Article

An integrated geoinformatics and hydrological modelling-based approach for effective flood management in the Jhelum Basin, NW Himalaya

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Abstract: In the present study, using static land system parameters such as geomorphology, land cover and relief, we calculated water yield potential (RP) of all the watersheds of the Jhelum basin (Kashmir Valley) using analytical hierarchy process (AHP) based watershed evaluation model (AHP-WEM). The results revealed that among the 24 watersheds of the Jhelum basin, *Vishav* watershed with the highest RP is the fastest water yielding catchment of the Jhelum basin followed by *Bringi, Lidder, Kuthar, Sind, Madhumati, Rembiara, Sukhnag, Dal, Wular-II, Romshi, Sandran, Ferozpur, Viji-Dhakil, Ningal, Lower Jhelum, Pohru, Arin, Doodganga, Arapal, Anchar, Wular-I, Gundar,* and *Garzan* in case of same intensity storm event. The results were validated with the mean annual peak discharge values of the watersheds and a strong positive correlation of 0.71 was found. Further, for forecasting the floods in the watersheds having small lag time, such as in case of *Vishaw*, *Bringi* and *Lidder*, we evaluated the performance of HEC-GeoHMS hydrological model to simulate stream discharge during storm events. It was observed that the model performs well for august-september period with strong positive correlation (0.94) between the observed and simulated discharge and hence could be used as a flood forecasting model for this period in the region.

Keywords: HEC-GeoHMS; AHP-WEM model; Water yield potential; Water yield; Basin lag time; GIS

1. Introduction

South Asia is at the brunt of climate change related disasters. India particularly, is witnessing increased incidences of weather-related extreme events, such as floods, droughts and heat waves [1]. In September 2014, Kashmir the Northern Himalayan state of India, witnessed the most devastating flood in the recorded history of the region. Since 2014, the flooding threats in this region have been a recurring phenomenon every year [2]. The magnitude of this event crossed all bounds of the recorded history of floods in the region not only in terms of discharge but also in terms of loss of life and property [3-6]. The event has generated a scientific consensus for an alarming need of robust flood mitigation strategy for the Kashmir region. Such a problem statement for the region requires extensive data for three stages of research. First is the estimation of the contribution of the storm events within each of the 24 watersheds towards the discharge of the Jhelum River. For this, a dense network of automatic weather stations is required in each of the 24 watersheds of the Jhelum basin. The real time data can serve as input in the chosen calibrated hydrological model of the region. The model will reveal the peak of concentration or basin lag time that will serve as warning for the downstream regions. Further, such a setup would also help in assessing the comparative basin lag times of Jhelum watersheds, thus helping in prioritizing the watersheds for constructing hydraulic structures that could help in extending the peak concentration, so that rapid concentration of water in the Jhelum river resulting in the huge wave of water to promulgate, as has been witnessed in the September 2014 floods, is delayed [3]. The third important step is the vulnerability assessment of the Jhelum basin, so that a final plan is drafted where people could be desisted from building structures in the flood prone areas or those who are already living in them could be resettled in safer zones [4-6].

Considering the gravity of the situation and the topographic complexity of the region, there was a need for an immediate flood assessment that could serve as a starting step of the mitigation strategy. The present research addresses the issue of prioritization of the watersheds for the hydrological response that could reveal, which watersheds of the Jhelum basin need immediate hydraulic or other overland flow (surface run-off) management strategies. This could be achieved with the more sophisticated methodology as discussed above or there could be an alternative empirical model developed, based on the geomorphology of the Jhelum basin. There is quite a good amount of literature on the relationships between geomorphological indices and the hydrological response. There is some more research to be cited here. Altaf et al (2012) assessed the hydrological response of the sub-watersheds of the west-Lidder watershed [7]. This study, on the basis of morphometric parameters evaluated the comparative hydrological response of the sub-watersheds and suggested which of the sub-watersheds of the 14 sub-watersheds of west-Lidder watershed shows quick hydrological response in the occurrence of a storm event. Meraj et al. (2015) assessed the comparatively hydrological response of the two watersheds of the Jhelum basin. This study has evaluated a semi-quantitative index called total run-off score (*TR*), based on the collective impact of morphometric parameters, land-cover, and slope categories on the hydrological response of the Lidder and Rembiara watersheds [5, 6].

In the present study, using static land system parameters such as geomorphology, land cover and relief, we calculated comparative water yield potential (RP) of all the watersheds of the Jhelum basin (Kashmir Valley) using analytical hierarchy process (AHP) based watershed evaluation model (AHP-WEM) [8]. Further we also tested the use of HEC-GeoHMS hydrological model for using it as flood forecasting model for the region [9]. We also generated map of the locations wherein flood structural measures could be constructed as a management strategy to increase the lag time of the rapid water yielding watersheds.

2. Results

We used an integrated geoinformatics and hydrological based approach in order to holistically address the flooding problem in the Jhelum basin. Geoinformatics helped in the deducing the highest water yielding watersheds of the Jhelum basin using analytical hierarchy process (AHP) based watershed evaluation model (AHP-WEM). To come up with a flood forecast model for the Jhelum basin we evaluated the performance HEC-GeoHMS hydrological model. Finally, we used GIS based overlay analysis to find the locations for the construction of structural measures for managing floods in the affected watersheds. These results are shown below.

2.1.Analytical hierarchy process (AHP) based watershed evaluation model (AHP-WEM)

2.1.1. Watershed morphometrics and land cover of Jhelum basin watersheds

Initially, we calculated 23 morphometric parameters to compensate for geomorphology and relief of the 24 watersheds of the Jhelum basin. In order to reduce the redundancy in the information, we performed multivariate analysis on the data and as such 7 parameters were inferred that represented all the morphometric information of the watersheds [8]. For land cover, we generated 8 land cover categories governing in part, the hydrology of the Jhelum basin. The results revealed that among the 24 watersheds of the Jhelum basin, *Vishav* watershed with the highest runoff potentail is the fastest water yielding catchment of the Jhelum basin followed by *Bringi, Lidder, Kuthar, Sind, Madhumati, Rembiara, Sukhnag, Dal, Wular-II, Romshi, Sandran, Ferozpur, Viji-Dhakil, Ningal, Lower Jhelum, Pohru, Arin, Doodganga, Arapal, Anchar, Wular-I, Gundar,* and *Garzan* in the situation of same intensity storm event. (Table 1, Figure 1).

Table 1. Water yield potential categorization of Jhelum basin watersheds on the basis of AHP-WEM results

S no.	Watershed	AHP-WEM TR Score	Water yield	S no.	Watershed	AHP-WEM TR Score	Water yield
1	Garzan	13.03	Low	13	Sandran	21.36	High
2	Gundar	15.99	Low	14	Romshi	21.63	High
3	Wular I	18.11	Medium	15	Wular II	22.37	High
4	Anchar	18.83	Medium	16	Dal	22.53	High
5	Arapal	18.83	Medium	17	Sukhnag	22.83	High
6	Doodganga	19.13	Medium	18	Rembiara	23.33	High
7	Arin	19.38	Medium	19	Madhumati	23.48	High
8	Pohru	19.62	Medium	20	Sind	23.86	High
9	Lower Jhelum	20.11	Medium	21	Kuthar	24.65	Very high
10	Ningal	20.35	Medium	22	Lidder	25.48	Very high
11	Viji-Dhakil	20.43	Medium	23	Bringi	26.02	Very high
12	Ferozpur	20.60	High	24	Vishav	28.09	Very high

2.1.2. Validation of AHP-WEM

For validating AHP-WEM results, we correlated the total water yield potential of the watersheds with the mean annual peak discharge (MAPD) values of the watersheds of 30 years. The results showed strong positive correlation of 0.71 between the modelled water yield potential and MAPD values of the watersheds (Figure 2).

2.2. HEC-GeoHMS hydrological model simulations

We evaluated the performance of the HEC-GeoHMS model as a possible flood forecasting model for the Jhelum basin. It was observed that the model performs well for august-september period with a strong positive correlation of 0.94 (r^2 = 0.88), between the observed and simulated mean monthly discharge in the validation period (Aug-Sept, 2006-2016) (Figure 3). The model was run at Sangam discharge station which covers *Vishav, Bringi, Lidder, Kuthar* and *Sandran* watersheds of the Jhelum basin for a period of 21 years (1995-2016) (Figure 1). The results inferred that this model is one of the good models freely available to the flood forecasters, when realtime precipitation is available, to give early warning and prevent disaster in the region.

2.3. GIS overlay analysis for structural measures location determination

Using slope, discharge density and land cover information of the high water yielding watersheds, locations were determined for constructions of piano key-wiers and check dams as a management practice, to delay surface runoff during heavy rains through GIS based overlay analysis. Finally, location map was generated, showing areas where structural measures must be setup to increase the basin lag time of the very high water yielding watersheds.

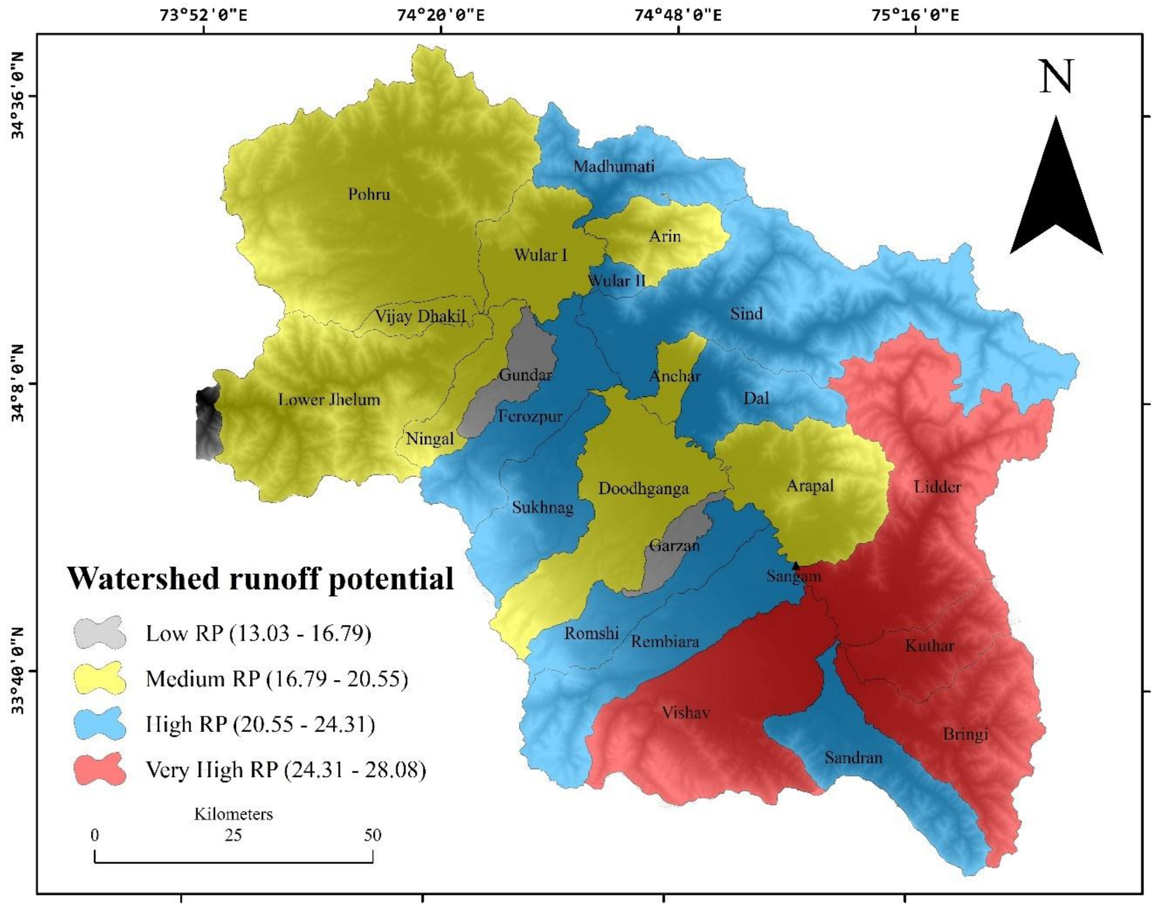

Figure 1. Comparative water yield potential categories of the Jhelum basin watersheds

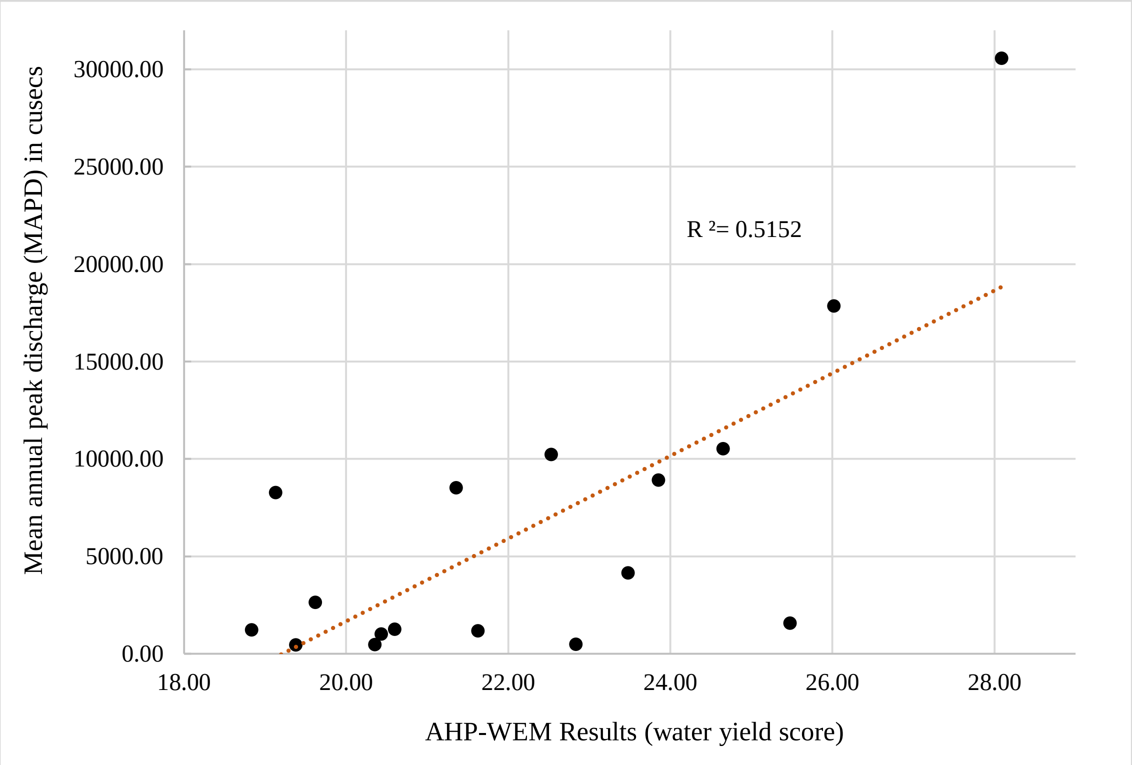

Figure 2. Scatterplot of MAPD and AHP-WEM results

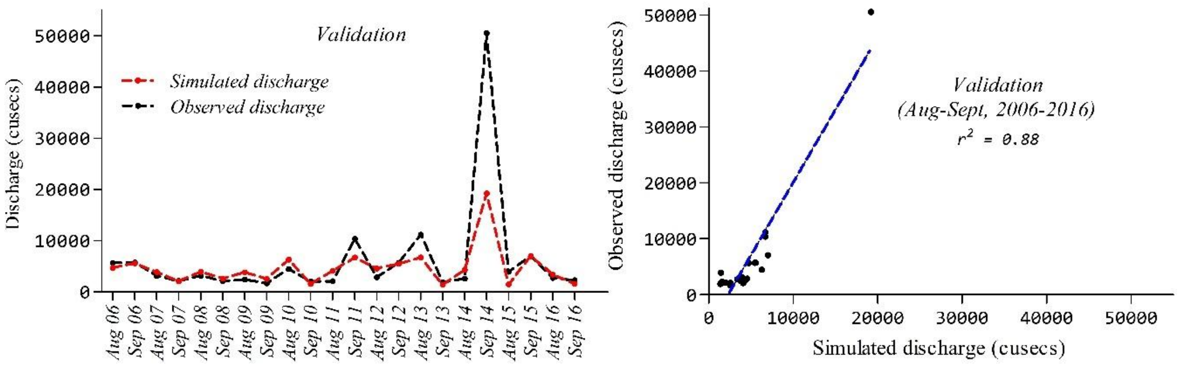

Figure 3 HEC-GeoHMS results of the validation period (Aug-Sept), 2006-2016

3. Discussion

The AHP-WEP model generated for this study, uses the drainage characteristics and land cover information of the watersheds for characterizing their water yield potential. The drainage system represents the geomorphology and lithology of the watershed very well [10]. Further, the type and distribution of land cover (LC) has a direct control on the ambient soil moisture, infiltration, evapo-transpiration and interception processes of the hydrological cycle and thus has a direct control over the overland flow. It is the land cover that is the major causal factor behind the frequency and occurrence of the floods in any region [11]. In this study, morphometry and LC of all the Jhelum basin watersheds were used to understand their comparative water yield potential. It was observed that south Jhelum watersheds (South Kashmir) have very high water yield potential, that results them being very fast in discharging their water, after a heavy downpour. This is one of the reasons, behind initial heavy flooding of south Kashmir villages, prior to overall flooding of the whole Kashmir valley during 2014 deluge. HEC-GeoHMS hydrological model was used to infer its applicability for near real-time flood forecasting at *Sangam* where almost all the very high water yielding watersheds collate (Figure 1). Model calibration was perfomed for a range of parameters such as CN and Muskingum. After lot of initial calibrations, the model was set up at $r^2 = 0.87$ for calibration and $r^2 = 0.88$ for validation. Further, since for effective flood management, it is necessary that flood control structural measures are set up at locations where abrupt inflow of water could be managed to delay the concentration of water at the downstream locations for early warning and evading the disaster. For this purpose drainage density and land cover layers were used to deduce such locations using overlay analysis. Areas with heavy drainage density and vulnerable land cover such as impervious surfaces and degraded land, were ranked high in the analysis [12].

4. Materials and Methods

The comparative water yield potential of the 24 watersheds of the Jhelum basin was evaluated from the analysis of the morphometric indices and the land cover of the basin watersheds in an AHP based watershed evaluation model (AHP-WEM). We used survey of India (SOI) topographic maps (1:50,000 scales), Indian Remote Sensing (IRS) P6 Linear Imaging Self-Scanning (LISS III) data with 23.5-m spatial resolution of October 21, 2008, and Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) 30-m resolution Digital Elevation Model (DEM) in AHP-WEM model. For HEC-GeoHMS, soil maps from the National Bureau of Soils Sciences & Land Use Planning (NBSS&LUP) at 1:250,000 served as base line data. Daily rainfall for years, 1995 till 2016 of *Kokernag*, *Qazigund* and *Pahalgam* stations, and mean monthly discharge data for the same period at *Sangam* station was used for setting up the model.

The AHP-WEM model is based on the below equations:

In AHP the normalized principal eigen vector that is used as an weighting coefficient for the analysis is calculated using following formula

$$W_i = \sum_{i=1}^{n} i/N$$

Where,

W_i is the principal eigen vector or the weighting coefficient

i = parameter

N = total no. of parameters

In order to make sure that the original preference or ratings are consistent, Saaty (2000) devised consistency index (CI) and consistency ratio (CR) defined by the following formulae

$$CI = \frac{\lambda\max - n}{n-1}$$

$$CR = \frac{CI}{RI}$$

Where,

λ_{max} is the average of the consistency measure of all the parameters

n is the total number of the parameters in a matrix

RI is the random consistency index is developed by Saaty (1990, 2008) for different matrix orders from 1 to 15. CR must be less than 0.1 for a matrix to be consistent. In the present study CR calculated equalled to 0.8 for both morphometry and land cover matrices and shows that the ratings used in the pairwise comparison matrix are consistent [13, 14, 15].

The water yield potential equation (AHP-WEM) is summed up as follows

$$RI = \sum_{i=1}^{n} WRS_i$$

$$WRS_i = W_i . RS_i$$

Where,

RI= Run off index of the watershed and is the sum of both morphometric and land cover parameters

WRS_i = AHP weightage based score of a parameter of watershed

W_i = Pairwise comparison derived weight of the parameter

RS_i = Run off score of the watershed for given parameter

n = Number of parameters of the watershed.

The overall methology of the HEC-GeoHMS model is shown in Figure 4

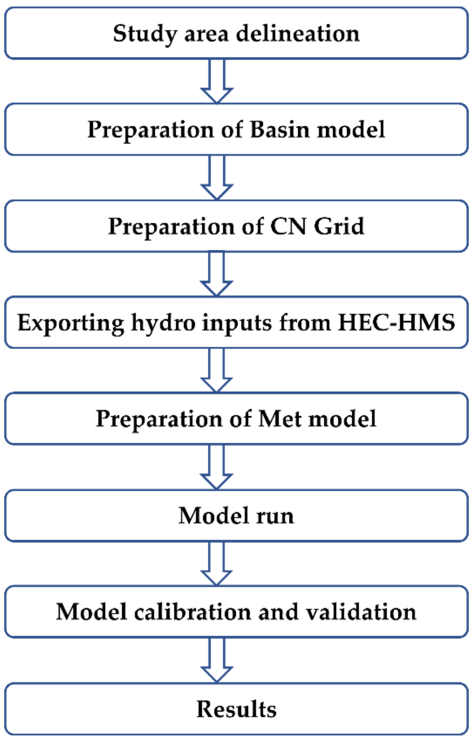

Figure 4. HEC-GeoHMS metholodogy included basin model generation and preparation of the CN grid followed by met model preparation.

5. Conclusions

The three tier strategy used in this work starting from determining, comparatively the highest water yielding watersheds to, finding the effective and efficient locations for the structural flood control measures, shall pave way to the disaster managers of the region for dealing the recurring floods of the region. The very high water yielding watersheds have to be managed on priority basis and a dence network of automatic weather stations has to set up for near real time flood forecasting using HEC-GeoHMS model. The integrated use of geoinformatics and hydrological modeling in this study has focused on the holistic flood management of the Jhelum basin and has also paved way for further research in this area.

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Author Contributions: Gowhar Meraj did the AHP-WEM analysis, prepared the maps and wrote the manuscript. Tanzeel Khan perfomed the HEC-GeoHMS modelling Bashir Ahmad Sheikh assisted in that. Shakil Ahmad Romshoo, Majid Farooq and Kumar Rohitashw conceptualized the methodology and helped in the preparation of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AHP: Analytical Hierarchical Process
WEM: Watershed Evaluation Model
HEC-GeoHMS: Hydrologic Engineering Center – Geographic Hydrologic Modeling System
MAPD: Mean annual peak discharge
GIS: Geographic Information System
SOI: survey of India
IRS: Indian Remote Sensing Satellite
ASTER: Advanced Space-borne Thermal Emission and Reflection Radiometer
DEM: Digital Elevation Model
NBSS&LUP: National Bureau of Soils Sciences & Land Use Planning

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