An Analysis of Water Quality at Orange County, California Beaches

Naomi Meurice
Pomona College

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An Analysis of Water Quality at Orange County, California Beaches
Naomi Meurice

In partial fulfillment of a Bachelor of Arts Degree in Environmental Analysis,
2022-23 academic year
Pomona College
Claremont, California

Advisors:
Professor Charlotte Chang
Professor Char Miller
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Acknowledgments

I would like to thank my amazing readers and advisors, Professor Charlotte Chang and Professor Char Miller, for their help and guidance throughout the process of writing this thesis. Professor Chang, our weekly meetings were invaluable - thank you for all the advice you provided, your help with my code, and for all that you shared with me about environmental research processes. Char Miller, thank you for the much needed comments on my drafts and for sharing much of your knowledge about Southern California water.

I would also like to thank Professor Jo Hardin for her help with the data analysis I performed for this project. Thank you, Prof. Hardin, for always being able to help me turn concepts into code. I am very grateful for your continued willingness to help.

Lastly, I would like to thank all of my friends and family, who have supported me through the semester and the last several years, and who have let me geek out about water quality and beaches.
Abstract

Beaches in Southern California are highly recreated by residents and visitors, making beaches socially and economically important. Public health departments in coastal communities are in charge of measuring water quality and ensuring it is safe for users. Research in the past has indicated that beach water quality gets worse after storms, with bacteria levels jumping on the day of a storm and staying high for up to five days. Studies have shown these spikes in bacteria to be associated with storm runoff, with beaches closer to runoff discharge locations experiencing more impact. However, prior research has not considered the period of dryness before a rain event and how that may impact beach water quality. For this research, I analyzed the impacts of the number of days without rain prior to a rain event, to see if this period of dryness influences the water quality for the day that it rains and the following five days. I performed a multiple linear regression to assess the relationship between water quality and days without rain, days since rain, and beach location, and found all three variables of interest to be statistically significant. Bacterial levels reach their peak on the day that it rains, and drop as time goes on. Following a longer period of dryness, bacterial levels after a rain event start higher, and thus take longer to reduce to safe levels. Given this information, coastal public health departments should automatically post signage following rain events that are preceded by long dry periods, which informs beach-goers that the water is likely unsafe to enter. In addition, county officials should consider potential projects to limit the amount of untreated stormwater that flows into the ocean. These projects could include stormwater capture or the treatment of water before discharging into the ocean.
Introduction

California is known for its Pacific coastline, which spans all 840 miles of its western border. Particularly in Southern California, where warmer summer temperatures help heat up coastal waters, people can be found swimming, surfing, snorkeling, scuba diving, and fishing in these waters year-round. Because of this high recreational usage, it is necessary for state and private organizations invested in public health and safety to regularly measure water quality at California beaches. State and federal legislation require water quality monitoring for these waters, meaning there is daily and weekly testing from government organizations, as well as unofficially by private organizations and NGOs.

This study focuses on Orange County, California (OC), a coastal California region located between Los Angeles County and San Diego County. Several large cities, such as Irvine, Santa Ana, and Anaheim, as well as heavily visited beach towns such as Laguna, Huntington, and Newport Beaches, are encompassed in this area. Three major rivers, the Los Angeles, the San Gabriel, and the Santa Ana, discharge into OC beaches, or approximately 20 miles away into nearby Los Angeles County beaches, all of which are in the San Pedro Bay. These three rivers are all channelized to some degree, meaning water traveling through the river stays in the concrete infrastructure instead of connecting back with the floodplain, as it is unable to permeate into the natural environment (US EPA Office of Water Recovery, 2011). If the river is channelized up until the ocean, it is discharged at the beaches or directly into the water. The Orange County Health Care Agency (OCHCA), a sector of the county’s local government, provides measurements of water quality at these points of discharge, as well as at other popular beach locations along the Orange County coastline. As part of the OCHCA Ocean Water Protection Program, which follows national water quality testing requirements, bacterial measurements (fecal coliforms, enterococcus, and total coliforms) are taken weekly at over 150
beaches in OC and are reported on their website dashboard for public reference (https://ocbeachinfo.com/).

While OC has over three million residents, neighboring LA County is home to around 10 million people. Due to the close proximity of residential communities to these beaches, human activities, such as leaving trash or dog waste on streets, or adding additional fertilizer to lawns, lead to pollution of coastal regions after precipitation events, which wash many of these substances to the ocean. Because watersheds and beaches are connected across Southern California, these 13 million people collectively impact the water quality of beaches in Orange County. Due to high population density and development levels, large parts of Orange County are paved, preventing water from permeating into the ground after precipitation events. In addition, many of the major rivers in the area are channelized, which further prevents water from seeping into the natural environment. When precipitation does occur, pollutants that have gathered on the roads - oils, nitrates, sediments, pesticides, and harmful bacteria - can be washed off and sent into channelized rivers and carried straight into the ocean, with no connection to the sewage system. This makes swimming after rain more dangerous: researchers in Santa Monica, CA in 2003 found that bacteria concentrations in the water stayed high for 5 days after rainfall occurred (Ackerman & Weisberg, 2003). Similarly, researchers in Orange County found that beaches closer to river discharge points have higher levels of bacteria (Dwight et al., 2002). These types of bacteria in water have been associated with higher rates of upper respiratory and gastrointestinal symptoms, as well as skin illnesses (Haile et al., 1999). Potential anthropogenic sources of these bacteria include municipal effluent, sewage system and storm runoff, boat discharge, and human activities in and around the water (Halliday & Gast, 2011). In addition, dogs, birds, and other animal life around beaches can produce fecal waste, potentially adding bacteria to the water.

While there have been several studies focusing on precipitation levels in the Southern California area that indicate higher levels of bacteria in the ocean following precipitation events
ACKERMAN & WEISBERG, 2003; DWIGHT ET AL., 2002, 2011; NOBLE ET AL., 2003), there is no known research conducted regarding the time between precipitation events and its impact on water quality. This research paper analyzes whether the period of dryness before a precipitation event influences marine enterococcus, fecal coliform, and total coliform levels at Southern California beaches following rain. These bacterial indicators can be informative of the relative level of bacteria in water, and thus, the potential public health impacts related to human contact with this contaminated water. This paper draws on water quality data from the Orange County Health Care Agency and pairs these data with Weather.gov daily precipitation levels, to determine whether the number of days between rain events impacts water quality after precipitation occurs. For this project, I am trying to answer the question of whether the number of days in between rain events significantly impacts water quality at beaches once it does rain. I hypothesize that water quality after rain will be worse the longer the period is without rain prior to that precipitation event.

The goal of this paper is to analyze water quality at Southern California beaches for several reasons. The first is to assess the factors that influence water quality at these beaches, which will help to determine what environmental conditions may lead to poor and unsafe water conditions. In addition, I am also hoping to identify which beaches are most frequently exceeding state standards to determine locations of interest. Knowing these environmental factors and these locations, I can then consider how humans may be contributing to the significance of these environmental conditions, and can also consider how future anthropogenic changes to the earth and climate might exacerbate or reduce these conditions that produce poor water quality. With more information on what environmental and human factors lead to unsafe water, public health departments can produce models that are better able to assess when water may be contaminated, and can help to determine human sources or causes to these conditions. With this information, I can then assess what potential solutions can be put in
place to limit future impacts on beach water quality, and attempt to determine how prior contaminants can be cleaned up.

Because water quality is only monitored on a weekly basis, it can take several days after a rain event for a beach to be tested. For this reason, it is important for the public health agencies in charge of posting warnings and closing beaches to be aware of what environmental factors are likely to cause unsafe water quality. In determining whether the number of days without rain impacts beach water quality, coastal public health agencies can make a more informed decision as to when to close beaches. These analyses are all done with the hopes of limiting negative human health impacts associated with swimming in contaminated water.

Given the knowledge that storm runoff into oceans can lead to spikes in water bacterial levels, there are several solutions to limit these impacts. Officials should first consider ways to limit the inflow of urban and storm runoff into the ocean. This could include using the established sewage systems to treat water, or establishing new treatment facilities. Treated water could then be used as supply to Orange County residents or could be used to recharge groundwater storage basins. It could also entail the establishment of rainwater capture devices, either on individual homes or at a large scale. This capture would allow homeowners to use this captured water instead of sourcing it through municipal lines. These practices would alleviate pressure on local water stores, while also helping to reduce instances of poor beach water quality. If capturing water is not possible, Orange County Sanitation should at least consider ways to treat storm runoff to some degree before it drains into the ocean.

As the climactic patterns change due to global warming, Orange County is projected to see longer periods between rain events and more intense storms when it does rain. As these variables continue to change, the county may need to consider different responses to maintain safe beach water quality. Setting up systems now for rainwater capture and treatment may be beneficial for years to come, as we see continued climate and weather changes.
Background Information on Orange County, California

Rivers and Rain in Orange County

For this thesis, I focus on beach water quality at Orange County, California beaches. Using a map produced by the Santa Ana Watershed Project Authority, I was able to determine what beaches are downstream of the Santa Ana River, the San Diego Creek, and the Newport Bay. This map indicated that beaches between Seal Beach and Corona del Mar are impacted by these three water sources, making this region my area of study.

Figure 1. Map of the Santa Ana River Watershed, which is shaded in. This included the entirety of the Newport Bay and Beach area, as well as the first reach of the Santa Ana River, the region of interest for this study (Santa Ana Watershed Project Authority, n.d.).
The Santa Ana River, one of the LA area’s three major rivers, discharges into the Pacific Ocean in Orange County. The river begins in San Bernardino County, in a valley between Sugarloaf Mountain and San Gorgonio Mountain. Snow covers these mountains in the winter, but as temperatures rise in the spring and summer months, ice turns to water, and snow turns to rain. Water flows down the mountains and into the Santa Ana River, and is carried west, following the valley floor. It travels for about 15 miles before reaching its junction with Bear Creek (CalFish, n.d.). Bear Creek originates at Big Bear Lake, a popular destination for lake activities in the warmer months and skiing in the cooler months. The river continues by traveling southwest, and eventually reaches the Seven Oaks Dam, which has the capacity to impound 145,600 acre-feet of water. Water released exits the mountains and begins its path through the greater LA county area, where much of the river becomes channelized. It first travels through San Bernardino County, then through Riverside County before reaching the Prado Dam. The Prado Dam is a 362,000 acre-foot capacity dam-and-reservoir complex located on the western edge of Riverside County, and just east of Chino Hills State Park. Built in the late 1930s by the US Army Corps of Engineers for flood risk management, the dam is just 30 miles away from the Pacific Ocean, and protects millions of downstream Orange County residents that were previously susceptible to flooding (Water Education Foundation, n.d.).

While flooding is of concern during wet months, Orange County is a fairly dry region, with total precipitation levels over the past 22 years has averaged at 11.22 inches annually. Precipitation generally follows a similar pattern each year, with rainfall increasing December-March, and dropping off to almost no rain during the summer months (June-September). From 1900-2000, annual precipitation averaged at 13.52 inches (National Oceanic and Atmospheric Administration, 2022). Thus, the last two decades have been lower than the century before, potentially indicating a trend of less annual precipitation in recent years.

Following heavy rain events in winter months, water from the San Jacinto River ends up in Lake Elsinore, a reservoir located west of the Santa Ana Mountains, just outside Orange
County. When it rains enough, the lake overflows into Temescal Creek, which flows into the Santa Ana River at a junction right before the Prado Dam (Santa Ana Regional Water Quality Control Board, 2018).

Just after leaving the dam, water from the Santa Ana River crosses over into Orange County. Shortly after doing so, its flow enters a 6 mile stretch of the river in Anaheim that is owned by the Orange County Water District (OCWD) (Orange County Water District, n.d.). In the dry season, the OCWD diverts all of the water from the river and uses it to recharge groundwater basins. However, in the wet season after large precipitation events, water flows past this region and into a canal, which goes through Orange and Santa Ana. Because the river has been channelized for this last section of the river, water is unable to permeate through the concrete river bed. Instead, the river reaches the Pacific Ocean at a discharge channel, located between Huntington Beach and Newport Beach. Overall, the majority of water that originated in the Santa Ana River does not reach the ocean due to the dams and usage of groundwater recharge techniques.

In addition to being fed by storm water (about 30% of the Santa Ana River total flow), in recent years, there has been an increase in the tertiary treated municipal effluent that has been discharged in the Santa Ana River (Hutchinson & Woodside, 2002). This tertiary treatment aims to remove persistent nutrients, such as phosphorus and nitrogen, which evaded other prior treatments. A study from 2022, which looked at different forms of tertiary treatment and their effectiveness in removing emerging contaminants, such as pharmaceuticals (PhCs), endocrine-disrupting chemicals, benzotriazoles, benzothiazoles, and perfluorinated compounds, found that these treatments are not fully effective at removing a diverse set of pollutants (Arvaniti et al., 2022). Thus, even with tertiary treatment, effluent that is discharged into the Santa Ana River will still contain harmful pollutants which can end up at nearby beaches. In addition, treated municipal effluent can bring fecal bacteria. A study conducted in 2004 noted
the Santa Ana River as a significant source of total coliforms, enterococcus, and fecal coliforms to the surrounding beaches (Kim et al., 2004).

Huntington State Beach is located directly adjacent to the Santa Ana River discharge channel. The Huntington Pier, a common overlook destination for tourists hoping to enjoy the ocean without actually entering the water, is three miles north of the beach. If you continue north, the city of Huntington Beach also encompasses the Bolsa Chica Ecological Reserve and the Bolsa Chica State Beach. The ecological reserve is a 1,300 acre coastal estuary, with wetlands and marshes that are home to a mix of mammals and sea creatures (California Department of Fish and Wildlife, n.d.).

Newport Beach is just south of Huntington State Beach, on the other side of the channel that discharges the Santa Ana River into the ocean. Unlike Huntington, which is a long stretch of sandy beach, Newport is characterized by its bay. The San Diego Creek brings water into the Upper Newport Bay Nature Preserve and Ecological Reserve, a 1000+ acre coastal wetland located about 3 miles inland. The Upper Bay is home to many wildlife species, including the California Gnatcatcher, San Diego Cactus Wren, and Burrowing Owl, three sensitive species, as well as native plant species such as coastal sage scrub. The Upper Bay is also a well known bird watching location in the winter, when up to 35,000 birds may be migrating through the area at once (OC Parks, n.d). In addition, the Upper Bay can be used as a recreational area, where people can be found kayaking, boating, walking, jogging, and riding horses.

Water from the Upper Bay eventually flows into Lower Newport Bay, one of the largest recreational harbors in the Western US. In the early 1900s, the Lower Bay was dredged to increase accessibility for boats, and artificial islands were built in the middle (Visit Newport Beach, n.d.). Today, close to 9,000 motor and sail boats line the harbor, many of which are used by the homeowners living on the man-made islands and in nearby neighborhoods.
Figure 2. Map of Santa Ana River. The river starts in the San Bernardino National Forest, travels through Riverside, Anaheim, and Santa Ana, before dumping into the Pacific Ocean at Huntington Beach (CalFish, n.d.).

Beach and Ocean Recreation in Orange County

Orange County has 40+ miles of coastline, including sandy, rocky, and tide pool beaches, making it a popular destination for locals and tourists alike. A 2007 study that looked at beach attendance in Southern California found that, from 2000-2004, Huntington Beach averaged 12+ million visits and over 5.6 million bathing events annually, making it the most popular beach in Southern California. Newport Beach, the fourth most popular beach in SoCal, averaged 7.6 million visits and 3.5 million bathing events each year. The same study also noted
that around half of all beach visits occur on the weekends, and a little over half of visits occurred during June, July, and August (Dwight et al., 2007).

Huntington Beach is also a particularly popular location for surfers - coined “Surf City USA”, Huntington Beach is frequented by amateur surfer’s year round. In August of each year, visitors flock to Huntington to watch pro surfers in the US Open of Surfing, the annual major surf competition for American surfers.

Newport Harbor is one of the largest recreational harbors in the US, popular for boats and water activities. Alongside being a place to keep boats, the harbor is used for commercial and sport fishing, paddleboarding and kayaking, and commercial boating operations and tours. Beaches around the Newport Harbor, such as Newport Beach and Corona Del Mar State Beach, are also frequented. Newport Beach is a 5-mile stretch of sandy beach that encompasses Balboa Pier and Newport Beach Pier. A bike path extends along the beach, and is commonly used for activities such as biking, skating, and walking (Visit Newport Beach, n.d.).

When considering the beaches that are downstream of the Santa Ana River and the San Diego Creek, according to Dwight et al., 2007, there are over 23 million annual visits to these beaches. From these visits, there are an average of 10.9 million bathing events annually. Given that millions of people are visiting and swimming at beaches, this indicates the importance of monitoring beach water quality and finding solutions for beaches that are above water quality standards.

Water Quality Measurements at Orange County Beaches

The Orange County Health Care Agency (OCHCA) performs weekly testing of 150 beach locations in Orange County. These samples can take several days to be processed in a lab, after which results are reported on the OCHCA website (https://ocbeachinfo.com/). Three measurements are taken from these samples - enterococcus, fecal coliforms, and total
coli forms. These bacterial indicators are not necessarily pathogenic themselves, but are frequently present alongside other pathogenic organisms originating from human and animal waste, making these three measurements helpful for determining safety of beach water (Noble, Moore, et al., 2003). While these raw data can be found on the OCHCA website (https://ocbeachinfo.com/data/), these measurements are displayed on the main page of the website, shown in Figure 3, indicating whether beach water: meets state health standards (green dot), exceed state health standards and may cause illness (yellow dot), or is closed due to sewage or contaminated water (red dot). Using these data, Orange County public health officials are able to post beach advisories, warnings, and closures.

Enterococcus (ENT) is a bacteria found in human and animal feces that is known to cause infections in humans. Unlike many other groups of bacteria, ENT can grow in saltwater, and thus can be measured in marine waters. ENT can be found living in algal mats, decaying seaweed, vegetation, sand, freshwater and sea sediment, and soils. At higher salt concentrations and with greater sunlight, ENT concentrations are reduced (Byappanahalli et al., 2012). ENT levels have also been found to correlate with human health risks - ENT is known to cause gastrointestinal illness, respiratory illness, and skin illness in individuals who come in contact with the water for recreational usage (Haile et al., 1999). In a meta-analysis of prior epidemiological studies performed at beaches worldwide from 1953-1996, researchers concluded that for marine ecosystems, enterococcus is the bacterial indicator best correlated with human health outcomes (Halliday & Gast, 2011).
Figure 3. The map created by the OCHCA to document water quality in Orange County beaches, provided to online users. Green dots indicate that the water meets state health standards, yellow dots indicate that the water exceeds state health standards and may cause illness, and red dots indicate beach closure due to sewage or contaminated water. Gray dots indicate missing data (Orange County Health Care Agency, n.d.).

Fecal coliform, another subset of bacteria that originate in the gut of animals but found in feces, are also quantified in coastal waters and used to determine relative safety of beaches. While there are several subgroups of fecal coliforms, E. coli is one of the more notable groups, and is also frequently measured in drinking water. While E. coli is also an indicator of fecal bacteria levels in recreational waters, and is associated with decreased human health outcomes, because the OCHCA does not measure E. coli by itself, and instead groups it with
other fecal coliforms, it will not be considered as an individual bacteria group in this study (Centers for Disease Control and Prevention, 2019).

Total coliform is a measure of all coliforms, encompassing fecal coliform and enterococci, and is a general indicator of water sanitation (New York State Department of Health, n.d.). In addition to human and animal sources, total coliform can originate from soil and vegetation (Schuerman, 2021).

In addition to testing water quality weekly, the OCHCA is also partnering with Heal the Bay, a Los Angeles area NGO, and Stanford University on their project NowCast. This website uses computer modeling along with environmental and weather data to predict the water quality at certain beaches (https://beachreportcard.org/). Because the weekly water quality testing is only done once or twice a week at each beach, NowCast can provide beach-goers with an accurate daily estimate of water quality, regardless of whether the beach had been tested that day. These estimates are made for beaches across California, including several beaches in Orange County (Heal the Bay, n.d.).

In addition to bacteria, beach goers in Southern California are also concerned about oil that can be found in the water and on beaches. Oil rigs located off the coast of San Pedro Bay, Long Beach Harbor, Huntington Beach, and Seal Beach are constantly at risk of producing leaks or spills into the surrounding ocean. While big oil spills, such as the 1969 Santa Barbara oil spill, the 1976 Sansinena spill in the LA Harbor, and the 1990 American Trader spill at Huntington Beach occur every few decades, smaller oil spills are more common today.

These spills have detrimental impacts on ocean ecosystems, causing harm and death for birds, dolphins, sea lions, other marine animals, and plants in the area (The USC Sea Grant Program, 2022). While sea birds and mammals are frequently the focus for oil spills, as they are most directly impacted, humans have also reported adverse health outcomes from exposure to oil in water. Because oil can travel in the water, areas surrounding the location of the spill can also see these impacts. Studies have linked exposure to oil to physical health impacts, such as
respiratory problems, skin and eye irritations, headaches, nausea, and vomiting (Laffon et al., 2016). However, without data regarding oil in water, I am unable to consider oil as a factor in my analysis.

Health Impacts due to Poor Water Quality

California’s beaches are some of the most popular in the US, with over 150 million beach visits annually (California State Water Resources Control Board, 2018). While most Orange County beaches are usually fairly clean, environmental factors can influence the quality of water and the persistence of bacteria. Especially in highly populated locations, beaches in California can be polluted with urban runoff, such as storm drain pollution and treated wastewater. This runoff can include trash and debris, but it can also contain oils, nitrates, sediments, pesticides, and harmful bacteria (Monterey Bay National Marine Sanctuary, n.d.). Researchers have found that swimmers at Los Angeles County beaches were more likely to get upper respiratory and gastrointestinal symptoms when they swam closer to storm drains. This can in part be due to the fact that there are higher levels of bacteria in the waters closer to drains (Haile et al., 1999). In addition, researchers in Florida looking at non-point sources of pollution found similar results, with swimmers showing higher rates of upper respiratory and gastrointestinal symptoms, as well as skin illnesses (Byappanahalli et al., 2012; Fleisher et al., 2010). A similar study conducted in Mission Bay, California found higher rates of diarrhea and skin rashes for swimmers as compared to non-swimmers (Colford et al., 2007). Researchers estimate that, at Newport and Huntington Beaches, recreational ocean users annually develop an average of 36,778 gastrointestinal illnesses, as well as 38,000 other illnesses, including respiratory, eye, and ear infections (Dwight et al., 2005). Other potential causes of health impacts include other forms of marine pollution, such as oil and cyanobacteria from algal blooms, which are also known to cause similar conditions.
Bacteria can also be found in beach sands, particularly in regions that are dry and infrequently wet. These regions are some of the most frequented areas of beaches, where people go to picnic, sunbathe, or play beach sports. Beach sands thus also serve as a potential public health risk for individuals coming in contact with the sand, or for after rain events, when sand bacteria are washed into the water (Halliday & Gast, 2011).

Because there are chemicals in oil, those who come in direct contact with the ocean after an oil spill are at risk of developing itchy skin, skin rashes, or peeling. In addition, individuals that ingest water containing oil can experience upset stomach, stomach cramping, nausea, vomiting, and diarrhea (Hawaii State Department of Health, 2021). Figure 4 shows a sign at a Santa Barbara beach, warning beachgoers of the potential for oil in the water. The sign advises users to avoid contact with the water when there is visible oil, citing potential health impacts, especially for vulnerable populations such as children, sensitive individuals, and pets. Although oil in coastal California waters is an important consideration for the health of individuals visiting beaches, because I am focusing on bacteria in marine water and do not have data regarding oil in water, I will not be including the presence of oil in my analysis.
Sources of Marine Fecal Bacteria and Pollution

Fecal bacteria can make its way into ocean waters from wastewater treatment and sewage system runoff, as well as from urban and agricultural runoff, boat discharge, and human activities in and around the water (Halliday & Gast, 2011). In Orange and Los Angeles counties,
most of the storm runoff that enters municipal drainage systems is flushed directly into the ocean, without prior treatment. In Orange County, some urban runoff is sent to sewage plants for treatment, but some runoff is still discharged into the ocean (Orange County Sanitation District, n.d.). Figure 5 shows an image of a storm drain, with a message warning people not to dump anything in the drain, as it goes directly to the ocean.

Other sources of marine fecal bacteria include dogs, birds, and animals found at beaches. Researchers have found that dogs are significant contributors to fecal contamination of beaches, both from direct contamination of the beach and from pet waste left on roads and sidewalks, which eventually can be washed into the sewer system and discharged into the ocean (Oates et al., 2017). Birds also have the potential to be sources of marine bacteria. However, studies have shown that the microbial load of a dog fecal event was equivalent to that of 6940 bird fecal events, indicating significantly lower impacts from birds (Wright et al., 2009).

Given these sources of marine fecal bacteria, researchers have considered the impacts of management of beaches and surrounding areas. A study conducted in 2018 found that, of the 316 beaches tested across Florida, beaches with low densities of humans, dogs, birds, and seaweed, as well as beaches with fees for access, employment of lifeguards, and no nearby marinas, were associated with lowest exceedances of enterococcus standards (Kelly et al., 2018). These results suggest that beach management practices influence water quality, and have the potential to limit marine bacteria.

While water is commonly tested for bacteria per the US EPA and California state regulations, bacteria can also thrive in coastal sands, which are less frequently tested. A 2011 study found enterococcus in almost all beach sands tested along the California coast, with higher levels in exposed sands (Halliday & Gast, 2011). Another study measured fecal indicator bacteria levels before, during, and after rain events, and noted higher concentrations of these bacteria in the sand during the storm at open beaches (C. M. Lee et al., 2006). When these rain events occur, bacteria, along with sand and sediment, can be washed into the ocean and
resuspended in the water, leading to increased levels of marine pathogens (Feng et al., 2015). These studies along with others indicate that sands are another potential route of exposure for beach-goers, and should be considered when monitoring beach bacteria levels. While I am unable to include sand bacterial levels in my analysis due to the lack of available data, it is still worth considering this as a potential factor for beach-goers’ health and safety.

Runoff after storms can also bring in oil and lawn fertilizers from the roads, which are washed in by rain waters. Excess fertilizers in the water have led to intense algal growths, which consume nutrients in the water and prevent the growth and survival of fish, seaweed, and other marine plants in the area (G. F. Lee & Taylor, n.d.). These algal blooms also lead to the production of cyanotoxins, which when exposed, can cause irritation of skin, eyes, nose, and throat, as well as vomiting and diarrhea when ingested (Centers for Disease Control and Prevention, 2022). Because enterococcus has been found to be living in algal mats and decaying seaweed, the formation of algal blooms due to fertilizers also has the potential to foster increased levels of bacteria in the area (Byappanahalli et al., 2012).
Figure 5. A sign next to a drain in downtown Los Angeles, asking people to refrain from dumping anything in the drain because it leads directly to the ocean (Photo taken by Naomi Meurice, 2022.

California Water Quality Standards

Per EPA and California State Water Resources Control Board (SWRCB) regulations, beaches in California are highly monitored and frequently tested for enterococcus, total coliform, and fecal coliform bacteria. Current state standards per 100 mL in recreational water are: “104 enterococcus, 10,000 TC, 400 FC, or 1000 TC, if the ratio TC/FC ratio <10” of coliform forming units (California State Water Resources Control Board, 2018). Beaches that exceed these standards are required to receive postings that warn beachgoers of the unsafe water. In extreme cases, such as when raw sewage is released into beach areas, beaches are
automatically closed and users are prohibited from entering the water. While these regulations are stipulated by the SWRCB, nine Regional Water Quality Control Boards across California are in charge of implementing testing to enforce these standards.

In addition to California regulations, California counties must also follow regulations from the EPA’s BEACH Act, an amendment to the Clean Water Act. Enacted in 2000, the BEACH Act stipulates that coastal states, tribes, and territories must abide by federally mandated recreational water quality standards and must also perform frequent testing of these waters. The single sample maximums are as follows: 104 cfu/100 mL for marine enterococcus and 235 cfu/100 mL for E. coli (Environmental Protection Agency, 1986). These standards were based on a 1986 EPA study, titled Ambient Water Quality Criteria for Bacteria, which aimed to keep bacterial levels low enough to ensure protection from the development of gastrointestinal illnesses (Environmental Protection Agency, 2004). The Act also set regulations that require the EPA to perform and publish studies regarding the impacts of certain pathogens on human health. Part of this amendment also permitted the EPA to issue grants to states, tribes, and territories to implement water testing and monitoring systems (US EPA, 2022).

Orange County meets the SWRCB testing requirements and follows the shared EPA and California regulation of 104 cfu/100 mL of enterococcus. The OCHCA measures the three standards, stipulated by the SWRCB, weekly and provides users with this information on their website, which indicates what beaches exceed these standards.

In addition, all beaches in the state must be accessible by the public per the California Coastal Act. This law has stood since 1976, and has allowed for the continued public entry to all coastal areas in the state. Although some barriers, such as private coastal homes or difficult terrain, have prevented beaches from being readily accessible, people cannot be legally barred from walking or swimming to these areas from adjacent beaches. While this Act is often mentioned when noting the lack of private beaches in California, this Act does also include phrasing that calls for the protection and restoration of water quality in coastal areas. The
California Coastal Commission, the group that enforces the Coastal Act, has been working to ensure that coastal communities do not break the regulations put forth in this Act and maintain safe beach water quality (California Coastal Commission, n.d.).

Methods

The methodologies for obtaining and analyzing data are described here. I obtained the water quality data for Orange County beaches from the Orange County Health Care Agency, via their data page on their website (https://ocbeachinfo.com/data/). The website provides historical water quality data from 1986 to present, giving total and fecal coliform levels for older data, with the addition of enterococcus measurements for more recent years. Water quality measurements were taken once or twice a week for each testing location in Orange County. Studies have shown that enterococcus is the bacterial indicator best correlated with human health outcomes, and thus, was the bacteria used in my analyses (Halliday & Gast, 2011).

For the purpose of this study, I am focusing on beaches near the discharge of the Santa Ana River and the San Diego Creek into the ocean. The Santa Ana Watershed Project Authority (SAWPA) provides information regarding the Water Body Beneficial Uses for water sources in the Santa Ana Watershed, which encompasses much of Orange County (https://www.sawpa.net/benuse/benuse.htm). They indicate that beaches as far north as Seal Beach and as far south as Newport Beach/Newport Bay/Corona del Mar are impacted by the Santa Ana River discharge region, and that beaches in the Newport Bay are impacted by water coming from the San Diego Creek. Because I was focusing specifically on Newport Beach and Huntington Beach water quality, I filtered the dataset to only include locations that were in these regions. Data provided by the OCHCA prior to 2015 is formatted differently, with station IDs and beach names not uniform across datasets. Because of this, this study only considers water quality data for the years 2015-2021.
I obtained precipitation data from the National Weather Service, using its NowData - NOAA Online Weather Data website (https://www.weather.gov/wrh/Climate?wfo=sgx). This website provides daily precipitation levels for a Newport Beach testing location that is in the Newport Harbor. This website includes precipitation data dating back to 1920, but for this study, I only looked at data from 2015-2021, to match up dates with the water quality data.

Prior research done by Ackerman et al. in 2003, which looked at rainfall and its relation to fecal bacterial levels in Southern California beaches, indicates that precipitation events of less than 2.5 mm of rain do not impact water quality to the point that it surpasses state standards. Using this metric of 2.5 mm, I used RStudio to indicate which rain events surpassed this threshold. I then counted the number of days in between rain events, where the number of days resets when a significant rain event occurs, to find values for my variable “days since rain”.

The same study also concluded that following a rain event, marine bacteria persisted at high levels for up to five days after the storm. To account for this, I created another variable, days without rain, a constant number determined by the number of days since rain before the most recent rain event. That number was then attributed to the bacterial levels for the following five days after it rained (Figure 6).

Using these metrics alongside the water quality data, I performed a multiple linear regression to assess the relationship between water quality and days without rain, days since
rain, and beach location.

Figure 6. Depicts the two variables of interest, days since rain and days without rain. Days without rain indicates the period of dryness before a rain event. This number is then attributed to the water quality data for the day that it rained, as well as the following five days, called days since rain. This variable is used to indicate the time that has passed since the rain event.

Results

For this study, I examined the impacts of the time between precipitation events on beach water quality measurements in Orange County, CA. I performed a multiple linear regression, looking at how enterococcus levels are influenced by the number of days without rain, the number of days since the last rain event, and the location of the beach. Results indicate that enterococcus levels are significantly impacted by days without rain, with enterococcus levels increasing with each additional day without rain (p-value < 2e-16). Days since rain also significantly impacted enterococcus levels, with levels decreasing with each additional day after a rain event (p-value < 2e-16). These results can be seen in Figure 7, which shows many measurements of enterococcus levels staying higher than the state standard, indicated by the red line, for up to two after the rain event. I performed the same analysis, this time looking at total coliform levels. This analysis produced the same results, with both variables significantly impacting total coliform levels. These analyses, with fecal coliforms, indicated the same results.
Figure 7. A box plot depicting ENT levels for the day of rain events and the following five days. Red line indicates the state standard for ENT in water (104 cfu/100 mL). Points above the red line are considered above state standards, and thus unsafe for humans.

As shown in Table 1, results indicate that enterococcus levels were above state standards for 9.0% of all tests. This occurred 2.9% of the time for total coliforms and 4.8% of the time for fecal coliforms. For enterococcus levels, Bolsa Chica State Beach, Huntington City Beach, and Newport Beach exceeded state standards less than 5% of the time. Newport Beach Creek had the worst water quality by far, exceeding state standards in 74.8% of tests. The remaining four locations (Huntington Harbour, Huntington State Beach, Newport Bay, and Seal Beach/Surfside) maintained relatively safe bacteria levels, exceeding standards between 5-10% of the time.
<table>
<thead>
<tr>
<th>Beach Name</th>
<th>Mean Enterococcus levels</th>
<th>Number of tests reaching above state enterococcus standards (count)</th>
<th>Percent of total tests over the state enterococcus standard (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolsa Chica State Beach</td>
<td>43.7</td>
<td>10</td>
<td>3.3</td>
</tr>
<tr>
<td>Huntington City Beach</td>
<td>54.3</td>
<td>17</td>
<td>4.0</td>
</tr>
<tr>
<td>Huntington Harbour</td>
<td>418.4</td>
<td>145</td>
<td>5.3</td>
</tr>
<tr>
<td>Huntington State Beach</td>
<td>127.1</td>
<td>118</td>
<td>6.8</td>
</tr>
<tr>
<td>Newport Bay</td>
<td>249.7</td>
<td>495</td>
<td>6.9</td>
</tr>
<tr>
<td>Newport Bay (creek)</td>
<td>1190.0</td>
<td>359</td>
<td>74.8</td>
</tr>
<tr>
<td>Newport Beach</td>
<td>51.8</td>
<td>58</td>
<td>3.6</td>
</tr>
<tr>
<td>Seal Beach/Surfside</td>
<td>151.3</td>
<td>102</td>
<td>9.2</td>
</tr>
</tbody>
</table>

Table 1. Mean enterococcus levels, the number of tests above state standards, and the percentage of tests above state standards for each of the eight beach locations considered in this study.

Figure 8 shows similar results: Newport Beach Creek had the highest median measurements for all three fecal indicator bacteria. Median enterococcus levels were similar for the remaining seven beach locations.
Figure 8. Box plot depicting the log of bacterial measurement levels for each of the eight beach locations considered for this study. Plot shows measurements for all three fecal bacteria indicators tested: enterococcus, fecal coliforms, and total coliforms.
Figure 9. Predictive model of multiple linear regression. Shows the predicted values of enterococcus levels, given the number of days since rain and the number of days without rain. Red line indicates the state standard for ENT in water (104 cfu/100 mL). Points above the red line are considered above state standards, and thus unsafe for humans.

Figure 9 shows a predictive model produced using a multiple linear regression, which analyzes the effects of days since rain and days without rain on enterococcus levels at the Orange County beaches in question. The model indicates what enterococcus levels are predicted to be, based on these two variables. Enterococcus levels are highest on the day that it rained, with levels dropping as time goes on. In addition, the figure shows that storm events that
occur after longer periods of dryness will experience higher levels of initial enterococcus measurements, and will thus take longer to reach lower levels of bacteria.

Discussion

Environmental Factors Influencing Water Quality

The results from the multiple linear regression indicate that days since rain, days without rain, and beach locations are all significant factors in determining bacterial levels at Orange County beaches. As the number of days since rain increases, the overall levels of bacteria in the water decrease, confirming results from prior research (Ackerman & Weisberg, 2003). Results of my study also found that after a rain event, bacterial levels will start higher when it has not rained for a longer period of time prior. Thus, long stretches of dryness have the potential to lead to more unsafe water conditions, while more frequent rain events are less likely to cause huge spikes in bacteria levels. Of the eight beach locations tested, seven of these beaches exceeded state enterococcus standards between 3-10% of the time, indicating some degree of consistency among the beaches in the study area.

The eighth set of testing locations, creeks that flow into Newport Bay, had the worst water quality in the testing area, exceeding enterococcus state standards 74.8% of all tests, which was significantly higher than the seven other locations. When looking into where the Newport Beach Creek sample sites were located, I found them to be further inland along the San Diego Creek, Big Canyon Creek, Back Bay Drive Drain Pipe, and the Santa Ana Delhi Channel. Water from these creeks all drain into the Upper Newport Bay, with the San Diego Creek accounting for 95% of freshwater sources to that area from 1978-2001 (California State Water Resources Control Board, n.d.). The Upper Newport Bay is not a traditional sand beach, but is still recreated, often by kayakers, paddle boarders, and small boats, and thus, this area is a location where individuals will potentially come in contact with the water.
Although these creeks contain unsafe levels of bacteria the majority of the time, because Newport Bay, the next testing site downstream, only exceeds state standards for enterococcus 6.9% of the time, much of this bacteria must either be dispersed throughout the larger body of water or must be cleared through natural or anthropogenic systems.

Given that 95% of freshwater in the Upper Newport Bay is sourced from the San Diego Creek, and the creek exceeds state enterococcus standards the majority of the time, the San Diego Creek presents an opportunity to identify other factors that may cause increased levels of water bacteria, and aim to reduce their pollution into the creek. Researchers have already identified urban and agricultural runoff as a source of pollution to the creek and may begin assessing techniques to reduce these contributions to the creek, or create a system that treats runoff before reaching the creek.

Public Health Implications

Results from this analysis show that bacterial levels exceeded state standards 9.0% of the time for enterococcus, 2.95% of the time for total coliforms, and 4.8% of the time for fecal coliforms for the study area of interest. For Orange County’s two most popular beaches, Newport and Huntington, enterococcus levels only exceeded state standards 3.6% and 4.0% of the time. With generally low bacterial levels during the majority of time at Orange County’s beaches, beach contamination does not pose a threat to most beach users.

However, unsafe water quality in the area is not negligible. These numbers also indicate that about 1 in every 10 times someone goes to the beach, they are exposed to unsafe water quality. This ultimately will lead to some instances of sickness directly caused by contact with the water - one report suggests 36,778 gastrointestinal illnesses and 38,000 respiratory, eye, and ear infections are acquired annually from swimming at Huntington and Newport Beaches (Dwight et al., 2005). Many of these illnesses may just be uncomfortable rashes, but individuals
that develop upper respiratory or gastrointestinal illnesses can have detrimental human health impacts for several days or weeks. Given that there are upwards of 75,000 instances of sickness caused from swimming at these beaches, individuals are clearly being impacted by this poor water quality.

Furthermore, researchers have shown that beach-related illnesses developed from coming in contact with water containing unsafe levels of bacteria at Huntington and Newport Beaches pose a $3 million public health burden each year (Dwight et al., 2005). Patients receiving medical attention for these illnesses take away resources from individuals with other medical needs. Because poor water quality can be, to some extent, attributed to human activity, these illnesses are preventable through the development of systems that limit bacterial pollution of waterways that feed into the ocean.

Poor beach water quality not only adds to the number of cases of human illness, but also takes away from visitors’ abilities to access and recreate at the beach. Southern California beaches host day visitors along with daily swimmers, surfers, and divers, who use the ocean to exercise. Orange County currently advises beach-goers to refrain from entering the water for 3 days following a rain event, however other research may suggest that recommendation could be closer to 5 days (Ackerman & Weisberg, 2003). If surfers and swimmers truly follow that 5 day rule, rain events can prevent people from exercising at the beach for almost a week. This inactivity may not cause long-term health problems, but can spark shorter-term mental health implications. Exercise has been proven to reduce symptoms of depression and anxiety, so limiting people’s abilities to recreate at the beach may include shorter-term public health impacts (DiLorenzo et al., 1999; Paluska & Schwenk, 2000).

Ultimately, beaches in this study area of Orange County are generally clean, and users are at low risk while entering the water. While the pollution of beach waters does not directly bar people from visiting the beach or going in the water, when water quality is unsafe, people must choose to refrain from entering the water or to risk illness. Neither outcome is favorable, nor is it
fair, given that human actors upstream are in large part to blame for these unsafe conditions. These anthropogenic factors shouldn’t be preventing people from exercising or risking them illness.

Solutions for Limiting Oceanic Bacterial Inputs

Urban runoff from the neighboring cities and highways has the potential to contribute to the high bacterial levels in the creeks and beaches in Orange County (Dwight et al., 2002). During dry weather, water originally used for irrigation, washing cars, and other human activities, picks up contaminants, trash, and bacteria off pavement. Looking specifically at the San Diego Creek, this creek runs through urban areas with large cities and high populations, such as Irvine, Santa Ana, and Tustin. According to an EPA research report done in 2012, much of the contamination of the creek is due to urban and agricultural runoff, which in turn has led to high levels of pesticides in the water (US EPA, 2012). Efforts made in 2014 to reduce the pesticide runoff from plant nurseries and agricultural sites within the watershed were successful in reducing certain pesticide concentrations in the area. However, given that the creek exceeded enterococcus state standards 66% of the time from 2015-2021, these efforts clearly did not address the major factors influencing bacterial levels in the area. More work must be done in the area to continue to identify other potential contaminants in the creek. Pesticides are also applied to yards and gardens, which have been shown to potentially create conditions that foster bacterial growth, and thus, researchers in the area should also be considering what fertilizers are contaminating the creek water. The prior efforts to remove pesticides in the creek were successful, suggesting other projects focused on different contaminants also have the potential for success.

There are currently systems in place that can prevent this contamination by collecting urban runoff. The Orange County Sanitation District collects runoff from storm drains in coastal
cities, such as Huntington and Newport, and diverts it into the sewage system for treatment. This program prevents contaminated water from reaching the Pacific Ocean. However, these systems do not have the capacity to accept runoff from larger storm events (Orange County Sanitation District, n.d.). This is because the Orange County Sanitation District also treats household sewage, and if these systems were to accept storm water, these increased flows could potentially overflow the treatment facilities, leading to sewage spills. Because of this, the Orange County Sanitation District only accepts urban runoff flows on days where there is no measured rainfall in the district area. County officials should thus consider ways to accommodate for the higher flows seen after rain events, as the analyses show spikes in bacterial levels following rain events. This could entail treating rain water before it enters the ocean, or limiting water’s entry into the ocean altogether.

The treatment of storm runoff could involve several solutions. County officials should consider the expansion of current facilities to uptake more water daily as one of their primary solutions for this issue. Because this infrastructure is already established and connected to the county’s water system, increasing the capacity of these facilities would allow for storm runoff to be treated instead of being sent straight to the ocean. Orange County already has two sewage treatment facilities located directly adjacent to the Santa Ana River, which carries large quantities of water to the ocean after storms. Increasing the capacity of these plants could be done by expanding the plants and creating storage areas nearby, which could capture and hold water for several days. This water could then slowly be treated by the plant at a rate that ensures that storm water inputs do not overwhelm the plant or cause raw sewage spills. Given space constraints at these existing plants, the county may also want to consider establishing new treatment facilities, dedicated to treating storm and urban runoff. This option may be more expensive, given the massive inputs needed to build new infrastructure, but nevertheless is still an option that has the potential to positively impact beach water quality.
While increasing the county’s capacity to treat water through traditional treatment plants offers great potential for helping reduce levels of harmful bacteria in Orange County coastal waters, these solutions are also quite costly, and therefore may be prohibitive. Thus, county officials may have more success expanding upon some of their prior projects, which use natural systems to treat water. The Orange County Water District, along with other city-based water districts, have established a collection of constructed wetlands throughout Orange County, which aim to treat contaminated water. Researchers in 2015 developed the Natural Treatment System Master Plan for the San Diego Creek watershed area. This plan aimed to retrofit and establish new wetlands in the area, with the goal of using these wetlands to naturally control sediments, nutrients, pathogen indicators, and other pollutants in the area. According to these researchers’ models, this proposed system of over 40 wetlands has the potential to decrease fecal coliform concentrations in the creek by around 20% (Strecker, n.d.). The plan was implemented in the Irvine Ranch Water District, and as of 2015, 26 wetland sites were established in the region (Irvine Ranch Water District, 2015). However, because the models considered all 40+ intended wetland systems, constructed wetlands still remain a possible solution for reducing bacterial levels in the San Diego Creek watershed, and thus, in the surrounding beaches impacted by this watershed. Researchers making this plan noted that these wetlands may be limited in their abilities to reduce bacterial levels during high-flow conditions, usually following large storms. Thus, as more wetlands are established, authorities in the area may want to begin looking at the benefits of increasing the capacity of existing wetlands to help deal with higher flows after storm events.

If expansion of treatment facilities or constructed wetlands is not possible, county authorities may also consider rain capture. During rain events, when water falls on impervious surfaces (roofs, streets, sidewalks, etc), the rain does not provide needed moisture to plants and animals, and is instead flushed into storm drains that flow directly into the ocean. If Orange County established a system of rainwater capture projects and devices, the amount of water
flowing to the ocean would be limited, therefore limiting bacteria and other contaminants from also reaching ocean waters. Rainwater capture would also benefit Orange County residents, where water can be scarce. Residents could set up small-scale versions of devices on their homes, which are as simple as large buckets or barrels, that capture rainwater. While these barrels may be several hundred dollars, with rebates to bring down costs, the county could incentivise individuals to install these on their property. Without treatment, this water can’t be used for drinking, cooking, or cleaning, but can instead be used for watering of plants and lawns, or used for flushing toilets. Some larger-scale at-home water collection systems are able to treat stormwater for drinking, however, these systems are much more expensive and require more land area than the small yards often seen in Southern California (Capehart & Eden, 2021).

For companies in Orange County that use water for non-consumptive purposes, such as cooling, larger scale commercial rainwater capture facilities can be installed on site, either on roofs or below ground. Because water used in these industries does not need to be treated, capture devices enable companies to establish a supplemental source of water. These capture devices may only be beneficial during the wet winter seasons, but nevertheless provide companies with free water when it rains, helping to reduce demands on water from the county.

Finally, the county could set up larger-scale rainwater capture projects, which would be used to capture water that is then used to recharge underground water storage basins or treated and supplied to residents in the area. The City of Los Angeles has established capture projects, including Green Stormwater Infrastructure, including bioswales and rain gardens, located adjacent to roads, driveways, and storm drain networks, which catches water as it flows by. Water that makes it past these barriers then enters storm drains. Instead of sending stormwater runoff to the ocean, the City of Los Angeles has also created spreading grounds, where runoff is diverted. At the spreading grounds, water can infiltrate into the ground, helping to contain large stormwater flows (City of Los Angeles, n.d.). Both of these projects aim to promote the infiltration of water into the ground, which can help recharge groundwater stores.
Such projects could be used as models for Orange County officials looking to implement projects that prevent rainwater from being discharged into the ocean.

Orange County should also consider implementing the large-scale capture of rainwater that is then treated and supplied to local residents. Although this does not seem to be a common practice in Southern California, the placement of capture devices near or at treatment facilities could aid in the collection of rain, which could then be treated through existing facilities. By limiting the amount of stormwater sent to the ocean, and instead using it for practices that would otherwise require outside sources of water, Orange County can limit their ocean water pollution while simultaneously reducing stresses on local water supplies.

Because all of these solutions that aim to limit or treat runoff that reaches the ocean require significant financial investments, Orange County will need to consider how they would fund these projects. Standard sources of funding included taxes, on both residents and visitors, as well as increasing costs of accessing beaches. This could mean charging tolls on highways that lead to coastal areas, adding a tax to vehicle registration specifically designated for improving stormwater capture and diversion from roads, or increasing the costs of beach parking. However, as mentioned before, Dwight and colleagues estimated that $3 million is spent annually treating illnesses acquired from coming in contact with contaminated water at Newport and Huntington Beaches alone. If systems in place limit runoff that reaches beaches, and thus limit bacterial inputs, this $3 million could be reallocated toward the construction of additional projects that aim to reduce ocean runoff. Over the course of several years, these systems have the potential to make great impacts on water quality in the area.

If these solutions are not viable at a large scale, due to limited funding or lack of political will, water quality at beaches following rain events will remain a public health concern. In these instances, officials from Orange County need to consider educational campaigns that focus on limiting human sources of bacterial contaminants. Providing residents with more context of storm water drainage and its impacts on oceans may help reduce tendencies to overuse
fertilizers, irrigate extensively, or leave trash and dog waste on roads and sidewalks. In addition, the Orange County Healthcare Agency needs to consider the effectiveness in their signage and messaging to prevent people from entering the water after it rains. Clear explanations of the potential health impacts from swimming after a rain event should be posted online, as well as at impacted beaches. This signage has the potential to limit beach visits when water is unsafe, and thus, can limit the public health burden of poor water quality at the county’s beaches.

Climate Change and Future Implications

Climate change has been impacting communities worldwide, however, effects have been particularly striking in California. Over the last several years, California has experienced extreme droughts, intense wildfire seasons, and steady temperature rises. Precipitation patterns in the last several years have given a glimpse as to what we may see in the future. Per California’s Fourth Climate Change Assessment, conducted by several state agencies, precipitation patterns will be more intense - dry spells will be even drier, and wet periods will bring even more rain (California Natural Resource Agency et al., 2018).

Following these trends, beaches in Southern California may experience fewer instances of poor water quality, given that there may be longer stretches of time without rain. However, because we may see more instances of long periods of dryness in the future, and high levels of oceanic bacteria are more frequently seen following these stretches of time, each individual rain event may have the greater potential to lead to higher levels of bacteria. In addition, prior research notes that precipitation events with a higher quantity of rain lead to higher levels of coastal bacteria levels (Ackerman et al., 2003). This, coupled with longer periods of dryness prior to rain, could mean more climate change-induced intense rain events that will lead to overall higher levels of bacteria following a rain event.

It is also worth mentioning that water in Southern California already has such a high value, which will only increase as this region gets less rainfall - per the modeled predictions,
less rain will fall in the area. Water resource managers in Orange County may begin looking at solutions that involve rain and storm runoff capture. Instead of allowing clean rain water to flow into the ocean, capture and treatment systems can use this water for groundwater basin recharge or can supply it to residents. This relieves stresses on the county to overdraw or import water, while also positively impacting beach water quality.

Many of these climatic patterns are also being seen in other coastal regions of the world. Florida and the US South have been experiencing hurricanes along with more intense precipitation events. These precipitation patterns have also been shown in coastal African cities, as well as globally (Abiodun et al., 2017). These regions too may experience worse beach water quality as a product of changing weather patterns. Residents here may also be at greater risk of becoming ill after swimming in contaminated waters and may also experience this increased public health burden.

As we move into a period in history where temperature thresholds are surpassed, and we begin to see more environmental repercussions for human actions, maintaining beach water quality will not be a priority for policymakers looking to minimize the impacts of climate change. Establishing systems now will be beneficial for generations to come.

Limitations

While this project does provide a comprehensive look at water quality at Orange County beaches, there are some limitations to the research that I have done. To start, I only have three measurements of water quality - enterococcus, fecal coliforms, and total coliforms. For my statistical analyses, I only consider enterococcus. These measurements are great for indicating bacteria levels at these beaches, but do not tell me anything about the presence of oils, metals, and other contaminants that are harmful to humans. Because of this, I am only able to report on
what potential human health outcomes result from water contaminated with bacteria, and can thus, only suggest solutions pertaining to removing or preventing bacteria from entering oceans.

In addition, I am limited by the information provided online regarding government initiatives to make beaches safer. Government websites are not updated frequently and often do not indicate a date when they were last updated. Without this information, there is no way for me to tell if details on their websites are up-to-date. In addition, it is difficult to get information on public projects when these websites are not well maintained. Because of this, I could not report on some of the details of certain county projects or laws, due to lack of accessible information.

Conclusion

From these analyses, I can conclude that the time between rain events significantly impacts water quality in Orange County beaches once it rains. Longer periods of dryness equate to worse water quality following a rain event. I theorize that this is the result of contaminants, trash, and bacteria that build up on streets and sidewalks - the longer the dry period, the more build up there is (Schiff et al., 2016). Thus, rain following longer periods of dryness has the potential to sweep much of that into storm drains, which eventually lead to the ocean. However, this theory must still be tested, and could serve as a future direction for additional research.

In addition, beaches in the test area, excluding the San Diego Creek, exceeded state enterococcus standards only 3-10% of the time, indicating relatively safe beaches for the majority of time in the Orange County area. The San Diego Creek exceeded state standards 66% of the time for enterococcus levels, suggesting water reaching this creek from urban, agricultural, and storm runoff is contaminated with bacteria, or the environmental conditions of the creek enable the growth of bacteria. Given more time, I would focus specifically on the San Diego Creek watershed, and its inputs to the Upper Newport Bay. I would attempt to test the
creek water at several points along its path, and also try to find sources of urban runoff that flow into this creek. Gathering this information would allow me to establish where this bacteria is coming from, with the goal of then reducing these inputs. This knowledge may also be useful in identifying other inputs of urban runoff to the surrounding Newport Bay and Santa Ana River that are negatively impacting beach water quality.

With more time, I would also further investigate environmental factors and their influence on water quality using data analysis techniques. Factors that I didn’t consider in my analysis include the quantity of water that falls in each rain event or over a period of time, time of year, wind and water movement, temperature, and other weather and climatic components. Using the data I already have, I could explore these environmental conditions to determine whether they significantly impact beach water quality. Knowing this information, I would hope to then work with county officials to help them determine, with even more precision, when signage should be posted about potentially harmful water quality. In addition, I would also attempt to work with NowCast, a project that uses models to predict water quality based on weather conditions. I would hope to learn more about the environmental factors used in these models, and guide further research into these topics.
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