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A Critical Study of Climate Change Impacts on Satluj River Floods and Disaster Management with GIS

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ABSTRACT: Increasing intensity and frequency of rainfall coupled with gradual retreating of glaciers due to climate change in Himalayan region likely to increase the risk of floods. A better understanding of risk zones which are vulnerable to flood disasters can be evolved from the detailed studies on slope, geomorphology and land use/ land cover pattern. Information of these parameters is an important input for the identification of vulnerable areas. Flood risk maps provide useful information about places that may be at risk from flooding. It offers a cost-effective solution for planning, management and mitigation strategies in risky areas. Traditional methods of flood risk mapping are based on ground surveys and aerial observations, but when the phenomenon is widespread, such methods are time consuming and expensive. The possible combination of DEM and other maps of area using an overlay operation method within the Geographical Information System (GIS) platform can lead to derivation and the understanding of spatial association between various parameters which could be used to predict flood risk zones. The study area i.e. Satluj River Basin has been broadly divided into five risk zones viz., very low, low, moderate, high and very high which helped to differentiate between areas that are at risk of different intensities of flood. The very high flood risk zone covers only 3.25 % of total study area, while the very low risk zone covers 13.63 %. The area falls within the very high and high risk constitutes 9.52 % of total basin area. Domain of moderate risk covers an area of 30.66 %. But the maximum area of river basin is constituted by low risk zone i.e. 46.19 %. Identification of such zones will help in timely adopting of mitigation and adaptation measures. Preparation of flood risk zoning maps also helps in regulating indiscriminate and unplanned land use practices in risky areas.

KEYWORDS: Satluj, GIS, climate, flood, risk zones

I. INTRODUCTION

River channel change is a dynamic process which involves erosion, accretion, lateral migration and changes in its width through the geomorphological process. Shifting of a river causes a direct impact on natural and manmade constructions which are located near the floodplain with consistent damage and devastation of the area. The objective of this study is to analyze the spatiotemporal variation along the Satluj river during the period 1990 to 2019 using Landsat TM, ETM+ and OLI satellite data. Spatiotemporal analysis of the river channel has been carried out to analyze the river channel [1,2,3]change morphology, mid-line channel shifting and changes in surface water area of the Satluj river using twenty randomly distributed cross-sections (X1-X20). For surface water area change analysis, the satellite derived normalized difference water index (NDWI) has been used. The obtained results indicates that the river width increased by 0.033 km in overall cross-section (X1–X20) in the year 2019 as compared to the year 1990. Mid-line shifting of the river is mostly towards the left bank of the river. The maximum channel shifting of 1.364 km took place from Chak Bandala village in Jalandhar district to Madarpur village in Moga district between the years 1990 and 2019. However, the NDWI results indicate that the river surface area has been reduced by −90.33 km^2 between the years 1990 and 2019. Additionally, the average shifting rate of the Satluj river during the period 1990 to 2019 is by 0.778 km.

The hazards linked to glaciers and glacial lakes in the mountainous environments, as well as their downstream implications, are highly alarming. Climate change and variability have exerted quite a substantial influence on the life span of glaciers in the Himalayan region in recent decades. As a consequence, several enormous glaciers melted, leading to the formation of numerous glacial lakes that have the potential to erupt and adversely affect the human and physical resources downstream. The present study seeks to identify the probable glacial lakes in the Satluj river basin that may be susceptible to a glacial lake outburst flood (GLOF) [4,5,6](GLOF). The study applies a three-step based semi-automatic methodology to locate the glacial lakes and further classify their outburst potentiality using Landsat time-series data. A total of 15 glacial lakes have been found in the Sutlej basin. Between 1990 and 2018, the frequency and extent of glacial lakes in the Satluj basin rose by 65% and 71%, respectively. Two of the 15 lakes discovered have

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grown moderately by 64% and 39%, respectively; 2 have grown only by 23% and 16%, respectively; and 3 lakes have grown insignificantly between 2004 and 2014 (decadal). The glacial lake (Latitude 31°39′40.81″ N and Longitude 78°10′7.32″ E) is one of the possible highest potentially dangerous lakes, whose maximum surface area is approximately 0.20 km^2 acquired on 16 September 2018 of Landsat-8 satellite image data. Though further research is needed to anticipate GLOF, it is recommended that an early warning system be constructed for the study area, which includes the deployment of a real-time sensors network at vulnerable lakes, as well as GLOF simulation models.

II. DISCUSSION

The complex relationship between topography and precipitation in mountainous regions such as Himalayas is evident from the pattern of rainfall distribution. The variation in precipitation with altitude is controlled by mean height of clouds and decrease in water vapours with altitude. Spatially distributed measurements of precipitation have gained renewed interest in connection with climate change impact studies. Precipitation values are usually available from a limited number of gauge stations and their spatial estimates can be obtained by interpolation [7,8,9]techniques such as Inverse Distance Weighted (IDW), Kriging and Spline. In the present study, precipitation-elevation relationship can be established using Digital Elevation Model (DEM) (Advanced Spaceborne Thermal Emission and Reflection Radiometer-ASTER, 30m resolution), Spline interpolation technique in Geographical Information System (GIS) environment and point data from various gauge stations spread over the Satluj River Basin. Changes of spatial distribution of precipitation with elevation show a distinct shift. Bhakra Dam (5854.60 mm) to Rampur (4451.10 mm), there is continuous variation in rainfall with increase in altitude. But beyond Rampur, variation is very high. Swarghat shows exceptional rainfall (8031.76 mm), may be due to position of mountains and their orographic effects.

Maximum rainfall was observed in the lower Himalayas i.e. Shiwalik range. Negligible rainfall was observed beyond Kaza (470 mm), above the elevation of around 3756 m. The general trend of rainfall exhibits that the lower and middle parts experience good rainfall whereas the upper part experiences less rainfall. Such spatial and temporal distribution of rainfall with elevation provides an important platform for hydrologic analysis, planning and management of water resources. Origin and Course: The Satluj River originates in the Tibet Autonomous Region of China, near Lake Rakshastal. It flows through the Indian state of Himachal Pradesh before entering the Punjab region. The river then continues its course through the states of Haryana and Rajasthan before eventually emptying into the Arabian Sea. The east-to-west flow of the Satluj is distinctive, connecting the Himalayan region with the rest of India.

Length: The Satluj River ranks among the longest rivers in India, with a total length of around 1,450 kilometers. This extensive stretch plays a pivotal role in influencing the lives of millions of people residing along its course.

Tributaries: Major tributaries of the Satluj include the Beas, Spiti, Rupi, and the Sutlej Yamuna Link Canal. Each tributary contributes to the overall flow and characteristics of the river, with the Beas [10,11,12]River being the largest and joining the Satluj at Harike in Punjab.

Physical Characteristics: The river features a wide floodplain and meanders through several valleys and gorges. Its high gradient and steep slopes in certain sections make it ideal for hydropower generation. The water of the Satluj River is sourced from the snowmelt in the Himalayas, impacting the region's climate and ecology significantly.

Map: A map visually represents the course and geographical features of the Satluj River, outlining its origin, path, tributaries, and points of significance.

Dams on the Satluj River

1. Bhakra Dam
- Located in Bilaspur, Himachal Pradesh.
- One of India's largest dams, serving irrigation, power generation, and flood control.

2. Nangal Dam
- Situated in the Rupnagar district, Punjab.
- Regulates the Satluj's flow and facilitates irrigation.

3. Nathpa Jhakri Dam
- In Himachal Pradesh.
- One of India's largest hydroelectric projects, with a total capacity of 1,500 MW.

4. Karcham Wangtoo Dam
- In the Kinnaur district, Himachal Pradesh.

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- A run-of-the-river hydroelectric project with a capacity of 1,000 MW.

5. Baspa-II Hydroelectric Project

- A 300 MW project on the Baspa River, a tributary of the Satluj, in the Kinnaur district.

The historical significance of the Satluj River is multifaceted, dating back to ancient civilizations and extending to pivotal events in Indian history. It played a crucial role in the development of the Harappan civilization, serving as a vital resource for irrigation and transportation. Additionally, the river holds prominence in Vedic literature, with mentions dating back to around 1500 BCE.

In more recent history, the Battle of the Satluj River in 1845 marked a turning point, initiating the First Anglo-Sikh War and influencing the geopolitical[13,14,15] landscape of the region. Furthermore, during the partition of India in 1947, the Satluj River delineated the border, leading to the displacement of millions of people.

Beyond its historical narratives, the Satluj River remains woven into the fabric of local communities. Culturally revered, it becomes the focal point for religious festivals and rituals. Moreover, the river plays a pivotal role in the economic sustenance of the region, supporting agriculture, serving as a source for hydropower generation, and fostering a thriving fishing industry. Thus, the Satluj River stands not only as a witness to historical events but also as a vital force in the daily lives and cultural practices of the communities along its course.The Satluj River, with its long stretch, various tributaries, and important dams, plays a crucial role in shaping the geography and socio-economic aspects of South Asia. Its distinct characteristics and historical importance highlight its lasting impact on the region. The blending of nature and human activities makes the Satluj a vital and influential presence in the areas it flows through.

III. RESULTS

Satluj River or Sutlej River (Hindi: सतलुज, Punjabi: ਸਤਲੁਜ, Urdu: ستلُج دریائے) is the longest of the five rivers that flow through the historic crossroads region of Punjab in northern India and Pakistan. The Sutlej River (/ˈsʌtlədʒ/) is the longest of the five rivers that flow through the historic crossroads region of Punjab in northern India and Pakistan. The Sutlej River is also known as Satadru.[3] It is the easternmost tributary of the Indus River. The Bhakra Dam is built around the river Sutlej to provide irrigation and other facilities to the states of Punjab, Rajasthan and Haryana.

The waters of the Sutlej are allocated to India under the Indus Waters Treaty between India and Pakistan, and are mostly diverted to irrigation canals in India like the Sirhind Canal, Bhakra Main Line and the Rajasthan canal.[4] The mean annual flow is 14 million acre feet (MAF) (roughly 1.727×10^{13} L) upstream of Ropar barrage, downstream of the Bhakra dam.[5] It has several major hydroelectric points, including the 1,325 MW Bhakra Dam, the 1,000 MW Karcham Wangtoo Hydroelectric Plant, and the 1,500 MW Nathpa Jhakri Dam.[6] The drainage basin in India includes the states and union territories of Himachal Pradesh, Punjab, Ladakh and Haryana.[7][8]

Course[16,17,18]

The source of the Sutlej is west of the catchment area of Lake Rakshastal in Tibet, as springs in an ephemeral stream. Lake Rakshastal used to be part of the Sutlej river basin long ago and separated from the Sutlej due to tectonic activity. The nascent river flows at first west-northwest for about 260 kilometres (160 mi) under the Tibetan name Langqên Zangbo (Elephant River or Elephant Spring) to the Shipki La pass, entering India in Himachal Pradesh state. It then has its main knee heading west-southwest for about 360 kilometres (220 mi) to meet the Beas River near Harike, Tarn Taran district, Punjab state. Ropar Wetland in Punjab state is located on the Sutlej river basin. Evidence suggests Indus Valley civilisation also flourished here. Ungti Chu and Pare Chu rivers which drain the southeastern part of Ladakh are tributaries of Sutlej river.[8][9]

Continuing west-southwest, the Sutlej enters Pakistan about 15 kilometres (9.3 mi) east of Bhedian Kalan, Kasur District, Punjab province, continuing southwest to water the ancient and historical former Bahawalpur princely state. [citation needed] Few centuries ago, Sutlej river was merging with the Ghaggar river to discharge in to the Arabian sea. In approx. 1797 BC, the course of the Sutlej river moved towards the north to join the Beas river.[10]

About 17 kilometres (11 mi) north of Uch Sharif, the Sutlej unites with the Chenab River, forming the Panjnad River, which finally flows into the Indus river about 100 kilometres (62 mi) west of the city of Bahawalpur. The area to the southeast on the Pakistani side of the Indian border is called the Cholistan Desert and, on the Indian side, the Thar Desert.[citation needed]

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The Indus then flows through a gorge near Sukkur and the fertile plains region of Sindh, forming a large delta region between the border of Gujarat, India and Pakistan, finally terminating in the Arabian Sea near the port city of Karachi, Pakistan. During floods, Indus river water flows into the Indian part of the Great Rann of Kutch. Thus Gujarat state of India is also a riparian state of the Indus river as the Rann of Kutch area lying west of Kori Creek in the state is part of the Indus River Delta.[11]

Puranic Mention and Etymology

In the Chaitra-Ratha Parva of Adi Parva of Mahābhārata, when sage Vasishtha wanted to commit suicide he saw the river named Haimāvata (whose source is Himavat), flooded and full of crocodiles and other aquatic monsters. So he jumped into the river. The river thinking that Vasishtha was a mass of unquenchable fire dilated itself and flew in a hundred different directions. Henceforth the river was named śatadra (or śatadru) which means the river of a hundred courses. So, Vasishtha landed on dry land and was unharmed.[12] Sutlej is an antecedent river, which existed before the Himalayas and entrenched itself while they were rising. The Sutlej, along with all of the Punjab rivers, is thought to have drained east into the Ganges prior to 5 mya.[13]

There is substantial geologic evidence to indicate that prior to 1700 BC, and perhaps much earlier, the Sutlej was an important tributary of the Ghaggar-Hakra River (thought to be the legendary Sarasvati River) rather than the Indus, with various authors putting the redirection from 2500 to 2000 BC,[14] from 5000 to 3000 BC,[15] or before 8000 BC.[16] Geologists believe that tectonic activity created elevation changes which redirected the flow of Sutlej from the southeast to the southwest.[17] [citation needed] If the diversion of the river occurred recently (about 4000 years ago), it may have been responsible for the Ghaggar-Hakra (Saraswati) drying up, causing desertification of Cholistan and the eastern part of the modern state of Sindh, and the abandonment of Harappan settlements along the Ghaggar. However, the Sutlej may have already been captured by the Indus thousands of years earlier.[citation needed]

There is some evidence that the high rate of erosion caused by the modern Sutlej River has influenced the local faulting and rapidly exhumed rocks above Rampur.[18] This would be similar to, but on a much smaller scale than, the exhumation of rocks by the Indus River in Nanga Parbat, Pakistan. The Sutlej River also exposes a double inverted metamorphic gradient.[19]

There has been a proposal to build a 214-kilometre (133 mi) long heavy freight and irrigation canal, to be known as the Sutlej-Yamuna Link (SYL) to connect the Sutlej and Yamuna rivers.[20] The project is intended to connect the Ganges, which flows to the east coast of the subcontinent, with points west, via Pakistan. When completed, the SYL would enable inland shipping from India's east coast to its west coast (on the Arabian sea) without having to round the southern tip of India by sea, vastly shortening shipping distances, alleviating pressures on seaports, avoiding sea hazards, creating business opportunities along the route, raising real estate values, raising tax revenue, and establishing important commercial links and providing jobs for north-central India's large population. However, the proposal has met with obstacles and has been referred to the Supreme Court of India. To augment nearly 100 tmcft (some 2.832×10^{12} L) water availability for the needs of this link canal, Tso Moriri lake/Lingdi Nadi (a tributary of Tso Moriri lake) waters can be diverted to the Sutlej basin by digging a 10 km=long gravity canal to connect to the Ungti Chu river.[8] The Upper Sutlej Valley, called Langqên Zangbo in Tibet, was once known as the Garuda Valley by the Zhangzhung, the ancient civilization of western Tibet. The Garuda Valley was the centre of their empire, which stretched many miles into the nearby Himalayas. The Zhangzhung built a towering palace in the Upper Sutlej Valley called Kyunglung, the ruins of which still exist today near the village of Moincêr, southwest of Mount Kailash (Mount Ti-se). Eventually, the Zhangzhung were conquered by the Tibetan Empire. The Sutlej River also formed the eastern boundary of the Sikh Empire under Maharajah Ranjit Singh.Parganah Hakkarah

Today, the Sutlej Valley is inhabited by nomadic descendants of the Zhangzhung, who live in tiny villages of yak herders.

The Sutlej was the main medium of transportation for the kings of that time. In the early 18th century, it was used to transport devdar woods for Bilaspur district, Hamirpur district, and other places along the Sutlej's banks.

Of four rivers (Indus, Sutlej, Brahmaputra and Karnali/Ganges) mythically flowing out of holy Lake Manasarovar, the Sutlej is actually connected by channels that are dry most of the time. Earlier the river was also called Shutudri or Zaradros river.[21]

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IV. CONCLUSION

Sutlej River, an important tributary of the Indus River is the longest of the five rivers of Punjab. It flows through Punjab in northern India as well as Pakistan. It is located north of the Vindhya Range, south of the Hindu Kush segment of the Himalayas and in Pakistan. It originates from the snow filled Lake Rakshastal in Tibet and ends in Pakistani Punjab near the port city of Karachi. Sutlej River is situated at an altitude of 20,000 feet above mean sea level. The Sutlej is the easternmost tributary of Indus River with a total length of 1550 km out of which 529 km is in Pakistan. The Sutlej River is also known as "Satadree".

Course of Sutlej River

River Sutlej takes birth on the southern slopes of the holiest of mountains - Kailash, near the Lake Rakshastal. After a long run, parallel to the Himalayas, it finally penetrates these at Shipki pass. Later it cuts through the Zanskar Himalayan Range, makes a diagonal thrust through the Himalayas and blasts a deep gorge at the base of the Kinnaur Kailash massif. Within Kinnaur district, the Sutlej runs parallel to the Hindustan-Tibet Road. At Karcham, in Kinnaur, it is joined by the crystal clear, blue River Baspa that drains the Sangla valley. After Karcham, the Sutlej turns aggressively, throwing boulders, rocks [19] and rubble around in mighty, foaming rapids.

Map of Sutlej River

A rush through Shimla hills and Bilaspur district, and it loses momentum, leaving Himachal Pradesh and entering the plains of Punjab at Bhakra where it mingles with the waters of Gobind Sagar Lake. The Sutlej River joins the Beas River in Punjab and then continues in the southwest direction in Pakistan to join the Chenab River.

Important Tributaries of Sutlej River

Spiti River, Baspa River, Soan River and the Nogli Khad are the major tributaries of the Sutlej River.

Hydrology of the Sutlej River

The hydrology of the Sutlej is controlled by spring and summer snowmelt in the Himalayas and by the South Asian monsoon. The rapid course with just the ideal volume of water makes it and its tributaries the "Power House of the Himalayas". The overall hydroelectric power capacity in Himachal Pradesh is evaluated to be 20,000 MW of which around 50% is from the Sutlej valley.

Developmental Projects on Sutlej River

The waters of the Sutlej are allocated to India under the Indus Waters Treaty between India and Pakistan, and are mostly diverted to irrigation canals in India. The river water is mainly used for power generation and irrigation and many large canals draw water from it. There are many hydroelectric and irrigation projects across the river such as the Bhakra-Nangal Dam, Kol Dam, Nathpa Jhakri Project and Baspa Hydel Scheme. There has been a proposal to build a 214 km long heavy freight canal, to be known as the Sutlej-Yamuna Link (SYL), in India to connect the Sutlej and Yamuna rivers.[20]

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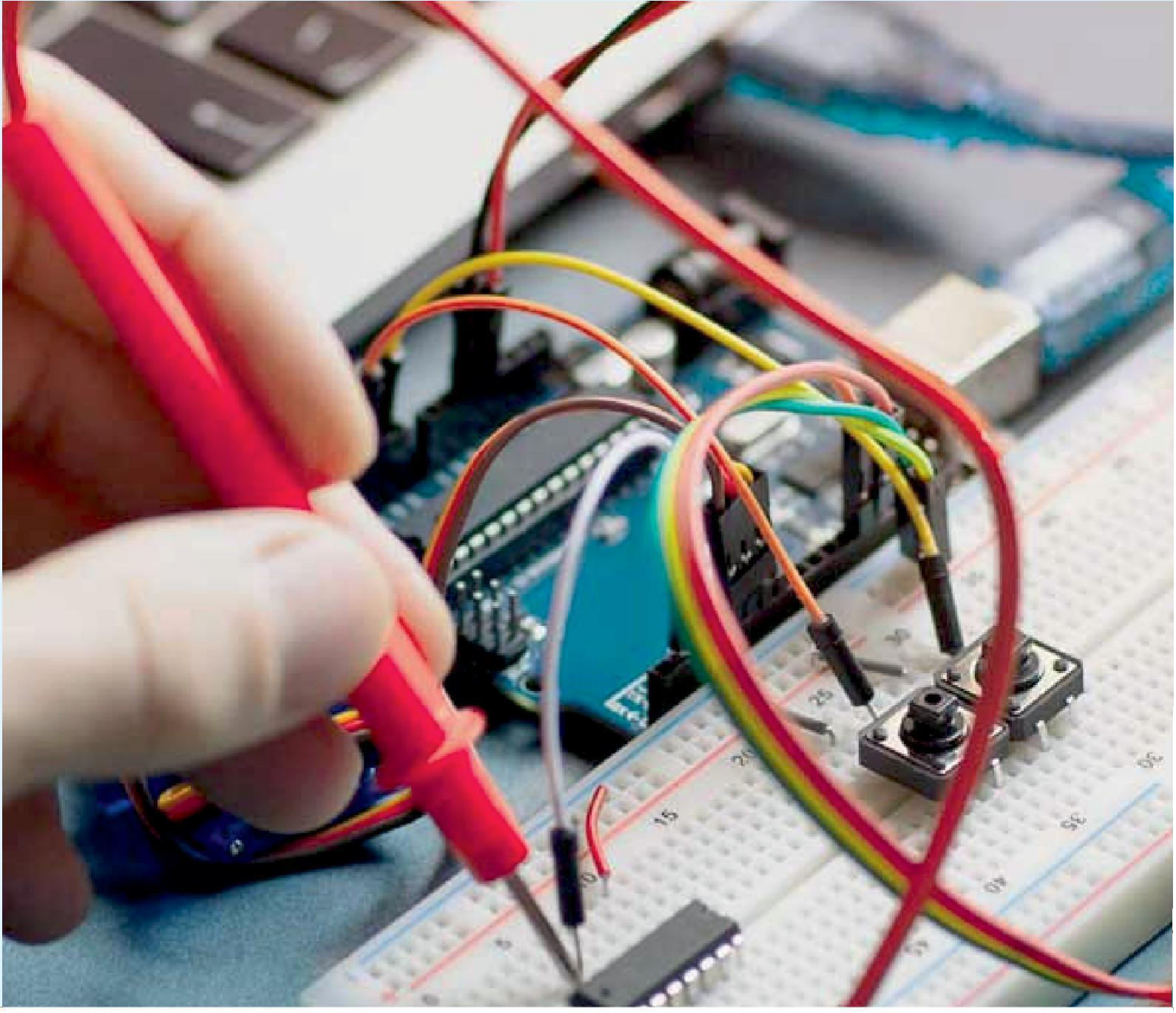

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