −2022 in the CV

The 2014 to 2018 map analysis reveals a significant correlation between nut acreage and groundwater level

As acreages increased, groundwater levels decreased significantly ($R^2 = 0.7$). A massive increase in agricultural land use for nuts occurred during 2014 to 2018 in the Central Valley. Almost all the counties added more than 9000 acres of agricultural land during this period. These counties include Kern, Tulare, Kings, Fresno, Madera, Merced, Stanislaus, San Joaquin, Solano, Sacramento, Yolo, Colusa, Glenn, Tehama, etc. For instance, Fresno alone had an increase of 81,000 acres, Tulare ~ 40,000 acres, Kern ~ 32,000 acres, Madera ~ 31,000 acres, and San Joaquin, Kings, Stanislaus, Merced, and Yolo ~ 20,000 acres (each) in this time. Consequently, most of the counties with massive acreage increases have shown to have decreased underwater levels in that period. For instance, Fig 13 shows that counties such as Fresno, Tulare, Kern, San Joaquin, Kinds, Yolo, Merced, and Stanislaus, which increased productive land by more than 20,000 acres also have numerous red data points which represent the decrease in groundwater levels by more than 10ft. The scatter plot and linear regression analysis on the relations between the groundwater level change and the increase in nuts acreage further provide significant results (Fig 14). The analysis's R-square value (after removing outliers) is found to be 0.70, statistically very significant, showing a high-level correlation. The outliers Fresno and Madera were removed from the data analysis because Fresno’s acres were four times the average acres for counties (extremely higher), and Madera’s average groundwater change was -30, which was seven times the average groundwater change.

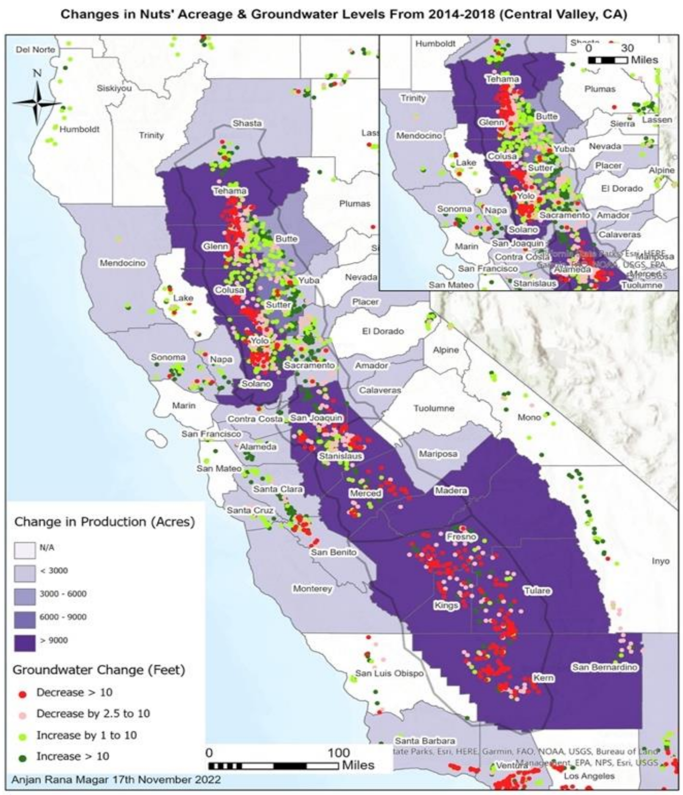


Fig 13. Changes in the acres of land used by nuts and underwater levels in 2014-2018

	County2014_2018	Acres_Change	Groundwater_Change
0	Butte	4425.20	0.79
1	Colusa	14243.01	-4.68
2	Fresno	81054.90	-10.56
3	Glenn	14073.43	-5.66
4	Kern	32410.82	-6.74
5	Kings	24300.51	8.15
6	Madera	31591.30	-30.00
7	Merced	21104.84	0.19
8	Placer	2542.67	0.64
9	Sacramento	2506.49	1.28
10	San Joaquin	25848.21	-9.21
11	Solano	13870.10	-4.04
12	Stanislaus	21296.42	-4.89
13	Sutter	7948.48	1.52
14	Tehama	12399.47	-4.61
15	Tulare	40398.39	-9.13
16	Yolo	21077.31	-3.63
17	Yuba	2247.58	4.30

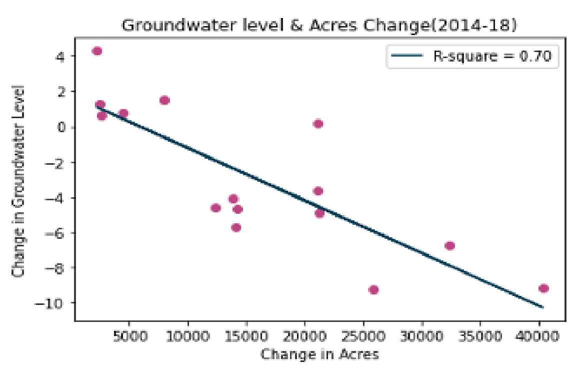


Fig 14. A table and chart showing the correlations between groundwater change of counties in the CV with an increase of 1,000 acres.

The 2018 to 2022 map analysis, however, shows no correlations between nut production and ground water levels

Unlike 2014-2018, the 2018-2022 map (Fig 15) shows less increase in agricultural land used for nut production. For instance, only two counties added another 9,000 acres for nuts production. Fresno added another 12,000 acres. Furthermore, three other counties, Sutter, Mariposa, and Shasta, added approximately 5000 acres, while Kern and King added ~ 4000 acres each. The groundwater level, however, decreased drastically despite the slow increase in agricultural land. Fresno county, for example, had the highest increase in acres and groundwater change compared to every other county. Unlike the 2014-2018 data analysis, the scatter plot and linear regression analysis on the relations between the groundwater level change and the increase in nuts acreage show no correlations (Fig 16). The R-square value is 0.02, statistically insignificant, showing no relationship.

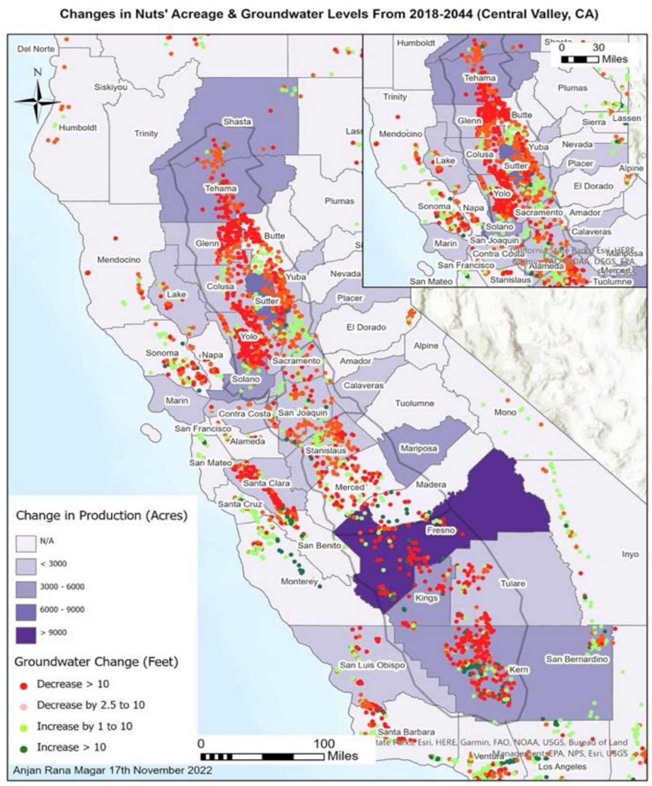


Fig 15. Changes in the acres of land used by nuts

and underwater levels in 2014-2018

	County2018_2022	Acres_Change	Groundwater_Change
0	Colusa	1726.12	-11.255797
1	Fresno	12786.60	-21.586846
2	Glenn	1378.80	-22.734136
3	Kern	4789.79	-13.277788
4	Kings	3907.88	-23.021304
5	Placer	826.26	-0.251043
6	Riverside	9159.24	3.146028
7	Sacramento	60.00	-3.440000
8	San Joaquin	55.00	-3.350000
9	San Luis Obispo	2970.19	-10.049649
10	Shasta	5782.24	-4.171111
11	Solano	3642.60	-16.088261
12	Stanislaus	438.57	-6.805550
13	Sutter	6272.15	-7.549228
14	Tehama	3013.42	-16.949500
15	Tulare	113.58	-17.986164
16	Yolo	61.35	-18.790000

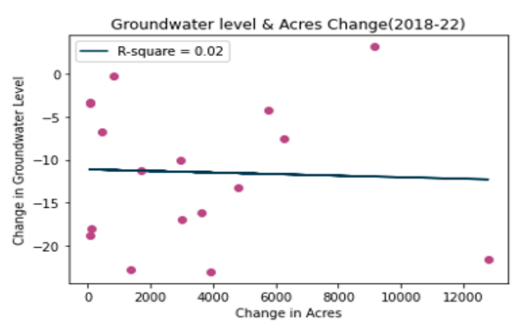


Fig 16. A table and chart showing the correlations between groundwater

change of counties in the CV with an increase of 50 acres.

Discussions

This study demonstrates that despite the recent drought of 2012-2016 and the 2014 rising public's concern over the water used by the nuts industry, nuts production in the CV has increased, affecting groundwater significantly. The main findings from my study are: (1) there was a significant increase in the acreage used for nut production in the CV from 2014 to 2018. However, just a slight increase in acreage for nut production was found from 2018 to 2022; (2) from 2014 to 2018, there was an increase in the groundwater level in the northern part of the CV, i.e., Sacramento Valley, and a decrease in the groundwater level in the southern CV, especially the San Joaquin Valley. However, from 2018 to 2022, the entire CV recorded a decrease in groundwater; and (3) a significant correlation was observed between the decrease in groundwater and the increase in the acreage for nuts production in the 2014-2018 time period indicating that the increase in nut production could further lead to a decrease in groundwater level.

Despite the significant drought affecting the CV and the public's concern over water scarcity, the nut industry kept increasing the land acreage for its production. For instance, the total land in 2014, which was 1.83 million acres, increased by 375,000 (i.e., a 20% increase in land). Two possible explanations help to validate the finding of why there was such an increase in nut production. First, the global market for nuts is growing. Second, there is lack of water regulations and investment firms are gaining control over water distribution.

Strong Global Markets

The boom in the nut industry, primarily almonds, then walnuts and pistachios, has given global markets more power than California residents. The rising demand for these nuts (especially almonds) came from abroad and has accelerated most dramatically in Asian and European countries such as China (E Reisman 2021) and India, Spain, Germany, and the United Arab Emirates (USDA Data Products 2022). In the USDA data products ranking, three countries from Asia hold the top five U.S. export destinations in the last four years, from 2018-2022. India ranks itself first with a share of 21.5% of U.S. export destinations by almonds volume; UAE is in the fourth rank with a share of 5.4%; however, China's ranks have fallen to being the fifth importer of U.S. almonds by volume (USDA Data Products 2022). During the drought in 2014, BBC reported, "Nearly 70% of the almonds produced in California are for export. And where do most of them end up? China. This does little to quell criticism that the Chinese – with their booming economy – may soon, quite literally, be sucking this place dry" (Willis 2014). Similarly, one television transcript began, "Asia's love for nuts is draining California dry" (NBC 2014). After understanding the Nut industry and water use issues at home, shipping these well-watered almonds overseas amid drought has looked idiotic to Californians. It might be because they are not engaged directly in agricultural industries and are mainly unaware of the deep reliance of American agriculture on exports to absorb surpluses (Winders 2009). However, nut production companies are still active role in fulfilling the global market demand.

The Almond Board of California is a company established in 1950 which engages in the production, nutrition, and market research; advertising and promotion in domestic and international markets; and quality control and statistical analysis of California's Almonds (California Almonds n.d). The company's mission reads, "Expand global consumption of California almonds through leadership in strategic market development, innovative research, and the accelerated adoption of industry best practices." As mentioned in their mission, even during the drought period, the board worked persistently to introduce and expand the Chinese consumption of almonds through advertising and trade negotiations (E Reisman 2021). Due to the global market demands, exported almonds has acted as a loss of control over water resources for Californians engaged in the almond debate. Moreover, rising wealth in India, China, and other countries in the future and their willingness to pay for exotic foods means the global markets might have more power over California's water use than most Californians (E Reisman 2021). Mainly, those historically disempowered become more vulnerable. For instance, in response to prioritizing irrigation supplies over river flows for salmon, a Klammath River Yoruk tribe member lamented, "Not only are they asking the Native Americans to sacrifice their culture, but we're doing it so we can sell almonds to the Chinese"(Bland 2014). Since water means a livelihood and is part of the culture and community development of many tribes in California, it cannot easily be detached from history, land, and livelihoods. Since 2014 and post-drought 2012-2016, the increase in market demands has created underlying tension between the global market power and governance, suggesting that global market forces played a major role in affecting the state's water (E Reisman 2021).

Although the global market plays a prominent role in the rise in nut production, blaming countries such as India, China, Spain, or UAE for California's water scarcity is not a reasonable solution. We must also look into the U.S. capitalist structure. For example, the concentration of power by investment firms, agricultural investors, and agricultural tycoons profiting off the nut industry helps us understand the issue further.

Concentrations of Agricultural Investors and Water Distribution

The rise of investment firms, agricultural investors, and agricultural tycoons seeking to profit in nut production has revealed the water politics played in the CV water distribution. Likewise, rising interest of Agricultural investors in nut production has led to an increase in acreage for growing nuts despite more frequent droughts.

The dominance of the nut industry by domestic investors and big firms has helped the nut industry blossom. It was not only the global demand and trendiness of these nuts in foreign destinations that encouraged the massive nut production in the CV. The boom in the nut industry confirmed the predominance of agricultural tycoons and investment firms. Politicususa (2015) writes, "A relatively large amount of California's dwindling water supply goes to large corporate farms growing and expanding by tens-of-thousands of acres, water-intensive nut trees; primarily profitable almond trees" (Rmuse 2015). For instance, Wonderful Orchards and Paramount Farms are among the largest almond-growing corporations in California, owned by Stuart and Lynda Resnick. The corporation has been highly criticized, and Californians found its great wealth and political power disturbing (Huffpost 2015). In response to Resnick and his almond-growing corporation, Scow and Hauter wrote that these "Beverly-Hills billionaires…raking in profits" (Scow and Hauter 2015) are known for their "sprawling agricultural holdings, controversial water dealings, and millions of dollars in campaign contributions to high-powered California politicians" (Hertsgaard 2015). Accordingly, lobbying politicians and playing the dirty game of water politics have helped corporations’ profits.

The power embodied by giant corporations has successfully diverted and tilted the water distribution in their industry's favor. For instance, Monterey Plus Amendment, which effectively put the publicly subsidized Kern County Water Bank under the Resnicks' private control, was emphasized by many reporters (Felde and Novak 2014; Krieger 2014). Resnick's company was accused of touting their profits from water control and was even met with protests at their Los Angeles office, where demonstrators held signs reading "More Resnick Almonds = Less H20 for CA" (Gumbel, 2015). According to Sorvino (2021), Resnick's company created an expansive farming operation with a sweetheart deal that gave them access to the Kern Bank. Sorvino further claims, "In 1994, some of Stewart Resnick's most trusted advisors met with several leaders from southern California water districts and state water officials to broker negotiations in what some critics have called secret meetings." Thus, more than any other crop at the time, the nut industry has embodied agribusiness giants' unchecked power to tilt water distribution in their favor.

At present, Blue Diamond Growers is the world's largest almond processing and marketing company. It is headquartered in Sacramento, California, and owned by half of the state's almond growers, who produce over 80 percent of the world's almond supply. In response to the previous drought, Blue Diamond educated its farmers through industry notes and explained why water shortages were a problem that needed to be addressed (Harvard 2017). In the long-term, Blue Diamond has committed to "collaborating with industry peers, water and environmental experts, consumer groups, regulatory bodies and policy-makers to address several key factors to combat water shortage" (Blue Diamond Growers 2017). However, California's water shortage is alarming, mainly because the nut industry has become a new attraction for a new group of agricultural company investors.

The new investors' interest in profiting from nut production (almonds, walnuts, and pistachios) explains my study's significant increase in acreage from 2014 to 2022. The acreage for nut production increased because new suites of companies bought many existing and new farmlands and converted them to grow nuts, especially almonds. For instance, the Terrapin Fabbri Management "bought a dairy company and some vineyards and tomato fields in

California, and converted all to grow almonds, whose price has soared as the international demand from India, China, UAE, and Spain have gone nuts for them" (Philpott and Lurie 2015). John Hancock Agricultural Investment Group 2010 bought the 12,000-acre Triangle T Ranch of Los Banos and converted it to an almond farm. Moreover, Trinitas Partners, a Silicon Valley-based private equity firm, turned 6,500 acres of rugged eastern Stanislaus County land from grazing to almonds (L. Krieger 2014). These examples align well with my study's finding of acreage increase for the nut production. So, what enabled the growth of these nuts despite the drought causing surface water shortages? The answer is groundwater pumping. In the next section, the paper explores the reliance of the nut industry on groundwater, the correlations between acreage increase and groundwater depletion found in this study, and finally, the impacts of groundwater depletion in California.

Groundwater Depletion with Increase in Nut Acreage

California groundwater is being depleted at an unimaginable rate. The finding from this study indicates that groundwater depletion has been increasing at a higher rate from 2014 onward. This is very concerning because that means more Californians are facing the harsh reality of water shortages. Moreover, the increase in the acreage of the nut industry, as shown by this study, during two time periods, 2014- 2018 and later to 2022, indicates that a massive volume of water is used in growing them. More importantly, because the state is already facing shortages in surface water, groundwater is the only plausible alternative that could help the industry's thriving nuts production. Therefore, the finding from the study, including the statistically significant correlation of 0.70 between nut acreage increase and groundwater level decrease (Fig 14), suggests the role of the nut industry in over-drafting the aquifers, aqueducts, and California's other groundwater resources.

Previous studies on groundwater loss in California's CV suggest that the over-drafting or over-pumping of groundwater resources has caused a decline in the groundwater level. In their study, Ojha et al. found that the accelerated rate of decline in groundwater levels across CV resulted from over-drafting and low rates of natural recharge and is aggravated by droughts (Ojha 2018). Their study confirmed that the aquifer system during 2007–2010, when the entire valley experienced a severe drought, lost ~2% of total aquifer-system storage permanently, owing to irreversible compaction of the system. Furthermore, they reported that the seasonal groundwater storage change amplitude of 10.11 ± 2.5 km3 modulates a long-term groundwater storage decline of 21.32 ± 7.2 km3 during 2007-2010. F. Levy et al. (2021) did a similar study where they studied the critical aquifer overdraft and its role in the degradations of groundwater quality in California's Central Valley. They found that high vertical-flux rates from intensive irrigation and pumpage drive the relationships between overdraft and water quality in the Central Valley (Levy 2021).

This study's findings align with the previous studies' findings about the relationship between acreage increase in nut production and groundwater change. Gebremicheal et al. did a similar study that found that during the drought period, at the Central Valley level, from 2007 to 2016, acreage of tree nuts (almonds, walnuts, and pistachios) grew by 371,000 ha(hectares) (+ 64%), which resulted in the substantial drawdown of groundwater up to 30m in some southern parts of Central Valley. A similar result was found in this study; for example, from 2016-2018, the counties in the south, such as Kings, Kerns, Fresno, and Tulare, shown in Fig 16, were found to have the greatest decrease in groundwater level. Although the findings were in the later year after the drought, the results suggest that the groundwater, when permanently lost, is hard to recharge again. Although the findings from this study showed an increase in the groundwater level in the Sacramento Valley's counties, such as Butte, Sutter, and Yuba, the average change (i.e., ~5 ft) still showed a decrease in water level from 2014-2018. For example, Butte had a slight increase of ~1ft, Sutter ~2 ft, and Yuba of ~4.5 ft, as shown in Fig 14. The average change in the groundwater from 2018 to 2022 was ~ -12 ft, in addition to the previous ~ -4.5 ft decline. However, the 2018-2022 data analysis did not show statistically significant correlations. The possible reason could be that fewer acres of land increased during this time, and all the counties experienced drought all at once, resulting in groundwater decrease irrespective of tiny/large acreage increase. For instance, Yolo County in 2014-2018 had an average water decrease of 3.63 ft with 21,000 acres of land increase, which in 2018-2022 only added a few acres, and experienced a -18.79 ft decrease in groundwater. Similarly, suggesting an overall depletion of the groundwater for almost all counties without following any pattern with an increase in nut acreage.

The R-square value calculated for 2014-2018 has established a significant correlation between the acreage increase and the groundwater decrease, highlighting this study's importance. Although various factors affect the groundwater level change, such as precipitation and droughts, the results have shown a solid correlation, indicating that the increasing nut production could further drive the groundwater shortages in the CV. This finding is significant for California's groundwater management.

Conclusions

This paper focused on nut production in the CV and highlighted the people's concern over water use by the nut industry. Almonds, walnuts, and pistachios are three perennials tree nuts whose global markets have been soaring in the past decades. Farmers and big corporations have been growing these nuts in the CV, where the land is dry, to make huge profits from the soaring markets. However, the main issue is the water shortages and the fact that this massive acreage of land is being converted and expanded to grow these high-water-intensive tree nuts. In growing these trees, lots of groundwater has been overdrawn, which has caused groundwater depletion and further water shortages.

This study uncovered that nut production has been expanding gradually, suggesting that the nut industry is still favored in central valley agribusiness due to its economic values. Furthermore, the study found that groundwater has been depleting at a dramatic rate, especially since 2014. Finally, the significant correlations (R-square = 0.70) between the acreage increase and the groundwater decrease from 2014 to 2018 have implied that the further increase in acreage could further decrease the groundwater leading to severe water shortages. Thus, strong water management legislation and a sustainable water framework are needed.

Although this study finds that groundwater depletion is caused due to overdrafting of the groundwater, especially by the nut industry, it does not claim that the nut industry is the sole actor in the issue. Future studies should also be conducted on other high and medium water-intensive crops such as alfalfa and fruits such as grapefruit, lemons, oranges, dates, avocados, and olives. It helps us understand the CV's overall pictures of water use and distribution.

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