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Sustainable Water Management in Indus Basin and Vulnerability Due to Climate Change †

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Abstract: Pakistan depends heavily on the Indus River Basin System (IRBS) which is essential for meeting the great majority of Pakistan's agricultural and home consumption requirements. The Indus River is responsible for over 90% of Pakistan's agricultural output and accounts for 25% of the country's GDP. Because of the problems with the water supply, Pakistan may soon face serious food scarcity. By 2025, the water deficit is expected to reach 32%, according to the World Bank's 2020–2021 study, leading to a food deficit of about 70 million tonnes. Recent predictions suggest that by 2025, the water storage capacity would be reduced by over 30% due to climate change. Extreme events i.e., temperature and precipitation occurred in Pakistan, and these affect the human beings. Pakistan has a very low per capita water storage capacity, at about 150 m^3. As a result of decreasing surface water supplies and rising groundwater abstraction, the viability of irrigated agriculture may soon be threatened. To maximize potential for increased storage, Pakistan must enhance its water-use efficiency and implement sustainable strategies for managing its groundwater and surface water resources. The crucial aspects in keeping irrigated agriculture viable in the Indus Basin are developing the infrastructure and eliminating distrust among the provinces.

Keywords: Indus River Basin System; food scarcity; climate change; water resources

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1. Introduction

Pakistan is the fifth most populous and developing economy having population over 22.50 million. The world's best irrigation system lies in Pakistan and 80% of country's population lives in Indus Basin. Despite that, Pakistan has become the water stressed country and as per the estimates of United Nations (UN), the availability of per capita water in Pakistan is 1090 m^3 [1,2]. Agriculture sector had been the key contributor towards the economic developments of the country since independence. The contribution of agriculture sector to GDP of Pakistan during FY 2021–22 has been around 22.7% by employing 37.4% of labor force [3]. The agriculture sector and water resources are under immense pressure as the population of the country is increasing 2.6% [4]. The increasing population demands more food which require to bring more area under cultivation. Pakistan Council of Research in Water Resources (PCRWR) have intimated about the water shortage by 2025 if no new water reserves are constructed. Farmers are fulfilling their agricultural water needs by over exploiting of ground water. The poor quality of ground water is resulting in salinization which is an alarming concern for sustainability of agriculture in

Pakistan [3]. Pakistan in among the list of countries which are significantly affected by salinity. Conjunctive management practices of ground and surface water can increase the irrigation effectiveness and efficiency [4]. About 70% of irrigated plains are using simultaneous use of ground and surface water. With growing economy, the distribution and management of irrigation waterways is a serious concern of the future. The municipal and industrial supplies in urban areas are predicted to reach 14 km^3 from 5.3 km^3 by 2025 [1] and per capita water availability will be reduced by 32%, resulting in a food shortage of 70 million tonnes [5]. Indus Basin was designed to supply low-intensity irrigation in large areas of canal command. The increase in cropping intensity is increasing the gap in supply-demand and creating incessant unrest.

Climate change is one of the worst developments of that century which has significantly affected water supply and cropping patterns. Glacial melt and retreat, change in precipitation patterns, and snow melt are the most observed uncertainties due to climate change. About 45% of basin flow is generated by snow and glacial melt, which indicates that vulnerability to climate change is very high. The Hindu Kush Himalaya (HKH) range is widespread over 2000 km^2 in the Asian continent and contains rivers like Brahma-Putra, Indus, and Ganges. Almost 1 billion people in Nepal, India, Bangladesh, Pakistan, China, and Bhutan are dependent on these rivers. Recent studies have predicted that glacial melt will be increased due to global warming which can increase the river flows by 40% [6] but the average flow rates will be decreased by 60% in Indus Basin [7]. The duration between May and September accounts for 85% of discharge in the Indus Basin in form of snow and glacial melt and monsoon. The hydrological cycles are expected to change as the floods of 2010 and 2022 are examples of a hydrological system [8]. Therefore, the need for time is to adopt and implement water management techniques, the building of new reservoirs for water storage, and the allocation of water resources in an optimum way. Also, the mitigation measures to tackle the effects of climate change to ensure water and food security and safety in Pakistan.

2. Materials and Methods

2.1. Study Area

The area of the Indus Basin is 566,000 km^2 and spread over four provinces of Pakistan i.e., Punjab, Khyber Pakhtunkhwa, Baluchistan, and Sindh. The basin length of Indus is about 2900 km which is fed by the eastern (Sutlej and Ravi) and the western (Chenab, Kabul, and Ravi) rivers, as shown in Figure 1. The river flows through an elevation of 18,000 ft from the Himalayas to the plains of Sindh and discharges into the Arabian Sea. The Indus Basin in Pakistan has a mean annual flow of 176 billion m^3 and 90% of the flow is used for irrigation purposes. The irrigation network consists of the main, branch canal, and distributaries with a length of about 57,000 km having 88,600 outlets.

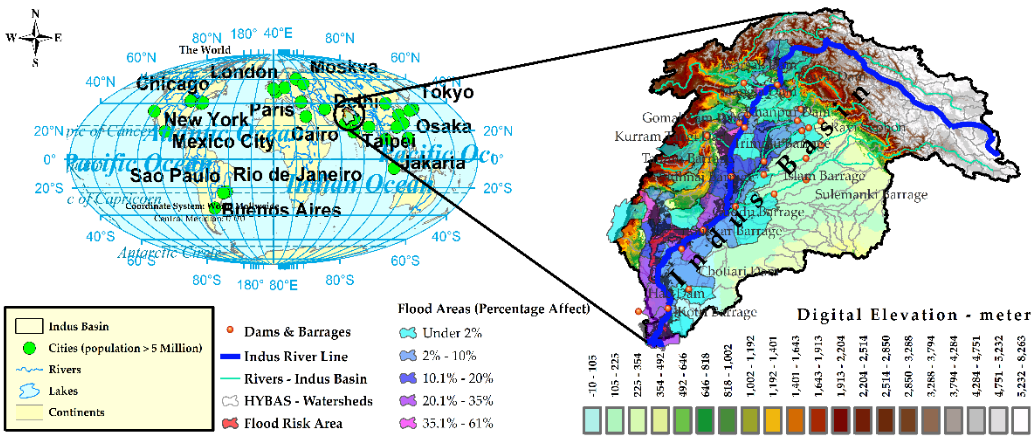

Figure 1. Digital elevation model of Indus Basin with dams, rivers, and flood-affected areas.

2.2. Data Collection and Analysis

Pakistan is one of the most climatically varied country due to its wide temperature range, which includes extremes such as the Sahara desert's temperature and the arctic cold of Alaska. Data on extreme events of climatic parameters i.e., temperature and precipitation was collected for the duration of 1919–2022. The data was collected from the World Meteorological Organization (WMO) [9] and Pakistan Meteorological Department (PMD) [10]. The collected data was processed in GIS to highlight the areas in which mainly extreme events occurred. As per the intensity of extreme events, the hot spotted areas were graded using Inverse Distance Weighing (IDW) method.

3. Results and Discussion

3.1. Sustainability of Water

Pakistan is the fifth most populous country in the world with an increasing population of 2.6% and expected to reach 250 million by 2025 [4]. The urban population of Pakistan was 37% in 2017 and is expected to reach 52% by 2025 [5]. The movement of the population towards cities will increase water consumption by 8%. The per capita water availability in Pakistan was 5000 m^3 in 1947 which was reduced to 1100 m^3 in 2005 and is predicted to drop to 800 m^3 by 2025 [5]. According to the estimates of the UN, the water demand in Pakistan is increasing by 10% per annum. The area-wise water withdrawal in Pakistan is calculated as 175 km^3. Out of which, around 71% (124.25 km) is from surface water and 29% (50.75 km) is from groundwater [8]. In Pakistan, surface water has always been a burning topic, but groundwater has also many problems associated with it, i.e., salinity, overdraft, and waterlogging. According to an estimate, there are 0.8 million pumps installed in Pakistan and 50% of agricultural water needs in Punjab are met by them. The over-pumping of groundwater has led to the salinization of 4.5 million hectares, about 50% of the area lies in irrigated plains of the Indus Basin. The inappropriate irrigation practices and water logging due to seepage from unaligned canals have affected nearly 1 million hectares of irrigated plain of the Indus Basin but the problem of salinity is worse in Sindh. The curative measure was taken to counter the problem of salinity but proved to be futile and land productivity is badly decreased. The water storage capacity of Pakistan is considerably low than that of developed countries. The per capita water availability in US and China is 5000 and 2000 m^3 respectively while it is 150 m^3 in Pakistan [1]. The storage capacity of Pakistan is only 30 days while our neighboring country India has 120 to 220 days. The maximum storage capacity of water is of US i.e., 900 days. The storage capacity of any country depends upon the reservoir and Pakistan has only two main reservoirs i.e., Tarbela and Mangla, and the capacity of both reservoirs have been reduced by 20 and 32% due to sedimentation [5]. Lieftinck report of 1968 stated that one Tarbela-sized reservoir every 10 years is necessary to meet the increasing demands of agriculture. It is also recommended to increase the storage capacity to 22 billion m^3 by 2025 to meet the projected requirement of 165 billion m^3. If no new reservoirs are developed yet the water availability will be reduced by 12% by the next decade due to sedimentation. Another reason for the development of new reservoirs is the increasing industrialization and urbanization which demands more energy to fulfill their needs.

3.2. Extreme Events

Extreme high and low temperatures, as well as the heaviest rainfalls, are all features of Pakistan's weather. In Turbat, Balochistan on 28 May 2017, a record-breaking 53.7 °C was measured, making it the hottest day in Pakistan's history [11]. On 26 May 2010, at Moenjo Daro, Sindh, Pakistan, a temperature of 53.5 °C was recorded, making it the second-hottest day in the country's history [12]. This was the fifth-highest temperature ever reported on Earth. On 23 July 2001, Islamabad received 620 mm of rain, the largest amount ever recorded rainfall in just 10 h.

3.2.1. Temperature

Heat waves mostly tend to associate high temperatures in Pakistan with the summer months, at any time between April and September. Temperatures exceeding 50 °C were common in parts of southern Pakistan, where they wreak havoc in these areas. The record-breaking heat wave of summer 2010 that occurred in the final ten days of May was the deadliest heat wave in Pakistan's history. The north-central region of Pakistan (Punjab and KPK) was scorching hot. In April 2017, regions of southern Pakistan were struck by a severe heat wave with temperatures reaching 50 °C. Cities throughout Pakistan set new April high-temperature records due to this heat wave. In Larkana, Sindh, the highest recorded temperature was 50 °C on April 19, breaking the previous record set in April 2000 when the temperature reached 48.5 °C. Mohenjo-Daro, Sindh, saw the hottest temperature ever recorded in Asia at 53.5 °C on May 26, 2010, while Larkana, Sindh, had the second-hottest temperature ever reported in Asia at 53 °C. The intense heatwave of summer 2010 lasted from May 22nd to May 31st, and it caused temperatures to rise beyond 50 °C in 12 different cities throughout Pakistan. At least 18 individuals lost their lives on May 27 because of extreme heat in Pakistan, when temperatures reached above 45 °C in several regions. In addition, 11 cities saw their highest reported temperatures of 50 °C or above during the intense heatwave season, while five locations experienced temperatures of 53 °C or higher. Over and beyond the 45 °C mark, eleven cities also saw highs of less than 50 °C, as illustrated in Figure 2. This breaks the previous record set at Jacobabad, Pakistan, on 12 June 1919, when the temperature reached 52.8 °C, setting a new Asian record.

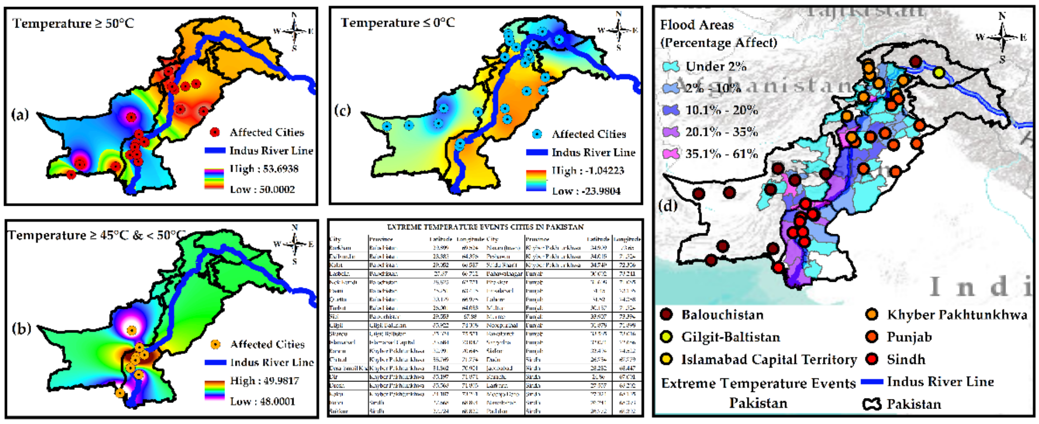

Figure 2. Temperature extreme events in Pakistan with varying ranges of temperature (**a**) Temperature ≥50 °C; (**b**) Temperature ≥40 °C and <50 °C; (**c**) Temperature ≤0 °C; (**d**) All the regions in Pakistan in which extreme temperature events occurred.

Most cold waves happened between October and March when temperatures drop significantly in northern and western Pakistan. The glacial regions of Gilgit Baltistan, where winter temperatures can drop below −20 °C, maybe Pakistan's coldest spot. Temperatures of −65 °C have been recorded on K2. Recently Pakistan saw the worst cold wave on record during the winter of 2020. Cities like Islamabad, Peshawar, and Lahore on the foothills of the Himalayas may record temperatures below freezing, while even the warmest areas in Pakistan had temperature drops of 2 °C or more.

3.2.2. Precipitation

Monsoon and Western Disturbances both were sources of precipitation in Pakistan. Pakistan experienced widespread flooding from July through September due to the monsoon season. From October–May, precipitation spread over the whole of Pakistan due to western disturbances, with the heaviest rain falling in Northern Pakistan. However, in June, Western Disturbances sometimes affect the northern areas of Pakistan. On rare occasions, the pre-monsoon season might begin in this month as well. In the first week of the month, the country was battered by a Monsoonal downpour reminiscent of August's when an extremely low air pressure system (29") developed over Kashmir and then swept eastward into Northern Pakistan. Devastating rains fell from 1–5 September, bringing death and destruction to many cities. The rivers Chenab, Jhelum, Ravi, Sutlej, and Indus in Pakistan all overflowed their banks during the latter two days of the period, which was particularly rainy. According to the Pakistan Meteorological Department, the region in northern Pakistan received around 200 mm of rain between 1–5 September 2014 as shown in Figure 3. A powerful low-pressure region formed in the Bay of Bengal in the latter days of August, after the extreme drought conditions in Sindh throughout the months of July and August. In the first two weeks of September 2012, a low-pressure region came into Sindh, bringing with it torrential rains in Upper Sindh. Jacobabad received 481 mm of rain in only 7 days, and 441 mm of rain in just 36 h, both world records. Larkana set a record with 239 mm, while Sukkur set a record with 206 mm. The worst of the flooding occurred in the Larkana district. In the last week of July 2010, Pakistan saw unprecedented severe monsoon rainfall, leading to flooding in the provinces of Balochistan and Sindh. Over 200 mm of rain occurred in a 24-h period in several locations in Khyber Pakhtunkhwa and Punjab. The previous 24-h rainfall record in Peshawar was 187 mm in April of 2009, but the recent total of 274 mm smashed that mark. The province of Khyber Pakhtunkhwa had rainfall in the cities of Risalpur, Cherat, Saidu Sharif, Mianwali, and Kohat.

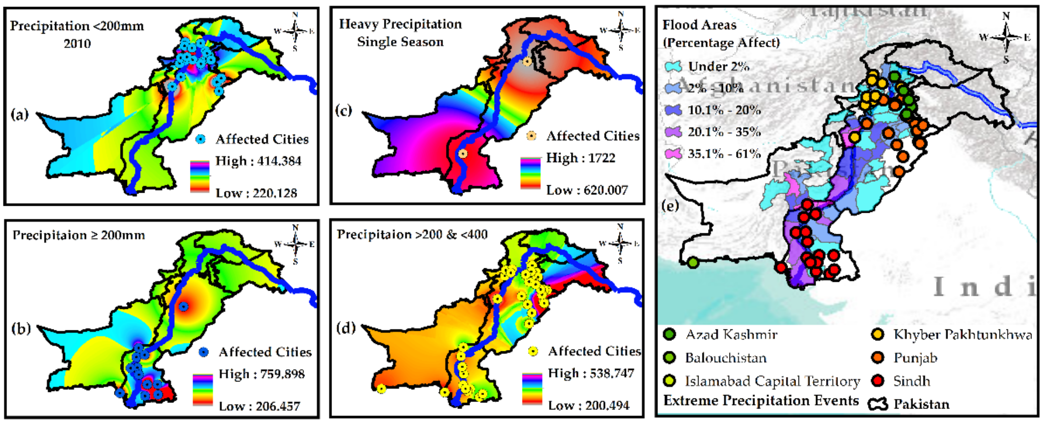

Figure 3. Precipitation extreme events in Pakistan (**a**) Precipitation in 2010 < 200 mm; (**b**) Precipitation ≥ 200 mm; (**c**) Heavy precipitation in a single season; (**d**) Precipitation >200 and < 400 mm; (**e**)All the regions in Pakistan in which extreme precipitation events occurred.

3.2.3. Vulnerability Due to Climate Change

Climate change's impact and the occurrence of extreme events on the Indus Basin's water supply are still impossible to predict. There is a lot of guesswork involved in predicting how melting glaciers, melting snow, glacial retreat, and changes in precipitation will affect specific areas. About 45% of the flow to the basin comes from glacier melt and snow in the Himalayas, making it very susceptible to climate change and glacial melt [6]. Spanning six different countries in Asia—Pakistan, Nepal, India, China, Bhutan, and Bangladesh—is the Hindu Kush Himalaya (HKH) range. There are many major rivers in this area, including the Indus, Brahmaputra, and Ganges. Nearly a billion people rely on these rivers as their primary supply of drinking water. The loss of local glaciers is consistent with global trends, providing more evidence that glacial retreat has increased over the last century. New projections suggest that the pace of glacier melt caused by a rise in global temperature will accelerate in the coming years. This will increase river flow by 40% [3]. In the long term, however, the Indus River's typical flows would decrease by over 60% [2]. In addition, rising temperatures are expected to increase evapotranspiration rates across the irrigated Indus Basin, leading to higher demands for irrigation water and fiercer competition for surface and groundwater supplies among the provinces. Between May and September, monsoon rainfall, glacier, and snowmelt account for over 85% of the yearly flow in the Indus Basin. The intensity, location, and timing of monsoon activity are all predicted to shift, causing widespread changes to the hydrological system during the next decade or two. One result of this shift in the hydrological system is the devastating flood that hit Pakistan in 2010. The thawing of glaciers had little effect on this.

4. Conclusions

Pakistan is an agriculturally based struggling economy and water plays an important role in the sustainable development of the nation. The increasing population of the country is creating an unbalance in the demand and supply of food and water, leading to an alarming challenge to food safety and security in the country. Currently, the country is facing severe water and food crises due to bad management and governance over water resources. Technically weak policies, lack of water storage capacity, extreme climatic events due to climate change, and inter-provincial disputes have resulted in crucial conditions. Although the contribution of Pakistan to climate change is less than 1% but is severely affected by cross-border pollution. The seasons are shifted with extreme temperature and precipitation events in the country. The summer season is prolonged while the winter is shortened, leading to the generation of more excessive runoff than usual. The unavailability of water storage structures has resulted in the form of water wastage in the Arabian sea causing floods. The recent floods of 2022 are an example of vulnerability due to climate change. Appropriate reforms for water and food policies are needed at the time by developing water reservoirs with efficient distribution and application of water i.e., drip and sprinkler irrigation, which will ensure sustainable agriculture and development of the country.

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