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Impacts of Land Use and Climate Change on Flood Events (Case Study: Ferdows)

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ABSTRACT

Flood is defined as an overflow of water that submerges land which is usually dry. Today, many parts of the world experience unexpected flood events due to different reasons. Among the most important factors, land use and climate change affect flooding in many ways. The present study aims to investigate the impacts of land use and climate change on flood events, as well as, its outcomes on urban communities(basin Ferdows in IRAN). Definition and evaluation of different adaptation options is a necessary step, because information in this area will help urban communities reduce their current and future vulnerability to floods. The extreme rainfall is supposed to increase during twenty-first century while the rate of changes is unclear due to climatic models. During 2013-2050, the peak discharge will increase between 12±8 and 13±7 for three models and the return period will exceed 50 years. There is more uncertainty for the next 50 years with an increase between 10±7 and 16±8 for two models. The results show that continuous changes happen with a degree of uncertainty while recent unplanned and rapid urbanization has a possibility to induce serious urban flooding in the near future which will lead to a greater hazard for societies.

KEYWORD

land use, climate change, flood events, Ferdows, Iran

INTRODUCTION

Adaptation planning involves responding to the impacts of climate change, both practically and reactively. It can include preventive measures to slow down the progress of climate change and mitigation measures to reduce the effects. According to the fourth report of Intergovernmental Panel on Climate Change (IPCC) which was released in 2007 (Adger et al., 2007), climate change adaptation measures are defined as changes to decision-making with the aim to increase the resilience or decrease the vulnerability in the face of future projected climate change. IPCC has developed scenarios regarding changes in the water cycle which are likely to increase the risk of floods.

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Urbanization along with increase in intense short-duration rainfall leads to probable increased risk of flashfloods (EEA, 2004). When large volumes of rainfall, flow quickly into streams and rivers floods occur. Many different factors influence flood events such as intensity and duration of storms due to climate change, removing vegetation and soil, grading the land surface, land use and so on. The expected 10-20% of increase in extreme rainfall by twenty-first century compared to a period of thirty years before this period, will raise more concerns regarding flood events. Investigations in the area of Ferdows (east of Iran, Northwest of South Khorasan province) show an estimated 9% increase in extreme rainfall over twenty-first century (Saberifar &Akhgari, 2008). As urbanization develops, the area of impenetrable surface increases which leads to higher flood risks (Deroo et al., 2003). Land use and other human activities also influence the peak discharge of floods by modifying how rainfall and snowmelt are stored. The increasing volume of floods and peak discharge makes the storage of high runoff more difficult and brings about more challenges in flood prevention. Iran has a continental type of climate and the weather is dry and warm in east with cold winters and hot summers. The annual rainfall does not exceed 30 cm (12 in) and the floods are characterized as dry's one, flash floods. This feature of floods along with inadequate management of land use coupled with the consequences of the climate change, have influenced natural environment and human life with tangible and intangible impacts. The present study investigates current land use and climate change schemes in Ferdows in order to understand the scope of urban land use and regional climate change in this city. A set of regional climate model outputs has been used for rainfall analysis from EU-FPS ENSEMBLES project at 25×25km horizontal resolution. Current bias corrective method is also presented and the impacts of land use and extreme rainfall on flood events have been evaluated with an assessment of their consequences on human communities. It is worth to characterize and evaluate different adaptation measures in terms of their ability to reduce the vulnerability of water resources to climate change. Adaptation planning will be useful in decreasing the progression of climate change and reducing its effects in general.

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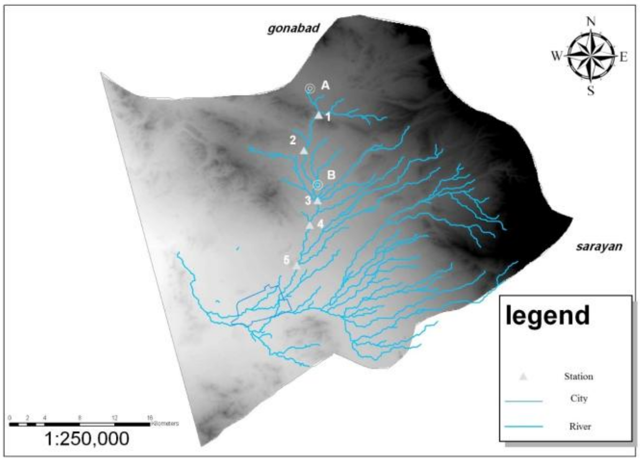
MATERIALS AND METHODS

This article basically aims to measure and calculate changes of land use and climate and their effects on flood events in Ferdows basin. Then its outcomes on human systems and structures will be investigated and analyzed. Ferdows is located in the northwest of South Khorasan province in east of Iran. It is about 345 kilimeters south of Mashhad and 200 kilometers northwest of Birjand. Ferdows basin covers an area with a complex land. It includes two main rural and urban populations. Water ecosystem services are supported by rich agriculture and industry and a large population is inhibited in the central low part of the basin. The major stream whose length is 15 kilometers has four branches (Map 1). A common daiy data period is selected for two meteorological stations (from 1986 to 2000). Moreover, two scaling stations are installed in order to record daily discharge data since 1997. The runoff is mostly surmounted by rainfall. Vegetation is heterogeneously distributed as follows: 1% of the overall area is dedicated to forest, 83% is covered by scrubs and pasture, and finally, pavements or built areas account for about 10% of total area. Five major stages were followed in order to achieve the specified objective of the present research. First of all, regional rainfall schemes were designed and calibrated with observation data; next, runoff was simulated and regional climate model data was represented; measurement of changes in land use, and areas which are apt to flood was done in the fourth stage; and eventually, changes in hazard to people and constructions or structures were assessed from point of view of flood depth and velocity (Mendizabal et al, 2014).Efficient climate models able to synthesize the behavior of a number of different types of systems, were used. The movement of the air, the currents in the ocean, the weather patterns created on land masses, the energy from the sun and the behavior of living organisms all generate data that can be fed into a climate model. Regarding the first stage, four regional climate models (RCM) were chosen which were included in the EU-FP6 ENSEMBLES project (Hewitt, 2005): DMI-HIRHAM, CNRM-ARPEGE, EHTZ-CLM,KNMI-RACMO. Advanced computer simulation using hydrologic and hydraulic modeling allows us to address future concerns and integrate plans and designs with existing water systems. The climatic models mentioned above have a good coverage for Ferdows basin. They aid in surface and groundwater modeling, flow measurement, flood analyses, and comprehensive flood event studies. In the ENSEMBLES project, simulations run under the IPCC AIB climate scenario and the period of 1961-2010.



Map1: The Basin of Ferdows

In the AIB scenario, the assumption is based on the increase of the transpirations over the lf of the present century which tends to decrease in the middle of the century thanks to the application of more efficient technologies and scientific methods (Nakicenovic et al, 2000).Data which was provided by Iran Natural Meteorological Agency was compared with model data. Five observations which complied with the criteria were selected. One of the requirements for observations was a good coverageto study area, containing missing values under the threshold (7%) and providing sufficient data over the control period. Application of reconstruction of series was performed by linear regression between best associated stations (Mendizabal et al, 2014).There has been a bias correction of the RCM outputs. In fact, bias correction of model outputs is necessary before their use in impact studies. The basic objective of this article is to provide the schemes at local level. Standardization of the RCM outputs and the observations which have been defined hereafter as references has been performed on a daily based frequency with the aim to provide the statistics of each month. A comparison was performed between the model and the reference series. Cumulative probability of daily precipitation records has been used along with standardization and bias correction method. Cumulative probability refers to the probability that the value of a random variable falls within a specified range. According to observations, the empirical return period of the data is better adjusted to an alternative model (Moncho et al, 2012) because probability distributions which are commonly used are not well fitted to the whole scope of precipitation. Description of Hydrological-hydraulic model Hydrologic models are simplified, conceptual representations of a part of the hydrologic cycle. They are primarily used for hydrologic prediction and for understanding hydrologic processes. The aim of modeling is to have a more global approach to the understanding the behavior of hydrologic systems to make better predictions and to face the major challenges in water resources management. For this study, the MikeShe-Mike11 hydrological and hydraulic coupled model has been selected. Mike She can simulate integrated surface water and groundwater system. Mike11 is a fully dynamic, one dimensional modeling tool for the detailed analysis, design, management and operation of both simple and complex river and channel systems. When Mike11 is coupled with Mike She, dynamic exchanges between the overland flow plain, groundwater system and the river system are simulated. The temporal resolution of the model is one day and the spatial resolution, 490×490 meter pixel all over the zone and 5 meters to the flood plain area. Mike21 is selected for flood simulation. This model which was developed by DHI is a computer program that simulates flows, waves, sediments and ecology in rivers, lakes, estuaries, bays, coastal areas and seas in two dimensions. Compared to KikeShe-Mike11, this model can simulate water velocity on the flood prone area better and more efficiently. Therefore, the model used here, helps runoff simulation at daily time steps for the present and future rainfalls (Mendizabal et al, 2014). Periods for which observations and runoff data are available get calibration and validation of the model (1997-2010). Mike She comprises three simulation engines and an automatic calibration method which calculates coefficient of determinant (R) and Nash Stcliffe (NS). The Nash-Stcliffe model efficiency coefficient is used to assess the predictive power of hydrological models. This method can be used to describe the predictive accuracy of other models as long as there is observed data to compare the model results to. The measured and simulated daily flow for state variable is compared in the model and the entire time period of evaluation in order to provide the calibration. R represents the strength of the relationship between observed and simulated data which is 0.74 for calibration period and 0.75 for validation period in this research. Runoff simulation through introduction of regional climate model data Modeling climate and earth system processes on a regional scale is essential for projecting the impacts of climate change. Data in this area provides standardized access to a vast and comprehensive set of observations, as well as, tools for performing common analysis and visualization tasks. Projected climatic variables are used in MikeShe-Mike11 hydrological hydraulic model in order to evaluate and measure the basin hydrological reaction to climate change. The model is supposed to assess the changes in amplitude of runoff. To achieve this aim and answer the associated questions, the present day discharge and the hydrological reactions to rainfall projections were compared together. Investigate and assess changes in areas apt to flood events These evaluations and assessments are used to determine the velocity and level of water in flooded areas under the impacts of future rainfall and as a result help to predict the hazard to people and prepare associated maps. Flood analysis is performed at the urban area under climate change conditions. The changes in flood prone areas, severity of the event and the hazard to people are all calculated. Assessment of changes in hazard to people(from aspect of flood depth and velocity) According to Ramsbottom et al (2003) and Penning-Rowsell et al (2005), a semi-quantitative equation can be used in order to relate the flood hazard to people with depth and velocity of water, as well as, the amount of detrition in the water.

$$HR = h(v+0.5) + DF$$

Here, HR represents the hazard rating of flood; h shows the water depth in meter; v indicates the water velocity (m/s); and DF is 0-1 score described the likelihood of debris (refer to table1).

Table1. Information on debris factors according to different flood depths, velocities and prevailing land use

Depth	Pasture/arable	woodland	Woodland Urban
0-0.25m	0	0	0
0.25-0.75m	0	0.5	1
d>0.75m and/or v>2	0.5	1	1

Ref: FD2321/TR1 (HR Wallingford, 2006)

The index of flood hazard represented above will help to estimate the level of hazard to people after which categorization is done as follows: low (HR= 0-0.75) which means caution (flood zone with shallow flowing water or deep standing water), moderate (HR = 0.75-1.25) representing danger for some i.e. children and elders (flood zone with deep or fast flowing water, significant (HR= 1.25-2.5) which indicates danger for most of people (flood zone with 1 meter depth and fast flowing water, 1.5 m/s), and finally extreme (HR>2.5) which means that hazard is probable for all (flood zone with depth higher than 1 meter and fast flowing water higher than 1.5 m/s) (Ramsbottom et al., 2003; HR Wallingford, 2006).Over the past several decades, concentration of greenhouse gasses has been rising. Even considering the medium greenhouse emission scenario, it is expected that extreme rainfall (percentile 0.99) will increase during the next century. Global precipitation has been reported far above normal and 2010 has been ranked as the wettest year since 1900. Many areas have received record heavy rainfalls and flooding during last decade. However, there is an uncertainty in the percentage of rainfall due to the climatic models. The expected changes have a spatial variability depending on local features. For most extreme models including CNRM, EHTZ, and HIRHAM, an increase of 25±1% (St. 1), 22±2% (St. 2), and 19±6% (A) is expected for a return period which exceeds forty years and the period of 2013 – 2050. For the less extreme model including KNMI, it is not expected to have significant changes for Central (St. 3) and North West (2) stations and for the time period of 2013-2050. However, for the next forty years from 2051 t0 2090, the results are supposed to change. For the most extreme model including CNRM, an increase of 9-29% of extreme precipitation is expected and the highest increases being recorded for North (A) and West (St. 4) stations. The less extreme model for this period is HIRHAM which experiences less increase than the previous period (except 2). Regarding the impacts of precipitation on discharge, an increase is expected in peak discharge (percentile 0.99) between 12$\pm$8 and 13$\pm$7 for three models and for the first period which is from 2013 to 2050 while the return period exceeds forty years for highest station, located before the urban area.For the next period, more uncertainty is observed and an increase between 10$\pm$7 and 16$\pm$8 is supposed to occur for two models with the same return period which exceeds forty years. The increase is not significant for the other two models while the return period is the same. Rainfall and flow projection are used as inputs in order to analyze the changes in areas which are pat to flood and measure natural phenomena severity before the urban area. Changes are expected to occur in flood event with its associated uncertainty. Based on the results, new flood-prone areaswith greater hazard to people can be identified. Floods can be such devastating disasters that anyone can be affected at almost anytime. Dealing with challenges in flooded areas where the hazard factor is 1 is very difficult for people and when the factor exceeds 1.4 it is certainly devastating (Ramsbottom et al., 2003; R Wallingford, 2006). For CNRM model which represents extreme results, an increase in the flood-prone area, as well as, the severity of the event is expected for both periods including 2013-2050 and 2051-2090. Over all, the extent of the lowest return period which represents 10 years does not change a lot (0.97%), while the medium return period (40 years) has more increase (4.7%). Regarding the first period, the highest return period including 100 years experiences a significant increase (70.1%). The situation is different for the second period from 2051-2050. An insignificant increase of the flood extent (1.7%) is expected for the lowest return period, while for the medium return period a decrease is observed equivalent to -1.1%. In the highest return period there's an increase in flood area extent but it's not as much as the first period (32.4%). In Ferdows basin, the municipal area and Islamyeh will have a 10% and 6% increase in extent of significant and extreme hazards and a 9% and 10% decrease in the extent of low and moderate hazards (CNRM model, the period of 2013-2050 compared to the reference period, 1961-2000). Moreover, there are new zones with significant and extreme hazards. These new areas are dedicated to residential buildings and roads. People will face difficulties to walk when the hazard rate is up to 1 and when it exceeds 1.4, they are supposed to fall down (Ramsbottom et al., 2003). This means that the vulnerability of the areas classified as significant and extreme hazard is very high.

CONCLUSION

Typically, severity and frequency of extreme events due to climate change lead to social and economic costs. The uncertainty behind further weather conditions should not stand in the way of action to manage the rising risks associated with extreme weather. One the resulting impacts is related to water discharge and flooding. If data is collected on discharge of stream over an extended period of time, statistical analysis can be performed to determine how often a given discharge is expected. The recurrence interval can be determined from the analyses and a probability for the likelihood of a given discharge is calculated for any year.The results of the present study showed that the expected precipitation and discharge changes in percentage and their variability depends on the climatic model, the period analyzed, and the spatial characteristics of the basin. However, the most important conclusion of the present study is that the extreme rainfall has more impacts on flood events compared to discharge before the town. The problems that urban systems face regarding capacity to absorb additional water and the challenges considering precipitation lead to the fast basin's response. Thus, it can be concluded that rainfall has a direct and immediate effect on the river. It is very crucial to gain sufficient knowledge about expected changes in extreme precipitation under the influence of climate change and its impacts on the discharge and flood events. Although there are uncertainties in this area of study, the importance of this issue should not be ignored for better land and water resources management. One of the critical influences of increased precipitation is hazards to people. As mentioned before, climatic processes increase the severity of consequent hazards which is more significant compared to the impacts of increase in the extent of flood-prone areas. Some residential buildings and roads are among new areas with high hazard probability which represent a very high vulnerability to flood consequences. In this regard, some adaptation strategies and standard measures are required in order to minimize the impacts. Research like this is helpful in recognizing proper adaptation strategies and defining necessary policies in order to understand the impacts of land use and climate change on peak discharge its impacts on flood events and generally human social and economic life, as well as, people's health at local scale. The results can be used as tools to complete the findings of previous studies and contribute to definition and evaluation of different adaptation options. This way, the ability of scientific tools and measures to reduce the vulnerability of the basin to the effects of climate change will be estimated. However, it should be noted that prediction of future climate is imperfect because of limitations by significant uncertainties that stem from several facts. First of all climate is naturally vulnerable. Moreover, we are not able to predict accurately future greenhouse gas emissions. And finally, our understanding of the total climate system is incomplete. Despite these facts, research should continue along with all associated uncertainties.

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