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RESEARCH ARTICLE

Hydrometeorology, sediment dynamics, and peak flow analysis of the Manohara Watershed, Kathmandu, Nepal

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ABSTRACT

The Manohara River, a fifth order river, is located in the north-east part of the Kathmandu Valley. Manohara River is the main source of groundwater for Madhyapur Thimi, Changunarayan, Sali Nadi, Tribhuvan International Airport and other places located around this river. The research work mainly focusses on the Hydrometrological impacts, sediments distribution and peak flow estimation of the Manohara River covering the area of the Kathmandu and Bhaktapur districts within its watershed. Desk and field study were carried out to collect primary and secondary data: and was used to interpret the sediment distribution and the peak flow of different return period of the Manohara Watershed. Data from Department of Hydrology and Meteorology were collected to study the variation in the rainfall pattern within the study area. The Manohara watershed experiences highest rainfall during the monsoon season, with less precipitation in post-monsoon. Rainfall is highest in the northeast while decreases along the southwest, influencing sediment transport from boulders upstream to finer materials downstream. The Manohara Watershed experienced significant variations in annual average precipitation, with a maximum of 7.4 mm in 2016 in the Sankhu section and a minimum of 1.97 mm in 1991 in the Airport section, while the Bhaktapur section recorded a yearly maximum of 195 mm in 2002. Estimating peak flow rates using the updated DHM method yielded maximum discharges of 455 m^3/s and 92 m^3/s for 100-year and 2-year return periods, respectively, while the Dickens method provided estimates of 325 m^3/s and 110 m^3/s for the same periods.

Keywords: ***Manohara River, Artificial recharge, Sediment dynamic, Peak flow estimate***

INTRODUCTION

The Manohara watershed, located on the southern slope of the Nepal Himalaya within the Kathmandu basin, spans approximately 73 km^2. It is primarily filled with Quaternary fluvio-lacustrine sediments (Yoshida and Igarashi, 1984) and underlain by older geological units such as the Precambrian Bhimphedi Group and the Lower Paleozoic Phulchauki Group (Stöcklin and Bhattarai, 1977). The Manohara River, a major tributary of the Bagmati River, flows from northeast of the Kathmandu Valley and is fed by several tributaries including the Sali Nadi, Ghatte Khola, Mahadev Khola, and Satghatte Khola.

Water from the Manohara River is essential for groundwater recharge. However, high population density, agriculture, and industrial practices have led to water crises and declining groundwater levels. The primary sources of groundwater recharge include monsoonal and non-monsoonal rainfall, seepage from wet farming practices, and seepage from water bodies. Significant surface runoff exacerbates groundwater depletion, necessitating artificial recharge. Flooding and river channel shifts, driven by bank erosion, down-cutting, and land use changes, pose significant threats to life, property, and local heritage sites such as Changunarayan and Sali Nadi Temple. Understanding the hydrometeorology, sediment dynamics, and peak flow characteristics of the Manohara watershed is crucial for mitigating these hazards and promoting sustainable water management practices.

Dongol (1985) describes the fluvio-lacustrine sediments of the Kathmandu Valley as predominantly consisting of fine and coarse sand, sandy loam, sandy silty clay, and gravelly conglomerate, covering around 200 square kilometers of Cambrian-Precambrian rocks. In the central portion of the valley, these sediments are nearly horizontal, but they are tilted in the southern section. JICA (1990) grouped the valley's sediment composition into two geological successions: Quaternary deposits overlying the central part's basement rock and Precambrian to Devonian basement rocks surrounding the valley. The depth from the surface to the basement rock ranges from tens of meters to 500 meters. Quaternary deposits consist of lacustrine and fluvial sediments, classified as arenaceous, argillaceous, and intermediate types. JICA also proposed three groundwater districts in the Kathmandu Valley based on water accessibility and lithological variation.

Jnawali and Busch (2000) prepared an environmental geological map of the Kathmandu Valley to highlight geological hazards. They identified the Manohara, Bansbari, Dhobi Khola, and Gokarna well fields in the north, which extract water from sandy layers of the Gokarna and Tokha Formations, and the Pharping well field in the south, which draws from the Lukundol and Kobgaon Formations. They also noted that surrounding mountain ranges are potential areas for groundwater recharge. Tamrakar and Bajracharya (2009) conducted geomorphological, hydrological, and sedimentological analyses of the Manohara River, revealing significant instability, including an 8% increase in the meander belt area and a 32% expansion in the river's average width since 1995. They recommended minimizing anthropogenic disturbances, implementing bank protection measures, and regulating riverbed mining. Pandey et al. (2010) used DPSIR analysis to assess groundwater in the Kathmandu Valley, finding that population growth, urbanization, and tourism have reduced surface water availability, decreased aquifer recharge, and increased groundwater extraction, leading to a groundwater level drop of 13-33 meters from 1980-2000 and 1.38-7.5 meters from 2000-2008, raising subsidence risks in areas with compressible clay and silt layers.

With this background, this study will explore the interplay of hydrometeorology, sediment dynamics, and peak flow in the Manohara Watershed. It aims to understand the region's precipitation and runoff patterns, how sediment transport affects stability and water quality, and how peak flow insights can inform flood risk management. As a result, it is expected to enhance the understanding of the watershed in order to support effective strategies for its sustainable development.

STUDY AREA

The Manohara River watershed (Fig. 1), located in the northeast of Kathmandu Valley, covers an area of 73 sq.km. Originating in the Shivapuri hills, the river has about 28 km length spanning between latitudes 27°40'00" N to 27°47'00" N and longitudes 85°20'07" E to 85°31'07" E. The study area includes parts of northeastern Kathmandu and certain regions of Bhaktapur districts. The river features a straightened upstream section and a meandering, broad downstream section. Its tributaries are the Sali Nadi, Satghatte Khola, Mahadev Khola, and Ghatte Khola. Well-connected by motor roads, including the Mulpani-Sankhu black-topped road and the Jadibuti-Mulpani road, the area is easily accessible.

DATA AND METHODS

For this study, a range of equipment and software was used. Fieldwork involved a GPS for location coordinates, a digital camera for photographs, a geological hammer for lithology, a measuring tape for sediment depth, and sample bags for collecting samples. Data processing and analysis utilized Google Earth, Microsoft Excel, Adobe Illustrator, and ArcGIS 10.4. Secondary data included topographic maps, published reports, and past rainfall records from the Department of Hydrology and Meteorology (DHM). High-resolution satellite images from Google Earth and a digital elevation model (DEM) from ALOS PLUE were used for recent land cover and geomorphological analysis.

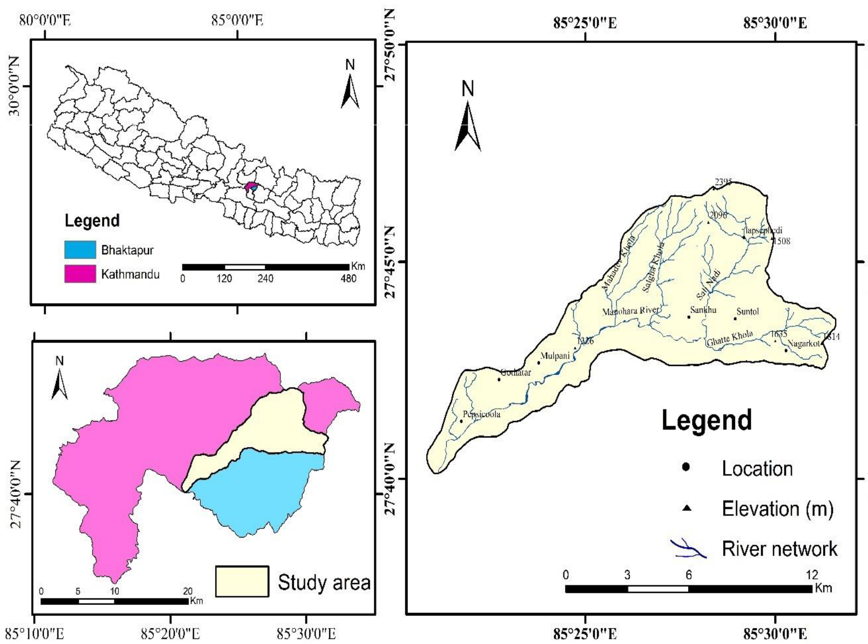

Fig. 1: Location map of the study area (a) Map of Nepal Showing Kathmandu and Bhaktapur districts (b) Present study area (c) Drainage pattern of the Manohara River watershed

Field work was carried out over 7 days to examine sediment distribution in the river deposits. This included documenting sediment dynamics, variations from upstream to downstream, and estimating the Manning's 'n' coefficient based on land use/land cover (LULC). Observations were made on river channel meandering, bank erosion, and sediment deposits. Land use/land cover and channel shifting were verified. Soil samples were collected from various locations for soil characterization and property analysis with preparation of the suitable columnar section of the different stretch of the Manohara watershed.

Estimation of peak flows of different return period

WECS/DHM method

The water and Energy Commission Secretariat (WECS) and Department of Hydrology and Meteorology (DHM) created empirical relationships based on data collected from many stations for use in the context of Nepal. The following equation form the basic approach.

$$Q_2=1.8767(A_{2000})^{0.8783}$$

$$Q_{100}=14.639(A_{2000})^{0.7342}$$

Where, Q_2 and Q_{100} are the 2-year and 100-year extreme flows respectively and A_{2000} is the Basin area (Km2) below 2000m elevation (higher elevation where monsoon rains have a stronger influences). The following Equation is used to determine discharge for other return period.

$$Q_r= \exp (\ln Q_2+ S\ \sigma)$$

Where Qr is the flood of T year return period (m3/s) S is the standard normal variate and σ is a parameter that is obtained from the following equation.

$$\sigma =\ln (Q_{100} / Q_2) / 2.326$$

Modified Diken's Method

Modified Dikens method is also widely used method in Nepal (Rijal, 2014) to estimate the extreme discharge. The formula used is

$$Q = C \times A^{2/3}$$

Where Q is discharge in m3/ s, A is drainage basin area in Km2 and C is coefficient ranging from 10 to 35 and is calculated by using the following formula.

$$C = 2.342 \log (0.6 \times T) \times \log(1185/p) +4$$

Where, T= return period in year, P= 100(a+6)/(a+A), A is total drainage basin area in Km^2 and "a "is perpetual snow area in Km^2.

RESULTS

Hydrometrological study

The hydro-meteorological conditions of the Manohara Watershed were assessed by using 22 years of rainfall data from Kathmandu Airport, Changunarayan, Bhaktapur, and Sankhu stations, sourced from the DHM. The study indicates that while precipitation influences river discharge, specific discharge data is unavailable as the river is ungauged. Rainfall data from Kathmandu Airport, Changunarayan, Bhaktapur, and Sankhu stations were used to calculate annual precipitation. The variation in annual average precipitation across these stations since 1990 is illustrated in fig 2.

Fig. 2: Annual average precipitation of the Manohara watershed from 1991AD to 2022 AD of the different stations

The yearly maximum precipitation recorded at Changunarayan Station was 165 mm in 2002, with high levels during the monsoon (June-September) and lower amounts in the post-monsoon (October-January). The precipitation has fluctuated from 165 mm in 2002 to 86.5 mm in 2022, showing a decreasing trend over the years. For Sankhu Station, the maximum precipitation was also 165 mm in 2002, but it fluctuated between 179.5 mm and 41.6 mm over the years, with a similar decreasing trend. Kathmandu Airport Station recorded a maximum of 177 mm in 2002, with high precipitation in the monsoon and less in the post-monsoon period. The precipitation here ranged from 177 mm in 2002 to 75 mm in 2022, showing a decreasing trend as well. The maximum precipitation in different station of Manohara watershed yearly has been presented in fig 3.

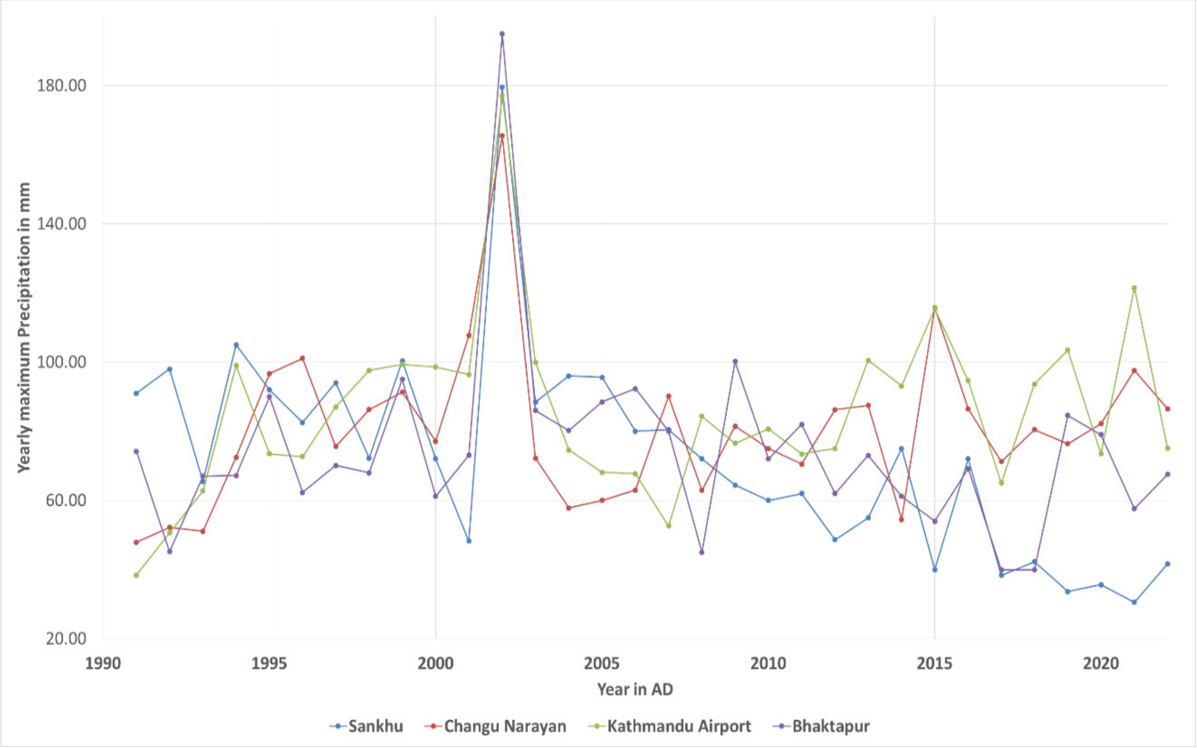

Fig. 3: Yearly maximum precipitation of the Manohara watershed from 1991AD to 2022 AD of the different stations

Sediment Dynamics

The origin of the Manohara River is at Shivapuri Hill and flows through flat plains of the Kathmandu Valley, depositing coarse sediments nearby its foothills section with sparse vegetation. The river deposits boulders, cobbles, pebbles, and sand, with larger gravel sizes up to 162 cm (dia) in the Danda Kateri and Sankhu segments. The middle section (Kurthali) is mostly sandy with some cobbles, pebbles, and clay, while the lower section (Mulpani to Sanothimi) has increasing sand deposits and decreasing pebble and cobble sizes, lacking boulders. Sediment composition (Fig. 4) varies, with upstream areas having sandy gravel and gravelly sand, and downstream areas having sandy silt and silty sand. Gravels in different sections are composed of various rock types, including granite, gneiss, and sandstone. During dry periods, abundant materials on the riverbanks are often extracted for construction.

Fig. 4: Sediment Distribution in the (a) Middle Section (Kurthali Section), (b) Middle Lower Section (near Nepal Engineering College), (c) Lower Stretch (near Har-Har Mahadev), and (d) Near the Confluence with the Hanumante River of the Manohara River

The columnar sections of the upper, the middle and the lower stretch of the Manohara River are presented in fig 5.

Peak flow estimation

The estimation of peak flow for the Manohara River across various return periods, calculated using three different methods, is detailed in Table 1, with a graphical comparison presented in Figure 6. The methods used to estimate peak flow include the WECS/DHM method and the Modified Dickens method. Among these, the modified WECS/DHM method consistently shows higher discharge values for longer return periods, indicating a greater expected peak flow during significant flood events. This comparison highlights the variability and potential impacts of using different methodologies for hydrological predictions.

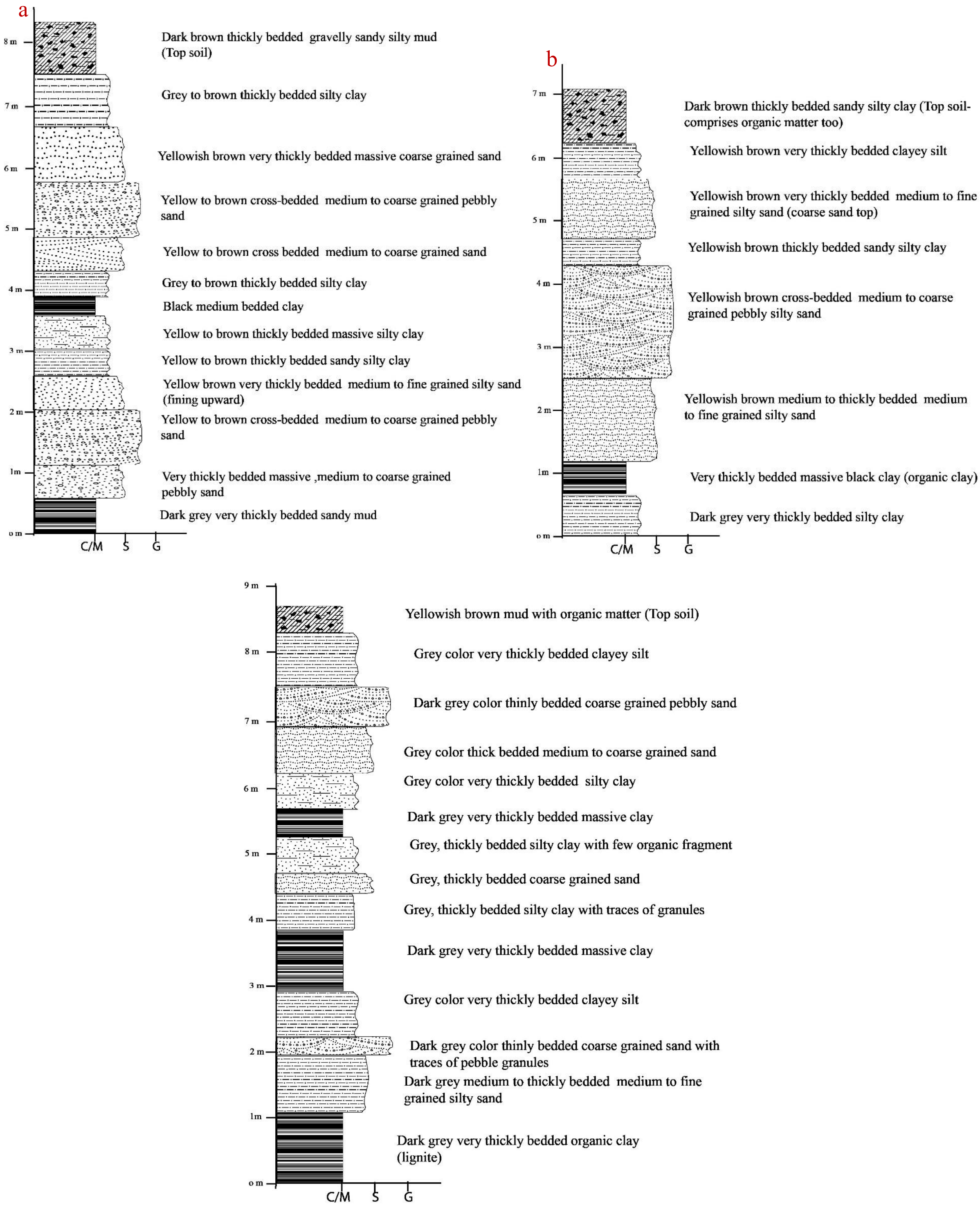

Fig. 5: Columnar section of (a) the upper stretch (Dadakateri Area), (b) the middle stretch (Kurthali area) and (c) the lower stretch (Jadbuti) of the Manohara River

Table 1: Estimated peak flow of Manohara River for different return periods

Return Period (Years)	Discharge (m^3/s)		
	Modified Dicken's Method	(WECS/DHM method)	Updated (WECS/ DHM method)
2	110	82	92
5	160	138	164
10	198	181	222
50	287	292	377
100	325	345	455

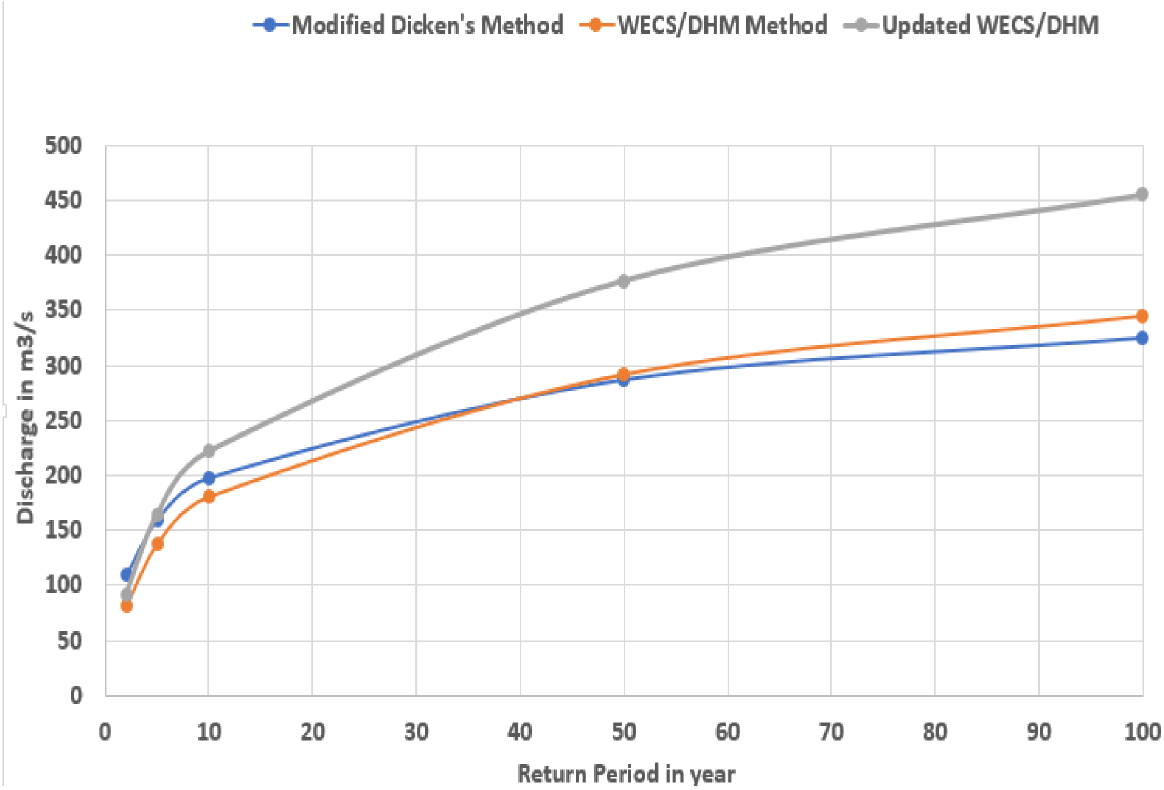

Fig. 6: Peak flow of the Manohara River estimated by different method for different return period

Analyzing the discharge for various return periods reveals that the Modified Dickens method estimates up to 325 m^3/s for a 100-year return period, whereas the WECS/DHM method estimates a higher discharge of up to 455 m^3/s. For a 2-year return period, the Modified Dickens method shows a higher discharge of about 110 m^3/s, while the WECS/DHM method indicates a lower discharge of approximately 92 m^3/s.

DISCUSSION

Similar to other regions globally, Nepal has experienced changes in rainfall patterns, with a noticeable increase in high-intensity rainfall events. This trend is largely attributed to ongoing climate change (Government of Nepal, 2011). As a result, the Manohara River is likely to face more frequent and severe floods, which could lead to greater inundation risks. By estimating peak flow rates, flood inundation maps can be created for various return periods. These maps are crucial for identifying potential hazard zones early, allowing for proactive measures to mitigate the impacts of flooding before disasters occur.

CONCLUSIONS

According to precipitation data from the DHM, the highest rainfall in the Manohara watershed occurs during the monsoon season (June to September), while the post-monsoon period receives significantly less precipitation. Long-term data indicate that average annual rainfall is highest in the northeastern part of the study area and it decreases toward the southwest. The Manohara Watershed experienced a maximum annual average precipitation of approximately 7.4 mm in 2016 in the Sankhu section, and a minimum of about 1.97 mm in 1991 in the Airport section. The watershed also recorded a yearly maximum precipitation of around 195 mm in 2002 in the Bhaktapur section.

The Manohara watershed, covering an area of 73 square kilometers, originates at Shivapuri Hill and flows through flat plains. Its major tributaries include the Ghatte Khola, Sali Nadi, Mahadev Khola, and Satghatte Khola. In the upper reaches, the river carries sediments ranging from boulders to gravel, while in the lower reaches, the sediment size decreases, with sand, silt, clay, and pebbles becoming more dominant.

Estimating peak flow rates enables the creation of flood inundation maps for various return periods. Using the updated DHM method, the maximum discharge was found to be approximately 455 m^3/s for a 100-year return period and 92 m^3/s for a 2-year return period. In contrast, the Dickens method estimates the maximum discharge to be 325 m^3/s and 110 m^3/s for the 100-year and 2-year return periods, respectively. These estimates are essential for identifying potential hazard zones early and implementing proactive measures to mitigate the impacts of flooding before disasters strike.

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