Buntun Water Level-Based Interactive Community Flood Map

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***Abstract*— Flooding, a destructive force of nature, has experienced a significant increase in both frequency and severity over recent decades. This calamity occurs when heavy rainfall causes rivers to overflow, resulting in numerous casualties and substantial economic losses. To address these alarming events, researchers have developed a river flood mapping system for the Cagayan River. By utilizing water level data obtained from the Buntun Bridge sensor, this system employs remote sensing and GIS techniques, particularly a Digital Elevation Model (DEM), to identify areas prone to flooding and visualize the extent of the flood. The system also identifies structures at risk and provides a list of affected families. To evaluate its usability, the study employed metrics such as efficiency, effectiveness, and satisfaction. The results revealed a high task completion rate and low user error, indicating successful task execution and demonstrating the system's well-designed and easily understandable nature.**

Keywords*— *river flood, geographical information system, remote sensing, digital elevation model (dem), river flood mapping, usability metrics

I. INTRODUCTION

The frequency and severity of natural disasters have increased in recent years, with calamities occurring three times more frequently than before, as reported by the Food and Agriculture Organization of the United Nations [1]. Among these disasters, floods stand out as the most dangerous natural hazard worldwide [2]. The immediate consequences of floods include loss of life, property damage, crop destruction, livestock loss, and the spread of waterborne infections, leading to deteriorating health conditions. Furthermore, floods can cause significant damage or destruction to critical infrastructure such as power plants, highways, and bridges, disrupting economic activities and displacing communities [3] [4].

Within Asia, floods have long been a significant threat, and the Philippines is no exception [5]. In November 2020, the residents of Cagayan experienced the devastating aftermath of Typhoon Ulysses, as the release of water from the Magat Dam resulted in a surge that affected nearly 350,000 individuals [6]. This incident prompted authorities to seek improvements in the region's flood early warning and monitoring systems, particularly in low-lying areas such as Cagayan Valley [7].

Previous studies have introduced solutions to address flood monitoring and early warning systems in the Philippines. For instance, one study developed a flood monitoring and early warning system using ultrasonic sensing and GSM technology, focusing on the northern part of the province of Isabela and the municipalities near the Cagayan River [8]. This project aimed to detect the water level of the river and provide residents with real-time information. However, it did not cover the other two crucial phases of flood management: preparedness and damage assessment. Another existing initiative is the University of the Philippines' Nationwide Operational Assessment of Hazards (UP NOAH) Center [9]. This nationwide disaster management program utilizes GIS techniques to generate multi-hazard maps, estimating flood sizes, affected districts and sub-districts, and overall flood risk [10][11][12]. GIS technology has proven valuable in flood control, adaptation, and water resource management, providing an excellent tool for addressing drought and flood risk [13]. However, the information available on the UP NOAH website is limited to visual representations of a 100-year flood return period and a five-meter storm surge extent.

The limitations identified in previous attempts have motivated researchers to develop a system to enhance flood information and management in three flood-prone barangays in Tuguegarao City. This study utilizes remote sensing data and Geographic Information System (GIS) techniques for flood analysis. The developed system collects water level readings of the Cagayan River from users and identifies structures and lists families susceptible to flooding based on the input values. Additionally, the system allows users to locate residences by typing residents' names. However, it is important to note that this study focuses solely on system development and requires further validation of the flood extent analysis.

II. RELATED WORKS

Floods are a pervasive natural catastrophe with devastating effects on both people and property. The frequency and magnitude of this natural disaster have increased in recent decades, leading to significant economic damage and the loss of thousands of lives [14]. While floods pose a global concern, the majority of flood-affected individuals reside in Asia, with more than two-thirds of the population in certain subnational regions facing the risk of flooding [15]. Numerous interventions have been implemented to assist communities in flood preparedness, risk mitigation, and emergency response and relief. However, many of these initiatives lack the necessary resilience and resources to provide sustainable and effective support to those in need. In other regions, remote sensing and geographic information systems (GIS) have been utilized to illustrate the impact of climate change-induced floods in Southern Africa, aiding decision-makers in formulating strategies for future occurrences [12].

A study conducted in Metro Manila emphasized the long-term and continuous effects of floods, establishing them as the most dangerous natural hazard. The researchers examined specific areas to guide future flood control measures, employing a multi-criteria technique that considered social and environmental factors within barangays. Population density, gender, age, structural materials, and recorded flood depths were taken into account, and GIS, using multi-criteria techniques, served as the analytical tool by gathering relevant GIS layers from various government agencies. The study revealed that higher population densities, a larger proportion of elderly and children, weaker structural materials, and higher recorded flood levels all correlated with an increased risk of barangay flooding [16].

A similar approach was applied in the transboundary Shatt Al-Arab basin in Iran, where researchers emphasized the potential threats floods pose to human lives, the economy, and the environment. To assess the overall flood risk, a hazard model was developed to identify flood-prone zones within the basin. Geographic information systems (GIS), multi-criteria decision analysis (MCDA), and the analytical hierarchy process (AHP) approach were employed to create a flood hazard map, assigning appropriate weights to different factors affecting flood risk. The study considered rainfall patterns, proximity to the river, slope, land use/land cover (LULC), drainage density, soils, and lithology. The resulting flood hazard map categorized the area into high, intermediate, low, and shallow flood hazard zones, covering approximately 20%, 40%, 39%, and 2% of the area, respectively [17].

In Pune City, Maharashtra, India, a Flood Map study utilized various data sources, including SOI toposheets, a Digital Elevation Model (DEM), ground truth data obtained through Differential-GPS GCP, and discharge data from the Water Resources Department of the Maharashtra Government. A DEM was created for the city's territory and processed using the Arc Hydro tool for fill and sink analysis. The study analyzed the likely discharge from the Khadakwasala Reservoir for different scenarios and determined the corresponding submergence areas. It revealed that wards situated downstream of the reservoir were most susceptible to flooding and experienced the highest extent of floods in terms of affected population [18].

Another study conducted in Ethiopia aimed to identify the factors contributing to flood occurrence by analyzing data on soil, slope, elevation, drainage density, land use, and land cover. The relative importance of these components was determined through expert opinions and the Analytic Hierarchy Process (AHP). The collected data were processed using ArcGIS and the AHP method. The study identified high and very high flood-risk zones covering approximately 43.28% and 13.09% of the area, respectively. The findings emphasized the need for regular and effective flood prediction, early warning systems, and management techniques [19].

III. METHODS

Fig. 1 depicts the flowchart outlining the process of creating the flood map. The study utilized a raster digital elevation model (DEM) to obtain elevation values for different parts of the study area. The following steps were followed in the process:

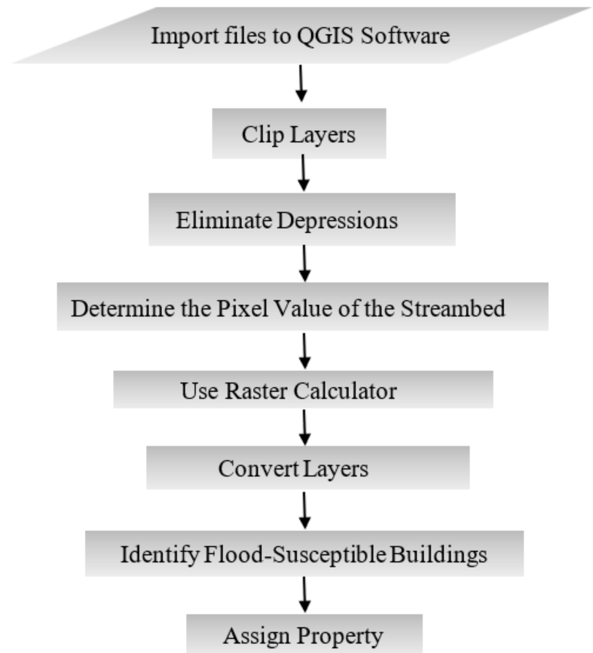

Fig. 1. Process Flowchart of the Study

The study area consisted of the barangays Annafunan East, Annafunan West, and Linao West, encompassing a population of over 10,000 people in the north-west part of Tuguegarao City.

For the study, the researchers used the ALOS PALSAR RTC Digital Elevation Model with 12.5m accuracy, obtained from NASA's Earth Data website. Before analysis, the merged DEMs underwent sink filling to ensure accurate basin and stream delineation. Sink filling was performed using the Sink Fill tool by Wang & Liu in the SAGA processing toolbox. Additionally, vector layers such as the study area shapefile and structures vector layer were obtained from the PHILGIS website and QuickOSM plugin, respectively.

To obtain the points representing each structure, the researchers employed the Centroids tool in the Vector toolbox, using the vector layer of buildings as the input. After converting the building polygons to points, the Select by Location tool was used to identify which structures were within the study area, while discarding those outside of it.

To identify flooded areas based on the rise in river water, the researchers calculated the average pixel value of the streambed, specifically the location where the water level sensor was installed. This was accomplished using the Value Tool in QGIS and the filled DEM. The Raster Calculator was then used with a specific expression to generate a raster indicating flooded and non-flooded areas. The resulting raster was converted into a polygon, disregarding zero-value pixels, and further converted into a vector using the Polygonize tool.

To identify flooded buildings according to the rise in river water, the researchers employed the Select by Location tool, comparing the centroids of structures with the flooded area polygon. The flooded structures were selected, and the attributes table was used to assign a water level property indicating at which level each structure would be flooded. This process was repeated for each increase in river water.

The study utilized QGIS, a cross-platform desktop geographic information system program, as the GIS software. QGIS is open-source and free, allowing developers to view, modify, and analyze geographic data. It offers tools for calculating raster values and supports various operating systems. QGIS provides features and capabilities similar to proprietary software programs, making it a competitive alternative. It is widely used in scientific investigations involving spatial analysis, urban planning, soil and water research, and ecology. The open-source nature of QGIS facilitates knowledge-sharing and allows people to access GIS technology and free data available online. QGIS was used in this study to prepare the GEOJSON data required for website development.

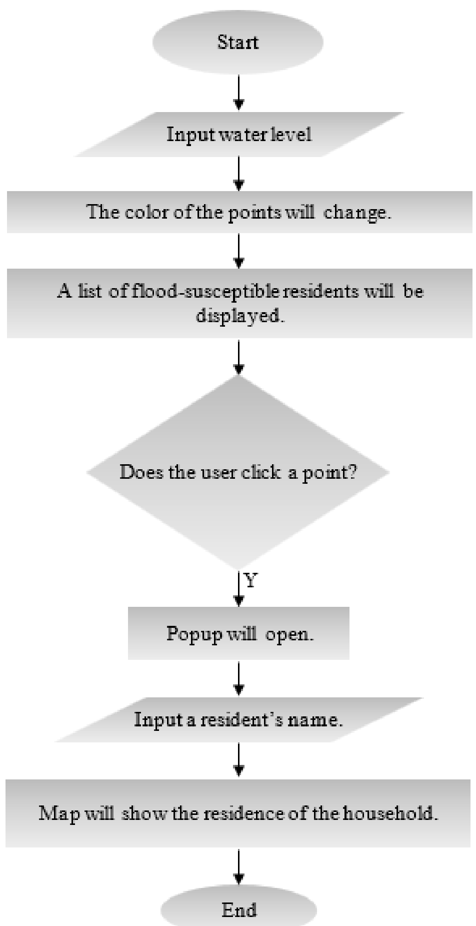

Fig. 2. Flowchart of Using the Website

The website development for this study was carried out using Visual Studio Code, an Integrated Development Environment (IDE) developed by Microsoft. The website itself was implemented using HTML5, CSS, Bootstrap5, and Javascript. Given that the website included a map, the researchers utilized the Leaflet library, which not only facilitated the integration of the map but also provided interactive functionality.

Fig. 2 illustrates the operations and functionalities of the system. When the user inputs the reading from the water level sensor on the Buntun Bridge, the points representing structures or residences on the map will dynamically change their color. The color variation corresponds to the severity of the flood that each structure or residence is projected to experience. Additionally, the system will display a list of affected barangays along with the number of residents at risk of river flooding in each barangay. When a user clicks on a specific point on the map, a popup window will appear, presenting additional information about the corresponding structure. Lastly, if the user submits a resident's name, the system will pinpoint the location of their house on the map.

The combination of Visual Studio Code, HTML5, CSS, Bootstrap5, and Javascript enabled the researchers to create a user-friendly and interactive website. The integration of the Leaflet library further enhanced the map functionality and allowed for the display of relevant flood-related information.

System evaluation is performed to assess if the system meets the demands of the users. According to ISO 9241-11, usability is “the degree to which defined users may use a product to achieve stated goals with effectiveness, efficiency, and satisfaction in a given context of usage” [23]. Three criteria are often used to assess usability: efficacy, efficiency, as well as satisfaction [24]. These three metrics were used to evaluate and examine the usability of this study’s system.

ISO9241-11 defines effectiveness as “the accuracy and completeness with which users fulfill stated goals.” This usability statistic solely considers how much a goal was reached, not how it was met. It is derived by calculating the task completion rate [24]. The task completion rate is regarded as an essential usability statistic. It may be calculated by assigning a binary value of ‘1’ to each completed task and a binary value of ‘0’ to each uncompleted task by a participant [24]. The task completion rate was computed as a percentage [24] in the study using (1), where NTCS is the number of completed tasks and TNTU is the total number of tasks attempted.

$$Task\ Completion\ Rate = \left(\frac{NTCS}{TNTU}\right) \times 100\% \qquad (1)$$

Another way to assess effectiveness is to tally the total number of mistakes a participant makes while completing a task [25]. Errors can take numerous forms, such as blunders, unintentional clicks, slips, or omissions made by a person while doing a task.

Another significant usability statistic is efficiency, which relates to the resources used to complete a task [26]. It can be quantified in terms of the average time required to complete a task [24]. Time on task is the most used metric of efficiency in usability evaluation [27]. A stopwatch was used to record each user's time on the task, and geometric mean was used to determine the average task duration for each trial. The geometric mean is used in research dealing with small sample sizes[28]. Satisfaction is the user's subjective reaction to a product or service after a usability evaluation is done [24]. To numerically assess user satisfaction, standardized surveys based on the Likert scale may be employed [29]. The Single Ease Questionnaire, a Likert scale variation, is known to assess task performance satisfaction on usability testing [30]. This task-level approval metric was issued after the users had tried doing the task, regardless of whether the task was completed. The SEQ consists of simply one question with seven levels as shown in Fig 3.

Overall, using the web application was?

Very Difficult						Very Easy
1	2	3	4	5	6	7

Fig. 3. Single-Ease Questionnaire

For the data collection phase of the study, a sample of fifteen individuals was selected as study participants. These participants were provided with personal computers or laptops that had internet access, and they were instructed to access the website for evaluation purposes. Among the participants, ten were individuals serving in their barangay's local government units, while the remaining five were information technology experts.

To ensure systematic data collection, a timekeeper was assigned to record the duration of each participant's interaction with the system. This timekeeping process aimed to capture the time spent by participants on various tasks and activities within the website. Additionally, an observer was responsible for documenting any faults or errors made by the participants during their interactions with the system. The observer also noted whether the tasks were completed. All usability data from each trial were carefully recorded in a Microsoft Excel file.

The data collection process was conducted independently for each participant, utilizing experimental approaches to gather usability metrics. Participants were informed that they were not obligated to complete the tasks and were free to stop or reload the system at any point during the evaluation. A timer was used to track the time taken to complete each task, while the observer noted any mistakes made by the participant during task execution. Once a task was finished, the participant would notify the observer. Furthermore, participants were asked to provide feedback on their satisfaction with the task upon its completion. To assess usability, the process was repeated three times to observe if any changes in findings occurred during the third use.

IV. Results and Discussion

Fig. 4 showcases an example of a flood susceptibility map, specifically highlighting the scenario when the water level reaches 12 meters. The study successfully generated flood susceptibility maps for each increment in river water level. Additionally, the figure provides a sample list of flood-susceptible residents corresponding to that specific water level.

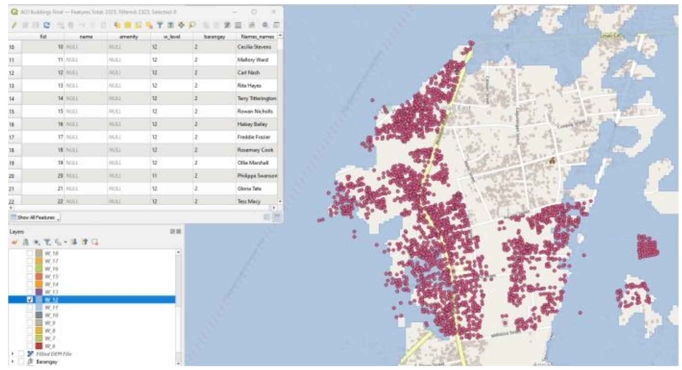

Fig. 4. GIS Flood Susceptibility Map (Water Level = 12)

The user interface of the system adopts a card-based design, ensuring that users can easily comprehend the overall data without worrying about navigation complexities. This design approach has proven effective in enhancing interactivity and usability [31] while maintaining a consistent user interface across different devices. On the left side of the interface, users can view the map displaying the structures within the study area, marked by points. The right side consists of textboxes, lists, and buttons that facilitate map interactivity.

Fig. 5. User Interface of the System

To input the water level, users can utilize a dedicated textbox within the system. The textbox restricts input to integers only. Upon clicking the submit button, the system dynamically fills the points on the map with distinct colors, each representing the severity of flood susceptibility. The color coding of the points is determined by the properties specified in the GEOJSON data. Additionally, the system presents a list of flood-susceptible residents corresponding to the selected water level.

The points on the map are clickable, enabling users to access additional information about each structure through pop-up windows. These pop-ups may provide details about the household or family residing in a particular structure. Furthermore, users can utilize the textbox to input a resident's name, and upon clicking the submit button, the system will display the location of that specific resident. The system also provides lists indicating the number of residents susceptible to flooding in each barangay. Users have the option to print these lists or save them as PDF files by clicking the print button.

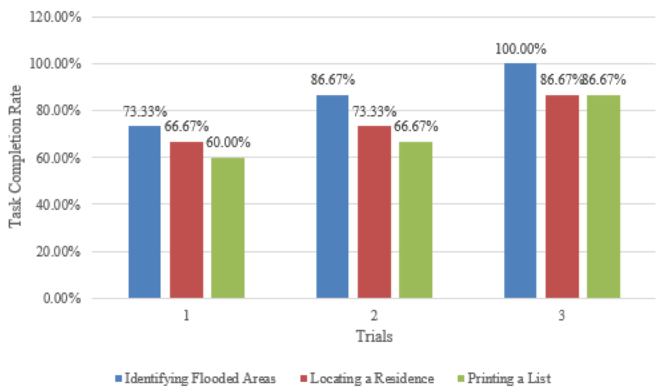

Fig. 6. Task Completion Rate per Trial

Fig. 6 depicts the web system's efficacy based on the task completion rate. Eleven of fifteen participants accomplished the task in the first trial of inputting a water level reading to see flood-susceptible structures. It should be mentioned that these participants were first-time users of the system. The task completion rate increased on the second attempt, with thirteen individuals completing the task. Because all the participants completed the task satisfactorily on the third trial, the completion rate was much higher.

The second task was to type a resident's name in the textbox to locate the place they reside. Ten out of fifteen users did the task successfully in the first trial. The task completion rate slightly increased during the second trial because eleven users successfully located a resident's house. On the third trial, thirteen individuals accomplished the task.

The last function to be evaluated was printing a list of flood-susceptible residents according to the input water level reading. This task has the lowest completion rate because the participants must remember to input a water level before clicking the print button. In the first trial, nine of fifteen participants completed the task. The rate increased in the second trial, with ten users successfully printing a list. In the third trial, there was a significant increase in the percentage, with thirteen users finishing the task.

Even though it was their first time utilizing the system, most trial participants completed the task. This is due to the system's brief, concise, and self-descriptive text content, which gave participants a sense of what type of data to submit into the text boxes. The mentioned characteristics of the website are desirable features of an exemplary user interface [32]. Furthermore, the system's architecture is user-considerate [31], allowing users to operate the program without previous training. The second trial for each task had a significantly greater completion rate than the prior, but still, some individuals were unable to finish some of them. The third trial exhibited a very high task completion rate that exceeded the average task completion rate benchmark of 78% utilized in prior research [33] [34].

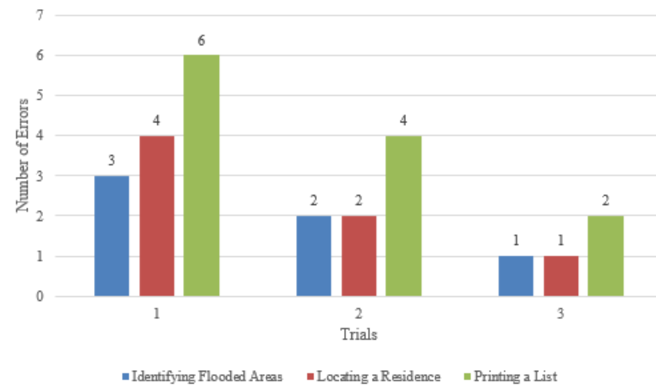

Fig. 7. Number of User Errors per Trial

The participants omitted errors while completing the different tasks, as shown in Fig. 7. The highest count of errors was during the first trial of each task. The numbers went down on the second and third try of the users. Among the three functionalities of the website, the errors were mainly in printing the list task, followed by searching for a resident's house. The users made little to no mistakes when entering water level values to identify flood-susceptible structures. The user errors included not entering a water level value before clicking any print buttons, accidentally closing the main browser instead of closing the printer options window, and typographical errors when typing a resident's name. Some users also included the word 'meter' or the letter 'm' when inputting a water level value, even though it is already indicated in the textbox placeholder that the input is treated in meters. The count of committed errors consistently went down on the subsequent use. This observation demonstrated that when users were already familiar with how to use the program, there would only be a tiny probability that they would make the same mistake again. perceived, anticipating and accepting user faults offers a layer of security and a sense of mastery in using the site and may contribute to a perceived excellent user experience [35].

Fig. 8 presents the average time it took for the participants to finish the different tasks. The first trial of each task holds the highest average time, but these numbers decreased in the subsequent attempts. There is no noticeable difference between the second and third trials. Among the tasks, list printing consistently held the highest average time. There was also a delay in locating a residence and identifying flood-susceptible structures because the slow internet connection caused the map to load slowly.

The positive efficiency testing results may be ascribed to the user interface's card base design. Participants were only confined to one screen to perceive the data clearly without worrying about where to go or what to navigate. The card design technique synced the gap between interactivity and usability [32] to establish a uniform user interface design across devices. The only issue was a sluggish internet connection, which caused the map to take too much time to load. This was also an issue with another internet-based system [26] because the Philippines has one of Asia's slowest internet connections.

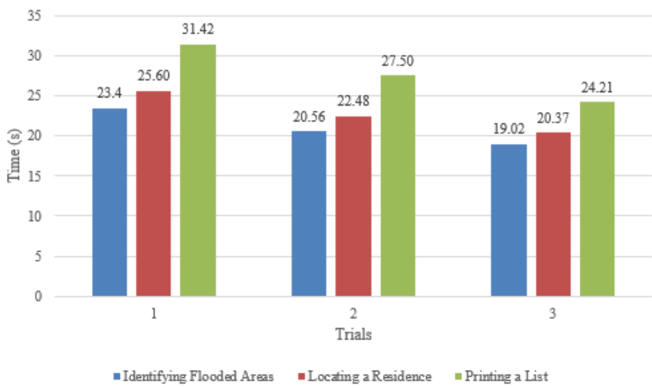

Fig. 8. Average Time on Task per Trial

Fig. 9 depicts user satisfaction with the system. After utilizing the system several times, seven participants thought the system was straightforward to use. The remaining commented that learning how to use the system is easy and can be mastered in no time.

The results showed that user satisfaction was related to task completion rate and the number of omitted errors. Participants who completed the test without errors thought the tasks were effortless, while those who made errors and did not finish some of the tasks regarded the assignment to be challenging. This is consistent with the reference study [36], in which task completion rate and error are associated with user satisfaction.

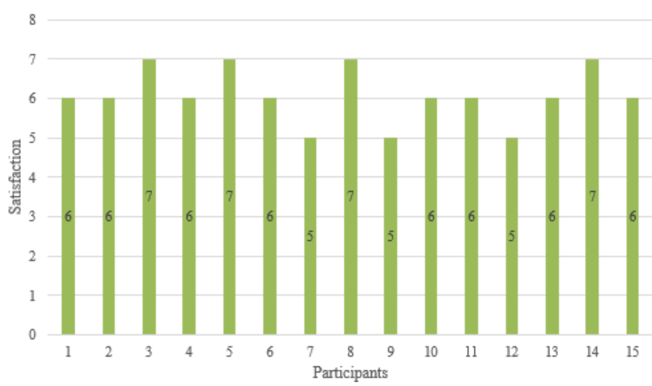

Fig. 9. Average Time on Task per Trial

V. Conclusion

This study aimed to assess the vulnerability of structures in the barangay local government units of Annafunan East, Annafunan West, and Linao West during a flood. It successfully achieved its objectives by implementing functionalities that allow users to input a water level value, locate a residence, and print a list of names of locals who are at risk of flooding. The usability metrics employed in this study indicate a high task completion rate and a low user mistake rate, suggesting that the participants were able to complete the tasks with minimal errors. These results reflect the effectiveness of the study design and its ability to provide reliable and valuable insights.

For future work, it would be beneficial to develop a mobile application version of the system. This would enable residents to access flood risk management information and receive notifications directly on their mobile devices. Additionally, conducting usability testing in a controlled laboratory environment with simultaneous participation from multiple individuals would enhance the accuracy of the results and provide further insights for system improvement.

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