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A REVIEW OF THE IMPACT OF CLIMATE CHANGE AND URBANISATION ON DRAINAGE SYSTEM IN OMAN

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ABSTRACT

The impacts of climate change have become increasingly evident, significantly altering the environment in unpredictable ways. One of the most affected infrastructures is drainage systems, which are struggling to cope with the rising frequency and intensity of extreme weather events. Rapid urbanization further exacerbates the issue, as expanding paved surfaces increase runoff, placing additional strain on drainage networks. Oman has witnessed a notable rise in extreme rainfall, resulting in frequent flash floods with severe economic, social, and environmental consequences. This paper examines the combined effects of climate change and urbanization on Oman's drainage systems, highlighting key challenges and vulnerabilities. The findings indicate a sharp increase in catastrophic events between 2009 and 2014 compared to 2000–2008, primarily due to climate change. These events have resulted in numerous fatalities, extensive infrastructure damage, and substantial economic losses. More pavement areas and poor drainage infrastructure and inadequate management in many Omani cities further exacerbate the problem, leading to widespread flooding during extreme rainfall events. Given the rising occurrence of flash floods, it is crucial to reassess Oman's urban development and infrastructure planning to enhance resilience against future climate challenges.

Keywords:
Drainage systems, climate change, urbanization, rainfall, flash flood

INTRODUCTION

The effects of climate change have been more clearly visible in recent years, changing the environment around us in significant and frequently unpredictable ways. Drainage systems is one of the infrastructures that face a noticeable impact. Extreme weather events are occurring increasingly frequently and intensely, and as a result, the demands for drainage systems improvement are growing (Zhou et al. 2018). Generally, cities and towns have been maintained by a sophisticated network of pipes, canals, and basins, but it is now having difficulty adjusting to the shifting climatic trends. Numerous locations across the globe are affected by climate change, which disturbs ecosystems, water cycles, and societies. Increased rainfall trends have been observed globally in a number of places. Oman's Salalah region is among those places most affected by climate change (Andreou et al., 2020). Changes in weather patterns have resulted in more rain and flooding in this area, which have severely damaged the infrastructure and affected daily life for the locals. Major extreme rainfall events have increased in frequency in Oman over the past few years, leading to frequent flash floods and significant economic, social, and environmental losses (Gunawardhana et al., 2018). The Salalah region's current drainage infrastructure is unable to handle the increased rainfall and flooding brought on by climate change. A better drainage system is now required in order to handle the extra water and lessen the effects of flooding. To preserve the security and wellbeing of local citizens as well as to maintain the region's economic activity, an upgraded drainage system is essential. The study will concentrate on the impact of climate change to the current drainage system in Oman. The finding will offer insightful information on the difficulties brought on by climate change and can be helpful to decision-makers, planners of infrastructure, and local citizens.

LITERATURE REVIEW

Urban drainage is an important aspect of city infrastructure that is meant to transfer excess water away from urban areas in order to keep floods to a manageable level (Zhou et al., 2019). Climate variability has contributed to precipitation unpredictability throughout the world in numerous locations, as well as frequent urban flooding. According to Thanvisitthpon et al. (2018), climate change and urbanization have the potential to affect not only surface floods, but also the planning and construction of drainage systems. Conceptually, climate change and urbanization cause as changes in stormwater flow (higher volumes and faster runoff), overloading of drainage systems due to increased surface water and rising frequency and severity of floods, which expose the limitations of current infrastructure. The drainage system demand reflects the need for expanded, upgraded, or new systems to manage increased water flow effectively. The demand encompasses enhanced drainage capacity, improved designs, and the adoption of sustainable solutions like green infrastructure and retention basins to mitigate flooding risks.

Urbanization

Urbanization is the process of population movement from rural to urban areas, increasing the percentage of people living in cities and towns. Kumar et al. (2020), stated that the already depleted natural resources are under severe strain as a result of urbanization. The phenomenon of urbanization is on the rise, with more than 75% of the world's population anticipated to live in cities by 2020. Urban areas have grown in recent decades as a result of population expansion. Water scarcity promoted migration from rural to urban areas in arid and semi-arid countries. Surface runoff is a significant component of the hydrological cycle in these areas (Mahmoud & Gan, 2018). The rapid urbanization of the world has been attributed to a variety of socioeconomic issues, with cities producing between 70% and 80% of the gross domestic product (GDP) of several nations [World Bank, 2020]. While urbanization and economic growth are anticipated to grow in the upcoming years, it is possible that more money will be required to deal with natural disasters because of how frequently they occur (Gu, 2019). Even Nevertheless, these rapidly expanding metropolitan areas will keep growing in accordance with regional differences.

The speed of urbanization in most cities has outpaced the infrastructure development rate in emerging nations. A lack of sewage facilities, increased water demand, insufficient wastewater treatment facilities, and increased impermeable surface all have a negative impact on water resources, as well as congestion in urban drainage networks has been increased by urbanization. According to Abd-Elhamid et al. (2020), One of the key factors contributing to the poor performance of drainage systems is urbanization. Construction areas and impervious surfaces are two features of urban form change that contribute to higher flooding volumes. Mahmoud & Gan (2018), stated that even in desert areas with little yearly rainfall, the risk of flooding has increased recently as a result of urbanization. Numerous flood risk studies have documented how urbanization affects surface runoff.

Alves et al. (2020) point out that water management will have to deal with more extreme weather occurrences, such as heavier rainfalls that will cause more urban flooding and water pollution. Due to these changes, it is also anticipated that other issues, such as heat waves, droughts, and air pollution, will worsen in urban areas around the world (EEA, 2016). Therefore, it's crucial to take into account a variety of benefits while building urban infrastructure in order to create sustainable solutions that can make cities more resistant to deteriorating future conditions.

Urban Drainage System

All around the world, cities have installed urban drainage systems for more than a century to swiftly drain metropolitan regions of runoff and minimize the annoyance of flooding. In several regions of the world, combined storm water and wastewater drainage systems have been developed with a similar goal. In the 1850s, urban drainage systems were created with the goals of ensuring public hygiene and preventing flooding. In order to reduce the flow of pollutants to natural water bodies, WWTPs were modified and extended starting in the 1960s as pollution loads and environmental implications came into focus (Lund et al., 2018). In developed metropolitan areas, drainage systems are necessary due to the interaction between human activities and the natural water cycle. This interaction happens mostly when water is extracted from the natural cycle to meet human needs and when impermeable surfaces are used to redirect rainfall from the nearby natural drainage system. (Butler, 2018).

City expansion can affect runoff patterns, including peak flow volumes and runoff speeds, as well as changes in urban intensity and distribution that can increase or decrease a region's vulnerability to flooding. According to Guptha et al. (2021), rapid urbanization alters land cover, transforming vegetative surfaces and barren plains into impermeable pavements and infrastructure. This would have immediate ramifications for the system's hydrology, and as a result, a significant volume of storm water runoff generation would put the city's existing drainage system to the test. In most cases, these drainage systems are unable to cope with rising urban runoff, resulting in the occurrence of urban flooding in numerous cities across the world. As stated by Gimenez-Maranges et al. (2020), the current urban drainage systems struggle to meet both present-day and foreseeable future issues.

Urban Drainage System in Oman

The perils of floods pose a threat to the urban population, and in Oman many communities have sprung up in flood-prone areas. This is mostly because water is readily available close to Wadi drainage basins. Nevertheless, it is altering as a result of wise land planning and actions made by the government. According to Al-Charaabi & Al-Yahyai, (2019) rains were not anticipated in Oman when the country was being built. But over the past few years, several storms and extremely heavy rainfall have been brought on by the effects and consequences of global warming. It is important to remember that the nation concentrated on creating drainage systems during the construction of metropolitan infrastructure since there were few places for heavy rains to escape, which created a platform for flooding during the rainy season. In urban regions, urban floods submerge streets, basements, ground floors of buildings, etc. The majority of them are caused by riverine, flash, and coastal floods, but some of them are also a result of the drainage system's inadequacy, which is especially prevalent in metropolitan areas. The excess runoff flows onto roadways and urban areas when the drainage system is overloaded or unable to drain effectively into an outfall due to high river levels (Al-Barwani, 2018) The traditional drainage systems have also implemented a combined sewer system, in which rainwater flows into sewers carrying unclean water and both are sent to sewage treatment facilities. Such drainage systems' capacity is dependent on the treatment facilities', and is frequently insufficient for even comparatively light rainfalls. In many Omani cities, the drainage infrastructure is either non-existent or poorly maintained. Therefore, many cities are flooded when flash floods happen. A prime example occurred when Muscat, Quryat, and Sur were severely inundated during Cyclone Gonu in June 2007 as shown in Figure 1.

Figure 1: Floods in one of the Oman coastal areas after the Guno cyclone in 2007 (Al-Barwani, 2017)

Because Oman had less rain in the past, the drainage system did not receive much attention. However, the previous three years of climate change have seen greater rain, which, combined with a lack of or inadequate drainage systems, causes sporadic flooding. According to Al-Charaabi & Al-Yahyai (2019), floods are a factor in major traffic congestion, fatalities, casualties, poverty, and car damage, which costs the government and insurance firms millions of Rials. The local government is working on incorporating rapid actions to solve the issue in order to prevent more difficulties of troubles brought on by the rains. This is accomplished by making use of practical and efficient methods for both the renovation of existing drainage systems and the building of brand-new drainage systems.

Climate Change

Variations in the global temperatures of the air and ocean have confirmed climate change, extensive snow and ice melting, and an increase in average sea levels. In many places of the world, unpredictable precipitation and frequent urban flooding are both caused by climate variability. According to Salimi & Al-Ghamdi (2020), climate change's far-reaching consequences on human and ecological systems are well documented, and continued emissions of greenhouse gases induce more warming and will have long-term repercussions on every element of the climate system on Earth. Changes in climate and urbanization are two of the most prominent elements that affect existing and future urban flood management systems. Zhou et al. (2018), stated that climate change has a substantial impact on the water cycle and patterns of precipitation extremes, which can have a direct impact on surface runoff as well as the frequency and amplitude of floods. Some case studies done by (Chang et al., 2009; Sun et al., 2021; Yang et al., 2021) have documented the effects of climate change on excessive precipitation and urban flooding.

Due to the predicted effects of climate change on urban water systems, such as changes in water runoff and urban flooding, it has been widely identified as a global issue. According to studies by many academics, depending on the region, the anticipated rise in new drainage system design due to climate change can range from 20% to 80%. The current drainage system, which was designed based on a specific return period, has been faced with a significant difficulty as a result (Zhou et al., 2019). Climate change, urbanization, and the growth of population are predicted to increase pressure on the environment and human infrastructure, as well as test the sustainability of water resources (Kourtis & Tsihrintzis, 2021). As a result, climate change is expected to impact the water cycle by influencing precipitation patterns, leading to an increase in design intensities. Flood danger is expected to rise in the future as a result of a combination of meteorological and socioeconomic changes, particularly in urban areas.

Salimi and Al-Ghamdi (2020) conducted research on how climate change is affecting the Middle East and found that temperature increase, wet-bulb temperature increase (which will call into question the population's ability to work and survive), sea level rise and altered precipitation patterns are climate change's key effects in the Middle East. The key infrastructure in the area, particularly water production and electricity, built-up areas (leading to an increase in energy demand), transport and telecommunication systems, in addition to human health and welfare, will be under pressure as a result of these climate phenomena. Similarly, Babovic and Mijic (2019) discuss the necessity to modify urban drainage systems so that cities can manage the growing hazards of flooding brought on by further urbanization and climate change. Thus, it is crucial to adapt to climate change because doing so reduces the likelihood of urban floods. Additionally, Babovic and Mijic (2019) note that there is significant uncertainty around knowledge of future conditions, which makes it difficult to develop effective adaptation techniques.

Climate Change in Oman

Oman's climate ranges primarily from semi-arid to hyper-arid, and it receives less than 100 millimetres of annual rainfall on average, compared to the 1123 millimetres received worldwide on average (Al-Charaabi & Al-Yahyai, 2019). Numerous locations of the world exhibit increasing rainfall trends, according to global-scale studies. Recent years have seen a rise in big extreme rainfall events in Oman, which frequently cause flash floods and cause significant economic, social, and environmental consequences. Oman is particularly sensitive to the effects of extreme climate events due to the country's aridity and semi-aridity, as well as the persistent conditions of chronic water stress, catastrophic flooding, and protracted drought. The rainfall values recorded by meteorological stations in Oman between 2000 and 2014 provide conclusive evidence of a change in the intensity of extreme rainfall occurrences (Müller et al., 2020). The frequency of these potentially harmful events rose in Oman between 2009 and 2014 compared to 2000 to 2008. According to the report by Müller et al., (2020), a significant increase in extreme rainfall occurrences on Masirah island to the east and Thumrait to the south of Oman.

The average amount of precipitation in Oman over the previous ten years has either declined or fluctuated continuously, according to Trading Economics (2023). Based on the data in Figure 2, 2014 had the highest average precipitation, with 83.49 mm. However, Oman's precipitation fell off in the years that followed, reaching a low of 31.94mm in 2021. To date, several water management facilities in Oman, including storm water collection systems, recharge dams and flood protection structures, have been designed using historical climatic data and the stationary assumption (the idea that rainfall variation features remain constant over time). Therefore, a more thorough evaluation that takes into account the potential effects of climate change is needed in order to prevent or, at the very least, lower the risks of flooding and infrastructure damage. (Gunawardhana et al., 2018)

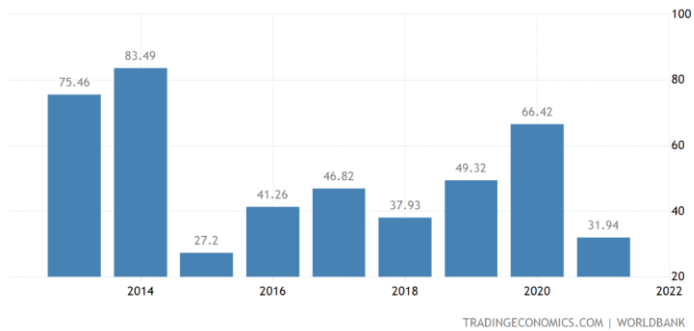

Figure 2: Oman average precipitation (Source: Trading Economics, 2023)

The recent experience of the cyclones Gonu in 2007, Phet in 2010, and Mekunu in 2018 in Oman illustrates the potential impact of an extreme meteorological event on metropolitan areas by the large number of fatalities, the damage to infrastructure, and the economic harm (Al-Awadhi et al., 2019). Due to flash floods and decreased aquifer recharge, severe weather harmed metropolitan areas. The frequency of these potentially catastrophic events rose in Oman between 2009 and 2014 compared to 2000 to 2008, according to a recent study that used data for one-hour and one-day high rainfall events. Some of these tendencies are anticipated to persist, posing a serious risk to the populace as well as the infrastructure (Gunawardhana et al., 2018).

Additionally, due to the combined effects of sea level rise and storm surges brought on by extreme weather events, Oman's low-lying coastal metropolitan centers will be more susceptible to flooding because of climate change (Al-Awadhi et al. 2016). Furthermore, future heavy rainfall events might result in an increase in the size and frequency of flash flooding (Al-Awadhi et al. 2018). Reevaluating Oman's growth plans for urban areas and infrastructure is necessary to take these dangers into account. Although Oman faces numerous threats related to climate change, no initiatives or policies have been created expressly to increase climate resilience in Omani cities. Building resilience will be crucial for urban regions in the future decades to respond to shocks and pressures from climate change, according to a number of studies (Leichenko 2011; Bahadur & Tanner 2014; Meerow et al., 2016; Zhang & Li 2018).

CONCLUSION

Existing studies clearly indicate that climate change and urbanization have significantly impacted Oman’s drainage systems. The current infrastructure, designed based on historical rainfall patterns, is now inadequate due to the increasing variability in rainfall intensity and frequency caused by climate change. Additionally, the expansion of paved surfaces has exacerbated the issue, leading to more frequent and severe flooding, particularly in urban areas. To mitigate these risks, it is crucial to conduct updated assessments of the drainage system and implement necessary improvements to enhance its capacity and resilience. Proactive planning and adaptation measures are essential to minimize future flood-related losses and ensure sustainable urban development in Oman.

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