ANALYSING THE EFFECT OF LAND COVER CHANGE ON CATCHMENT DISCHARGE

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ABSTRACT

The study was conducted to analyse the effect of land cover change on the catchment discharge and thereby to investigate the sensitivity of the hydrological model to those changes. The study area was Hjaltadalsá River which is located in the Hjaltadalur Valley in the north of Iceland. The WaSiM hydrological model was used to test the sensitivity of land cover change and GIS tools were applied to process the catchment delineation and manipulation. The analysis was performed under fictional formed five land covers such as grass land, wet land, barren land, heath land and forest land on the Hjaltadalur watershed. The simulated discharge under different land covers was tested with the observed discharge. The WaSiM model simulated the catchment discharge well. Generally, the simulated discharges for different land covers and observed discharges had similar trends with only small differences. However, the highest discharge was observed for barren land cover and the lowest for forest land cover for the summer and spring seasons. From the study it seems that

simulated land cover change had little impact on the catchment discharge of the Hjaltadalsá River even though a slight difference was observed among the land covers. For further research in this field it would be worthwhile to simulate the joint effect of land cover and soil type change together.

Keywords: land cover change, catchment discharge, WaSiM, ArcGIS, sensitivity analysis

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1. INTRODUCTION

The need to manage our physical environment sustainably is caused by growing population and the enhanced capabilities of the humans to utilize earth's resources. Important part of sustainable resource use is to manage the land cover where it is, has been or is likely to become under a large stress.

Land cover is defined as topography and biophysical characteristics of the earth's surface such as vegetation, water, organisms, soil, and structures created by human activities (Lambin et al. 2003). The human activities in utilising and managing these land resources mainly affect the biophysical characteristics, whereas land use change is any physical, biological or chemical change in the conditions or the resources due to management to satisfy human interests (Quentin et al. 2006). A proper management of the land cover requires a thorough knowledge of the physical characteristics of the land cover through direct measurements and application of physical models and extends to fields such as biology, soil sciences, meteorology and hydrology.

One of the main challenges in recent hydrological research is assessing the effect of diverse environmental changes. Climate and land use/cover are the main factors affecting the hydrological behaviour of catchments (Hörmann et al. 2005; Brath et al. 2006; Huisman et al. 2009). Land use change is one of the most visible changes of the landscapes in the world. Along with climate change, land use change has a strong impact on the water budget and hydrology of river catchments (DeFries & Eshleman 2004; Wang et al. 2006). Different studies applying different modelling approaches have identified possible land use change impacts on catchment hydrology (Siriwardena et al. 2006; Krause et al. 2007).

Understanding the hydrological processes is crucial towards better water and land resource management, as the hydrology is largely influenced by land cover and is highly important to agricultural productivity (Easton et al. 2010). Large changes in land use have often been associated with changes in the local hydrology as hydrologic responses of a catchment are influenced by land cover (Nejadhashemi et al. 2011). In line with the above facts, Siriwardena et al. (2006) indicated that there was significant effect on discharge yield due to land cover change. The highest discharge was observed for cleared forest land when it was compared with forested land.

Physically based models are instrumental tools in performing hydrological studies. The validated models under different environmental conditions can be assumed to be transferable to altered conditions. They can be applied to reflect the effect of land use change on hydrology as well as to an IPCC scenario based on agricultural land use scenarios (Ewert et al. 2005; Li et al. 2009). However, model sensitivity should be analysed and discussed against the background of other scenario studies in comparable environments as well. One approach is to increase confidence through sensitivity analysis of the model under different land use conditions and soil types (Huisman et al. 2004).

In this study, results from the physically based and distributed hydrological model WaSiM-ETH (Schulla & Jasper 2006) was used to conduct a sensitivity analysis and investigate the effects of land cover change on catchment discharge. A result for the catchment of Hjaltadalsá River, which is located in the north of Iceland, was analysed. Simulated discharge series obtained using different parameter sets were compared with observed discharge series in order to select the best model run. The land cover input of the model was changed and the

effects on the catchment hydrology reviewed by analysing changes in the simulated discharge. The outcome was used to analyse the sensitivity of the discharge to land cover related soil hydrological parameters.

1.1 Goal

The overall goal of this project was to analyse the effect of land cover change on discharge and thereby to investigate the sensitivity of the hydrological model to those changes.

1.2 Objectives

Obtain experience in analysing outcomes of hydrological modelling and to enhance GIS skills necessary for spatial data processing.
In doing so:
- To delineate the watershed and extract the land cover characteristics using ArcGIS
- To manipulate the land cover characteristics for the watershed
- To analyse the sensitivity of the hydrological model by using the manipulated watershed land cover characteristics and comparing the modelled discharge results

2. LITERATURE REVIEW

Water is fundamental to life and one of the earth´s most precious resources. Hydrology is the science dealing with the natural processes, explaining the complex behavioural association of the hydrological cycle and the management of environmental systems. Hydrological models are essential tools of hydrologists to address the issues of predictions of the runoff - rainfall process (Thanapakpawin et al. 2007; Thapa 2010).

A physical based model represents the underlying hydrologic and land surface processes in greater detail than conceptual or statistical models (Beven 2001). However, more parameters and greater calibration effort are required as the degree of physical representation of relevant processes in a model increases. According to Cornelissen et al. (2013) comparison study, the results of land use scenarios revealed that the distributed models SWAT and the physically based WaSiM are suitable for assessing land use change because they provide similar results.

Different scientists such as Gustard and Wesselink (1993), Calder et al. (1995), and Thanapakpawin et al. (2007) have identified the impact of land cover change on hydrological processes using various hydrological models such as lumped, distributed and conceptual. They also concluded that land clearing and conversion from forests to agricultural lands have increased surface runoff and consequently a rise in lake volume.

Gustard and Wesselink (1993) applied a lumped conceptual model for their studies to investigate the effect of land use change on hydrology and they found that discharge and flow duration decreased and the storage increased with increasing afforestation. On the other hand, Kuczera et al. (1993) argued that the lumped catchment models need more attention to minimise model conceptualisation limitations of the hydrological process and to better predict the impact of land use change on the catchment runoff.

The discharge flow varies by land cover since the hydrological cycle is influenced by the vegetation cover of an area. Krause et al. (2007) have conducted a simulation model for land

use change and land cover scenarios on how the land cover change affects the hydrology. They concluded that runoff yield and the ground water balance of the catchment were affected by land cover change. Similarly, Verbunt et al. (2005) stated that the surface runoff was significantly influenced by the land cover of the catchment between pastures, forest and barren lands. It was also different in terms of altitude and soil depth. They also indicated that shallow soil depths at higher altitudes, which limit the root growth of plants, hamper the increase of evapotranspiration after afforestation.

Land use and climate are two important factors influencing hydrological conditions by changing flood frequency, severity and discharge (Crooks & Davies 2001; Wang et al. 2006). Li et al. (2009), in their study in China, revealed that land use change influenced the hydrology less than did the climate variability. According to their findings, they concluded that the combined effects of climate variability and land use change from barren lands to vegetated lands decreased surface runoff and increased soil water content. Similarly, Siriwardena et al. (2006) also stated that the land use pattern and vegetation cover change considerably affected the catchment hydrology.

Spatial land use impacts on peak flows are generally most pronounced at small scales. However, the impact of land use change on the water balance is relatively small at large catchment scales due to compensating effects in a complex catchment (Tollan 2002). The short-term impacts of land use change and climate variation could often be seen on the peak runoff rate while the long-term impacts were more apparent on the average-annual runoff (Costa et al. 2003; Wang et al. 2006).

Niehoff et al. (2002) in their study illustrated that WaSiM-ETH is suitable to represent the water flows of lowland landscapes. Elfert and Bormann (2010) concluded that WaSiM-ETH simulated the catchment discharge and observed small differences in land cover change. However, there were systematic changes in the water balance and the runoff generations mechanisms. They also added that WaSiM-ETH has a strong sensitivity to land use changes projected by agricultural land use scenarios based on an international panel for climate change (IPCC) global climate scenarios in relation to the forecasted climate change.

3. MATERIALS AND METHODS

3.1 Description of the study area

The study was conducted on the catchment of the Hjaltadalsá River which is located in Hjaltadalur Valley in the north of Iceland. It extends roughly between 65°47'30" to 65°34'30" North latitude and 18°51'30" to 19°18'30" West longitude, as indicated in Figure 1 below. During the watershed delineation the merge (outlet) point of the river catchment was taken a little bit above the existing river discharge measuring station in order to get an accurate catchment that contributed runoff water to the river. The detailed information on why the pour point was selected above the discharge measuring station and how it was processed is described in sub-section 4.3. The total area of watershed was about 300 km^2. The catchment included eight land cover types such as grass land, barren land, heath land, wetlands, forest land, lake, river and glacier. The land cover types were 8, but when converted to the 1 km by 1 km cell size/grid only four land covers were seen on the map. This resolution was favourable since all the input data of the hydrological model WaSiM must have the same resolution and this resolution is used at the IMO (Icelandic Meteorological Office).
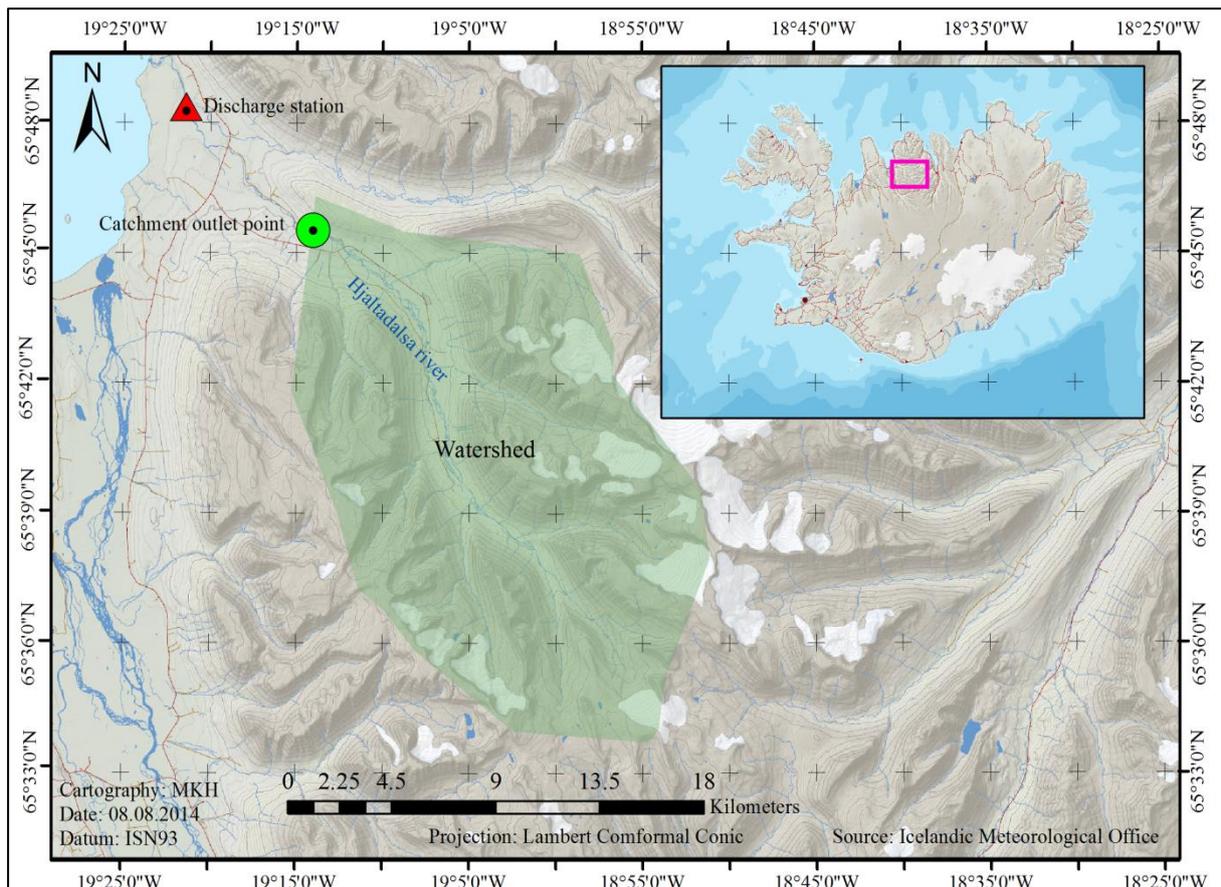
Figure 1. Overview of the study area watershed

3.2 Methodology

The project had two components. The first component deals with GIS data gathering, preparation, processing and manipulation. The fully processed data were used as required input for the WaSiM model. A digital elevation model (DEM) was selected, acquired and prepared to process flow direction and flow accumulation data using ArcGIS which are important in hydrology and hydrological modelling. Accordingly, the detailed flow chart for the overall methodology and for the GIS processing is as presented in Figures 2 and 3 below.

The second component is analysing the discharge data. In this case, data management and data cleaning were very important before proceeding to the main task which is choosing the best model run to use for the ongoing work. The available observed discharge series covered for the period (1960-2003) and more than thirty years (1981-2003) of simulated discharge data were used. The observed discharge data had a lot of missing data which were not recorded in time, a factor that made it difficult to interpolate or extrapolate since the missing data were for consecutive days. By considering these facts, the data for the year 1986 were selected for analysis and interpolation. After data cleaning was carried out, some of the missing data for observed discharges were computed using an interpolation method since the days with missing discharge for the chosen year were few in number and not for many consecutive days. The best fit parameter for the model was calculated using the standard Nash Sutcliff efficiency for all 27 simulated discharge series. Accordingly, the best fit discharge series was selected. The detailed flow chart for the overall methodology and for the GIS

processing is presented in Figures 2 and 3. The discharges were simulated by using the combination parameters: drainage density values (5, 10, and 15); recession constant values (0.3, 0.5, and 0.7) and temperature threshold for snowmelt values (0, 0.5, and 1.0). However, for the best fit the values (5, 0.3 and 1) were used for drainage density, recession constant and temperature threshold, respectively.

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┌─────────────────────────────────┐
│ Data gathering and preparation  │
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                 ▼
┌─────────────────────────────────┐
│     Watershed delineation       │
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┌─────────────────────────────────┐
│   Model Runs (WaSiM model)      │
│  Hjaltadalsá different land     │
│           cover                 │
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┌─────────────────────────────────┐
│      Outcome analysis,          │
│  effect of different land cover │
└─────────────────────────────────┘
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│ Result, interpretation and      │
│           report                │
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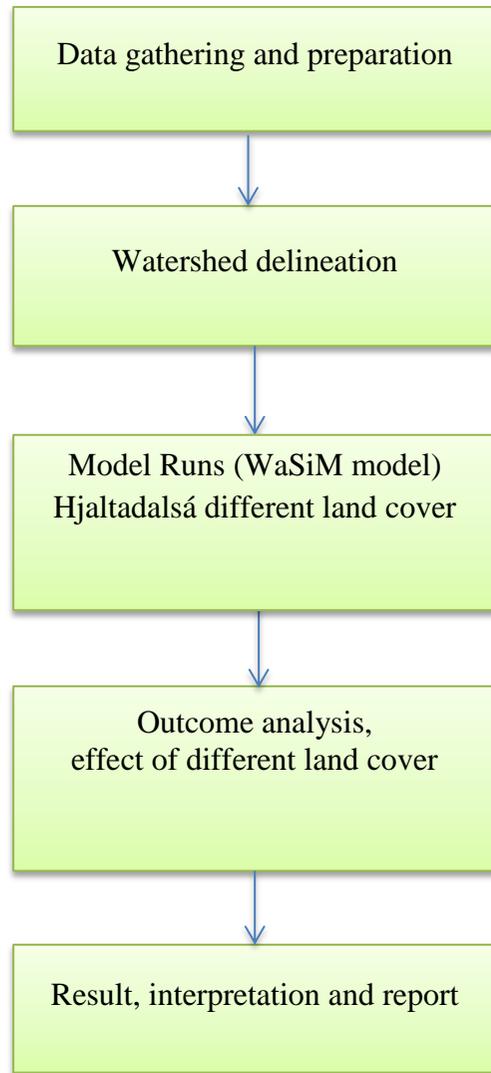
Figure 2. Flow chart of the general methodology of the study

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  ╭───────────────╮           ┌─────────────────────┐
  │ Stored land   │           │   DEM Generation    │
  │ cover data    │           │  acquisition and    │
  ╰───────────────╯           │    preparation      │
         │                    └─────────────────────┘
         ▼                              │
┌─────────────────────┐                 ▼
│ Convert to raster   │       ┌─────────────────────┐
│ and reclassify the  │       │ DEM resampling, flow│
│   land cover data   │       │  direction and flow │
└─────────────────────┘       │  accumulation map   │
         │                    └─────────────────────┘
         │                              │
         │                              ▼
         │                    ┌─────────────────────┐
         │                    │ Watershed           │
         │                    │ delineation         │
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                        ▼
            ┌─────────────────────────┐
            │ Clip the land cover data│
            │ with watershed outlines │
            └─────────────────────────┘
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            ┌─────────────────────────┐
            │   Input data sets for   │
            │   hydrological model    │
            └─────────────────────────┘
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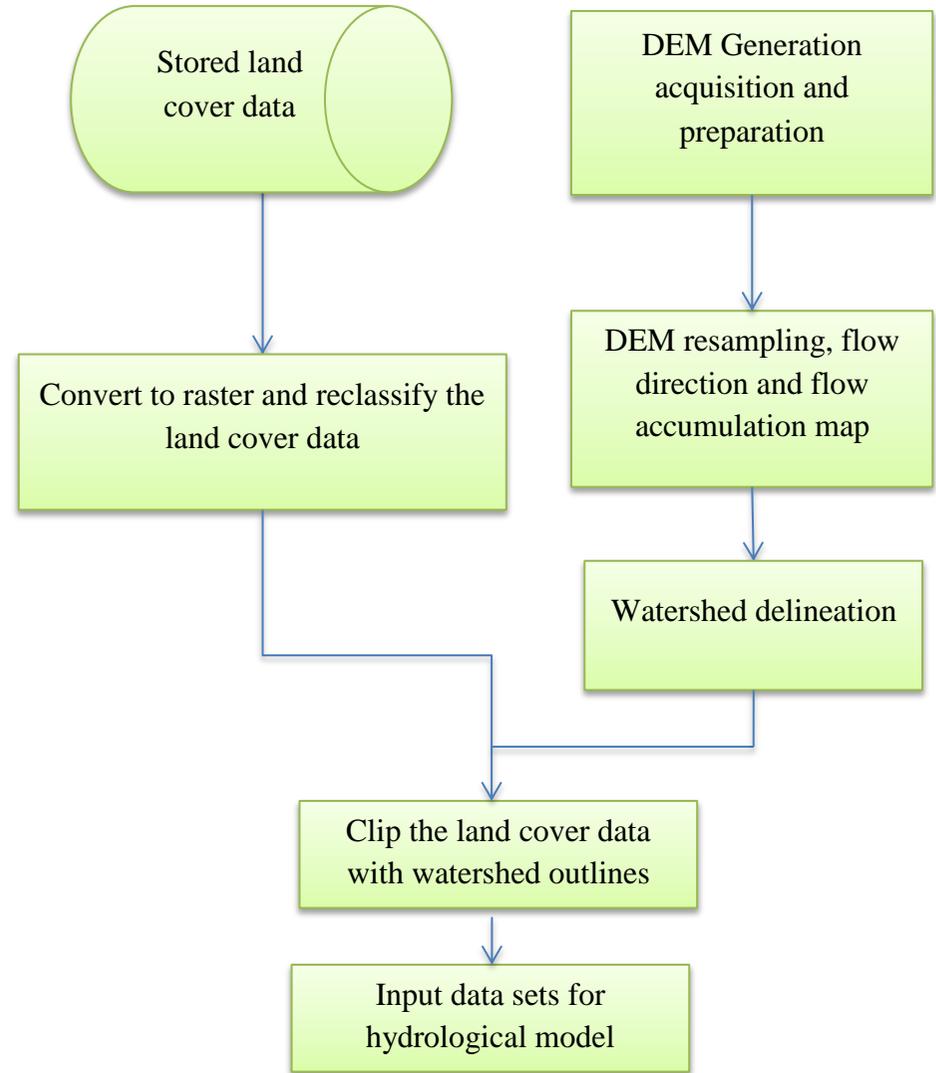
Figure 3. Flow chart of the methodology for GIS

3.3 Digital Elevation Model (DEM) selection and preparation

Digital Elevation Model (DEM) stores continuously varying variables such as elevation, ground water depth or soil thickness. Before downloading the DEM image, a selection process for the type and quality was carried out because the DEM should cover the study area in Iceland. The two types of DEMs, Shuttle Radar Topography Mission (SRTM) and Advanced Space-borne Thermal Emission and Reflection Radiometer Global DEM (ASTR GDEM) were visited, selected and prepared since they are freely available, quality checked and open to the public domain.

3.4 Flow direction (fdr) and flow accumulation (fac) grids processing

Flow direction defines the route that water will take from one cell to others. As the flow direction grid cells in the raster indicate in Figure 4 below, the top left image shows the elevation of the surface from each cell and the top right shows the flow direction into each cell. There are eight valid output directions relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as an eight-direction (D8) flow model. The direction of flow is determined by the direction of steepest descent, or maximum drop, from each cell.
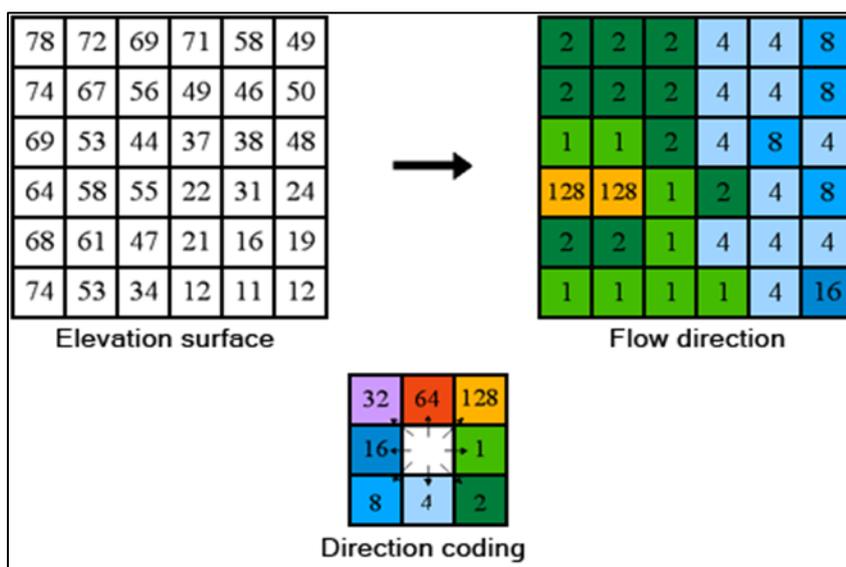
Figure 4. The conversion of the elevation raster into fdr according to the direction coding
 (source: http://resources.arcgis.com/en/help/main/10.1/index.html#//009z00000063000000)

One of the keys to deriving the hydrologic characteristics of a surface is the ability to determine the flow direction from every cell in the raster. The flow accumulation tools in GIS calculate accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. To process flow direction (fdr) and flow accumulation (fac) grids/cells, at first the original DEM was needed and downloaded. The original image was clipped with a rectangle polygon by considering the maximum extent of the study area and resampled to 1 km x 1 km to use it as input for the WaSiM model. Using the resampled DEM as input to a flow direction, the flow direction grids in which water would flow out of each cell was created. The output flow direction raster created in a previous step was used as input to create flow accumulation grids. Flow accumulation was used to calculate the number

of upslope cells flowing to a location. The flow chart to create flow direction (Fdr) and flow accumulation (Fac) is presented in Figure 5.

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┌─────────────────────────────┐
│   Orginal DEM (input)       │
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              │
              ▼
┌─────────────────────────────┐
│   Cliped original DEM       │
│         (input)             │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│   Resampled raster (input)  │
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              │
              ▼
┌─────────────────────────────┐
│      Flow direction         │
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              ▼
┌─────────────────────────────┐
│     Flow accumulation       │
└─────────────────────────────┘
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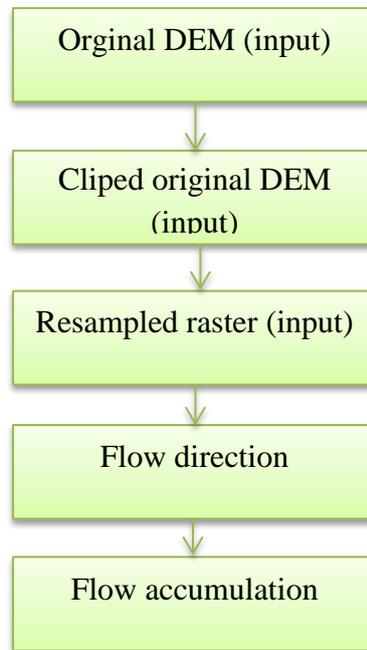
Figure 5. Flow chart for flow direction and flow accumulation grid processing

3.5 Watershed delineation of the study area

Watershed delineation is creating a boundary that represents the contributing area for a particular pour point or outlet and used to define boundaries of the study area. The watershed grids were delineated using the pour point shape files and flow accumulation raster data as input. The flow chart for the watershed delineation is indicated below in Figure 6.

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┌─────────────────────────┐    ┌─────────────────────────┐
│  Created pour point     │    │ Flow direction and flow │
│  (outlet) shape file    │    │   accumulation grids    │
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              └──────────────┬──────────────┘
                             ▼
                 ┌─────────────────────────┐
                 │   Hydrology toolset     │
                 │      (Watershed)        │
                 └─────────────────────────┘
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                 ┌─────────────────────────┐
                 │ Raster formate delineated│
                 │        watershed        │
                 └─────────────────────────┘
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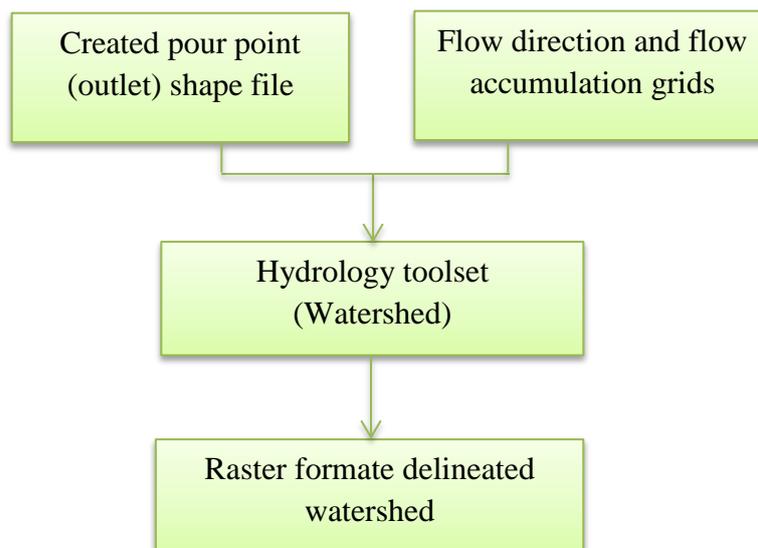
Figure 6. Flow chart for watershed delineation of the study area

3.6 Land cover data preparation and processing

After delineating the watershed of the study area, land cover data preparation and processing it was very crucial to have land cover data for the watershed. The sources of the data were the Agricultural University of Iceland and the Icelandic Institute of Natural History. To process a land cover map of the study area/catchment, stored land cover data of Iceland and the processed raster format watershed map of the study area were used. The raster format watershed map was converted to vector format to use it as a clipper over the Iceland land cover map. Procedurally, the original land cover map was clipped and reclassifying was continued. As output, a vector format land cover map was developed with different land covers. Since the objective of processing this map was to use it as input for the WaSiM, the map was converted to raster format again. Finally, the land cover data were converted to ASCII raster format as required for input into the WaSiM hydrological model which will provide the discharge results needed to conduct the sensitivity analysis. The flow chart for the land cover processing is indicated in Figure 7.
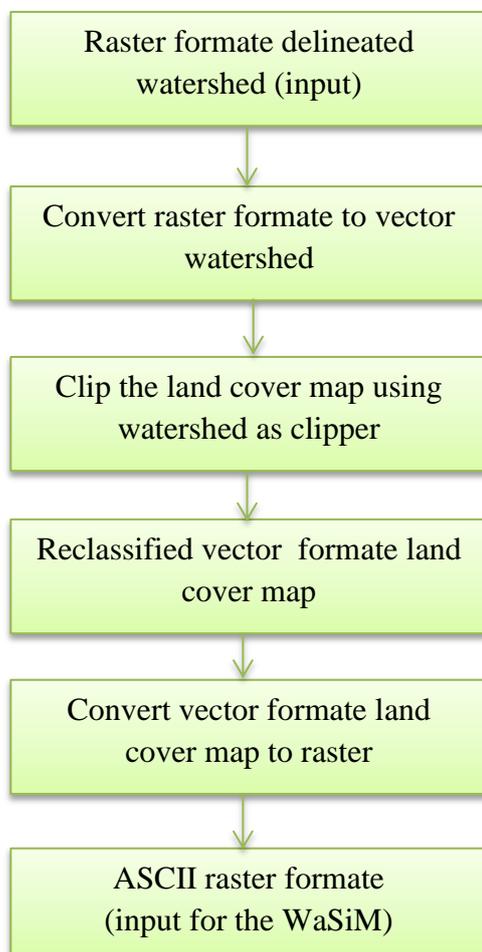
Figure 7. Flow chart that shows raster conversion to vector, reclassification and ASCII format

3.7 Inputs for the WaSiM model

Geographical and hydrological data

For WaSiM model application at least three basic data geographic datasets are needed; a digital elevation model (DEM), land use data and soil data. The DEM data sets are the basis for generating other, derived data sets like slopes, river network, and sub-basins. From hydrological data, the observed discharge per time step at the hydrometric station was provided for the model by the IMO. The sources of the land use and soil data were the Agricultural University of Iceland and the Icelandic Institute of Natural History.

Meteorological data

For the WaSiM model application: precipitation, temperature data, radiation, wind and humidity data were used. Crochet et al (2007) and Crochet et al (2011) procedures were adopted for precipitation and temperature respectively. Wind, radiation and humidity were also computed using the PSU/NCAR MM5 numerical weather model (Grell et al. 1994; Rögnvaldsson et al. 2007).

The model structure

The modular structure of WaSiM is as shown in Figure 8 below. There are outlined both the model components and the simulated vertical and lateral water fluxes. The modules in the grey shaded area calculate the water flow in each grid cell, whereas processes such as runoff concentration are performed on the basis of sub-areas.

The input parameters used for the model

The model was run for different land covers such as grass land, wet land, barren land, heath land and forest land. The following parameter values change between those different land covers: albedo, leaf area index (LAI), leaf surface resistance (Rsc), IntercepCap, rs_evaporation, aerodynamic roughness length (Z0), vegetation cover fraction (VCF) and root depth, as indicated in Table 1 and 2 below.

Table 1. Parameters for the WaSiM model with the same value throughout the year

Category	Intercep Cap (mm)	Albedo	rs_evaporation (s/m)	Root Depth (m)
Grass Land	0.4	0.2	400	0.4
Wet land	0.2	0.14	200	0.4
Barren land	0.1	0.15	100	0.1
Heath land	0.2	0.2	200	0.2
Forest land	0.6	0.2	1000	0.5

where,

        IntercepCap - Specific thickness of the water layer on leaves in mm
        Albedo - List of values for each sample day
        rs_evaporation - Soil surface resistance in s/m (for evaporation only)
        Root Depth - Root depth in m; one value per sample day

Table 2. Parameters for the WaSiM model with different values across the seasons

Parameters	Land cover category	Julian Days											
		Winter			Spring			Summer			Autumn		
		15	46	74	105	135	166	196	227	258	288	319	349
Rsc (s/m)	Grass Land	90	90	75	65	50	55	55	55	60	70	90	90
	Wet land	90	90	75	65	50	55	55	55	60	70	90	90
	Barren land	250	250	250	250	250	250	250	250	250	250	250	250
	Heath land	90	90	75	65	50	55	55	55	60	70	90	90
	Forest land	80	80	70	70	50	50	50	55	55	70	80	90
LAI	Grass Land	2	2	2	4	4	4	4	4	4	2	2	2
	Wet land	2	2	2	4	4	4	4	4	4	2	2	2
	Barren land	1	1	1	1	1	1	1	1	1	1	1	1
	Heath land	2	2	2	4	4	4	4	4	4	2	2	2
	Forest land	3	3	3	5	5	5	5	5	5	3	3	3
Z0 (m)	Grass Land	0.15	0.15	0.15	0.4	0.4	0.4	0.3	0.3	0.3	0.15	0.15	0.15
	Wet land	0.15	0.15	0.15	0.4	0.4	0.4	0.3	0.3	0.3	0.15	0.15	0.15
	Barren land	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Heath land	0.1	0.1	0.1	0.2	0.2	0.2	0.15	0.15	0.15	0.07	0.07	0.07
	Forest land	1.5	1.5	1.5	2.5	2.5	2.5	2.5	2.5	2.5	1.5	1.5	1.5
VCF	Grass Land	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
	Wet land	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
	Barren land	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Heath land	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Forest land	0.9	0.9	0.9	0.95	0.95	0.95	0.95	0.95	0.95	0.9	0.9	0.9

Where,

Rsc - leaf surface resistance in s/m, one value for each sample point

LAI - Leaf Area Index (1/1); one value per sample day

Z0 - Roughness length in m; one value per sample day

VCF - Vegetation covered fraction; one value per sample day
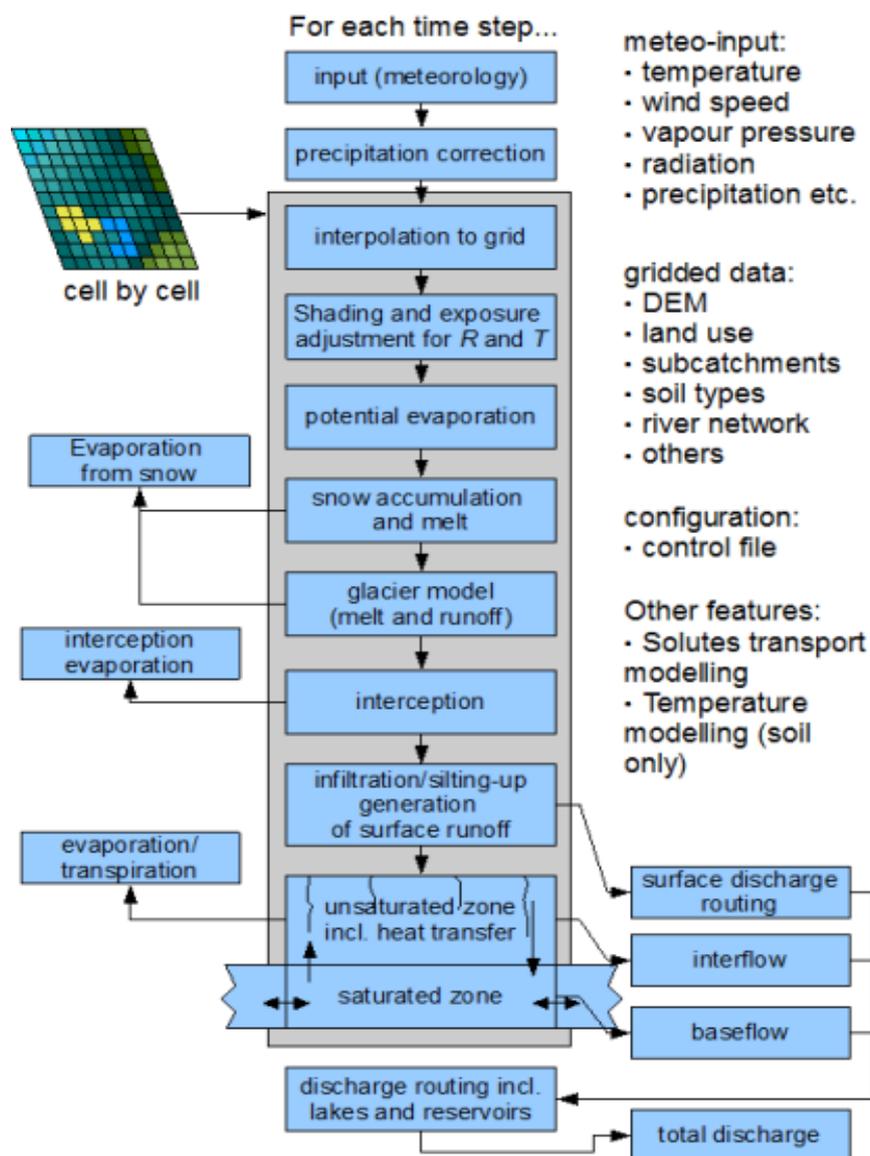
Figure 8. Model structure of WaSiM-ETH (Source: Schulla & Jasper 2006)

3.8 Sensitivity analysis

It is known that the hydrology models are influenced by different factors such as land cover and climate. The goodness of fit of the model was computed using the objective function called the Nash Sutcliffe coefficient of efficiency (E) using the formula in equation (1) below. Accordingly, the best fit of parameter set for the model was selected. At first the best fit of the overall run was selected with the value of 0.81 Nash Sutcliffe coefficient of efficiency and this coefficient of efficiency was computed from one year's data, namely 1986, even though it could have contribution to get high value. In the second step, the sensitivity analysis of the WaSiM model was carried out by changing the land cover of the catchment and the model was run with the selected parameter set values 5, 0.3 and 1 for drainage density, recession constant and temperature, respectively. Finally, the model output of various runs using different land cover for the Hjaltadalsá catchment, together with its observed discharge series,

was analysed. The Nash Sutcliffe coefficient of efficiency (E) was computed using the following formula:

$$E = 1 - \left[\frac{\sum_i^n (\text{Qm,i} - \text{Qs,i})^2}{\sum_i^n (Qm,i - Q)^2} \right] \qquad \text{Equation (1)}$$

where, Qm – Observed discharge (m^3/s)
   Qs – Simulated discharge (m^3/s)
   Q – Average discharge (m^3/s)

4. RESULTS

4.1 Digital Elevation Model (DEM) selection and preparation

According to the study area of interest, the Shuttle Radar Topography Mission (SRTM) was found to be inconvenient because the study area was not covered by their satellites and extends only from North 60 degrees to South 60 degrees. Because of this the Advanced Space-borne Thermal Emission and Reflection Radiometer Global DEM (ASTER GDEM) was selected and downloaded since the satellite's coverage is North 83 degrees and South 83 degrees and therefore covers the area of Iceland. The DEM output format is GeoTiff, signed 16 bits in units of vertical meters, which is suitable for use in ArcGIS and to process it. The DEM was Geo-referenced with WGS84/EGM96. Prior to other activities the projection of the image was carried out to an ISN 1993 Lambert map projection and clipping the study area in a rectangular form with the maximum extent continued. Since the intention was to use this DEM as input for the WaSiM model, the grid cells had to be converted to a form suitable for the WaSiM model. Accordingly, the grid cells were resampled from 30 m by 30 m to 1 km by 1 km and the most appropriate resampling algorithm (bilinear interpolation) was selected for the processing because the DEM takes into account continuous elevation differences (i.e. continuous data).

4.2 Flow direction and flow accumulation grids

Flow direction (fdr) and flow accumulation (fac) are two types of grids which are commonly created from digital elevation model data for watershed delineation using GIS. Flow direction grids show in which direction a certain grid cell is "flowing". Flow accumulation grids show how many "upstream" grid cells drain through a particular cell in the flow accumulation grid. The appropriate tool (resample) under the raster processing toolset was adopted to resample the DEM. Processing for fdr and fac was done by using the hydrology toolset of the spatial analysis toolbox in ArcGIS. The output of the flow direction and flow accumulation map of the study area is shown below in Figure 9. The flow direction (fdr) numbers (different colours) indicate the flowing direction of the grids. A single grid has a chance to flow to eight directions. Flow accumulation also represents how many grid cells flow/pass through a single cell. The white colour indicates the path of the river.
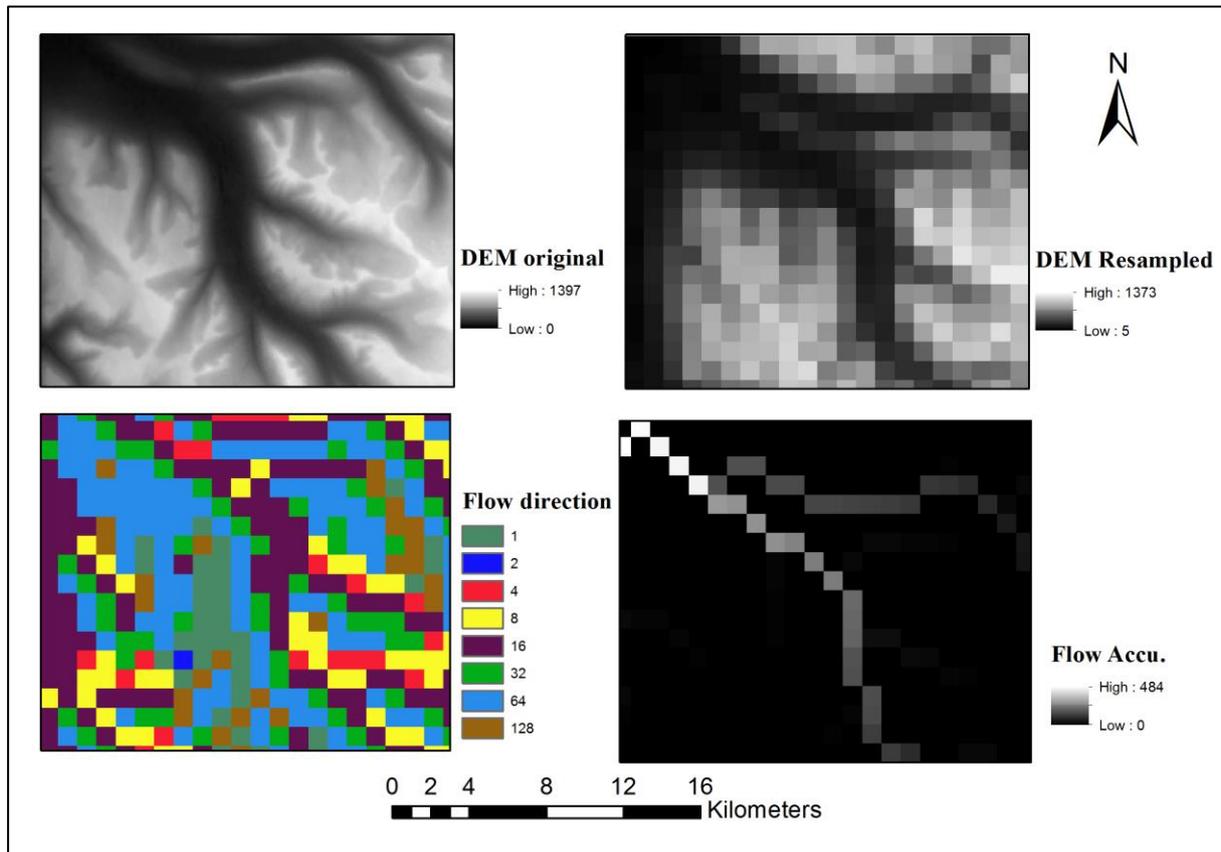
Figure 9. Map of DEM original, DEM resampled, flow direction and flow accumulation grids

4.3 Watershed delineation

The watershed of the study area was delineated using the first processed flow direction (fdr) and flow accumulation (fac) grids and pour point shape file as inputs. Before watershed delineation, first the pour point was created by taking the outlet coordinate point of Hjaltadalsá River. Actually the pour point was taken a little bit above the discharge measurement placed to delineate a relatively accurate watershed. If the discharge measuring place was considered as the pour point, places that flow to other catchment areas which do not contribute flow to the study area watershed might be included. To avoid this the pour point was taken above this place. The pour point shape file was projected from a decimal degree geographic coordinate system into a new feature class in the Icelandic Projected Coordinate system ISN 1993 Lambert 1993 in order to fit to the base map and flow accumulation grids. The map of the watershed is presented in Figure 10.
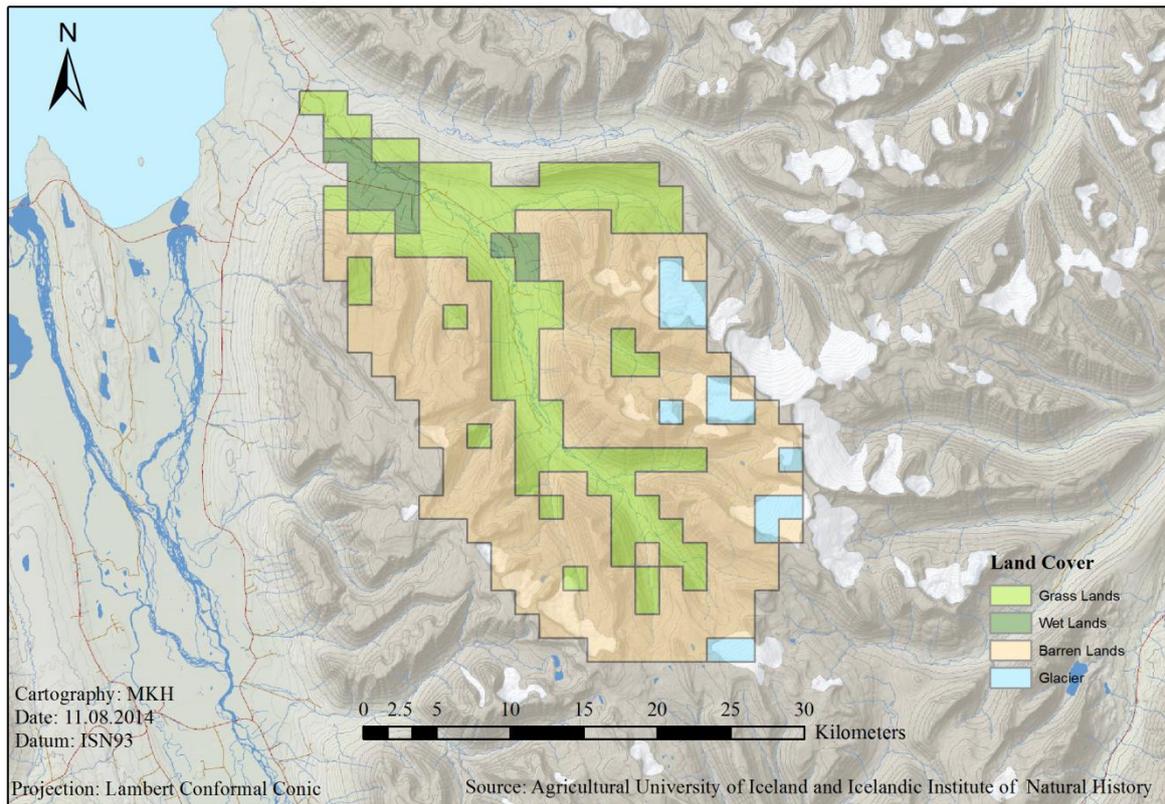
Figure 10. Map of the delineated watershed and rasterized land cover data.

4.4 Land cover data

Land cover data is very important for watershed delineation and reclassification. The land cover data were obtained from the Agricultural University of Iceland and the Icelandic Institute of Natural History. Using these data as a source the land cover was processed and reclassified. The reclassified map was used to indicate the land cover of the study area which was processed from DEM. First the original land cover was clipped by the watershed. To use it as a clipper the raster was converted to a vector. The appropriate tool used was clipped under the extract toolset in the analysis toolbox.

Since the WaSiM model required grids (raster data) as input, the land cover vector data were converted into appropriate raster format, grid size and different land covers. This map was used as a base map or natural existing land cover input into WaSiM to compare it with other land cover scenarios. The conversion process was done using the toolset polygon to raster found under the conversion toolbox. Reclassifying the original land cover raster was carried out based on the attribute column category found at the attribute table of the map as presented in Table 3. The WaSiM model setup used at the Icelandic Meteorological Office uses the same categories of land cover but with different numbers. Reclassification of the land cover was done by putting the numbers which are similar to the WaSiM model adopted so that the data were used as input in the model runs. Reclassifying was done using the reclassify tool in the spatial analysis tool box.

At first we had observed eight land cover types in the watershed with the original data. Using the results from the previous reclassification, after resampling the watershed into 1 km by 1 km only five land cover types were visible and others (lake, river and glacier) not visible during reclassification. At the end five different raster format grids where all the cells are of one land cover, either grass land, wet lands, barren land, heath land and forest land was developed and made ready as input for the WaSiM model as shown in Figure 11. Since the objective of processing this land cover grids was to use it as input for the WaSiM model, at the end five fictional watersheds such as glacier-grass land, glacier-wetlands, glacier-barren lands, glacier-heath lands and glacier-forest lands were created. Glacier was used with all land covers because it is a source of water for the watershed and is difficult to change in the IMO's WaSiM model.

Table 3. Values and definitions for land cover classes in the original vector data and in WaSiM grids

Category	WaSiM	Definition
500	1	Grass lands
503	2	Wet lands
600	3	Barren lands
509	4	Heath lands
743	5	Lakes
504	6	Forest lands
701	7	River
621	8	Glacier
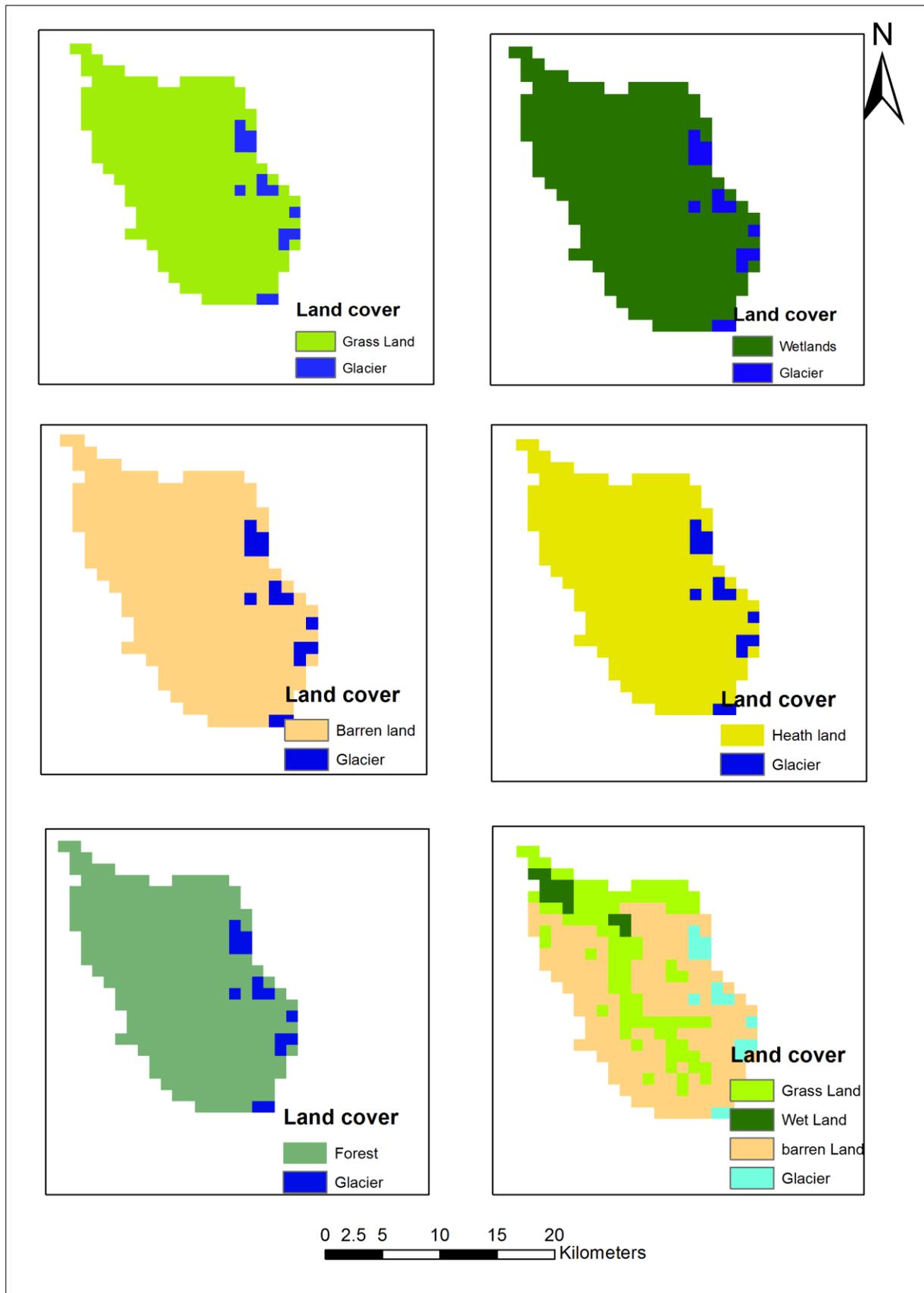
Figure 11. Map of the fictional land cover data and original land cover in lower right corner

4.5 Sensitivity analysis of the catchment discharge

Sensitivity analysis is very important to investigate how discharge can be affected by the land cover change. The WaSiM model was run using the fictional different land covers of the watershed combined with the glacier cover. Five different land cover types (grass land, wet land, barren land, heath land and forest land) were used to test the sensitivity of the catchment discharge against land cover change. The observed discharge was tested with the simulated discharges under different land cover. As presented in Figure 12, the general trend of the simulated discharges under different land cover was similar to the observed discharge. The observed discharge had its highest peak values for the summer, autumn and winter seasons and the lowest value for the spring season when compared to all the simulated discharges. The simulated discharges had almost no difference for land cover changes for the winter and spring seasons starting from December to June and they had a similar trend. For the months starting from August to November (summer and autumn seasons) a small difference in discharge among land covers was observed. The highest discharge was recorded for the barren land and the least for the forest land. The remaining simulated discharges were laid in between the forest and the barren land covers. Generally, from the five different land covers in the study area, for the summer and autumn (June and December) seasons the barren land had the highest discharge and the forest the lowest discharge. However, at some points for the period with low discharge, the observed discharge had lowest value than the simulated discharges.
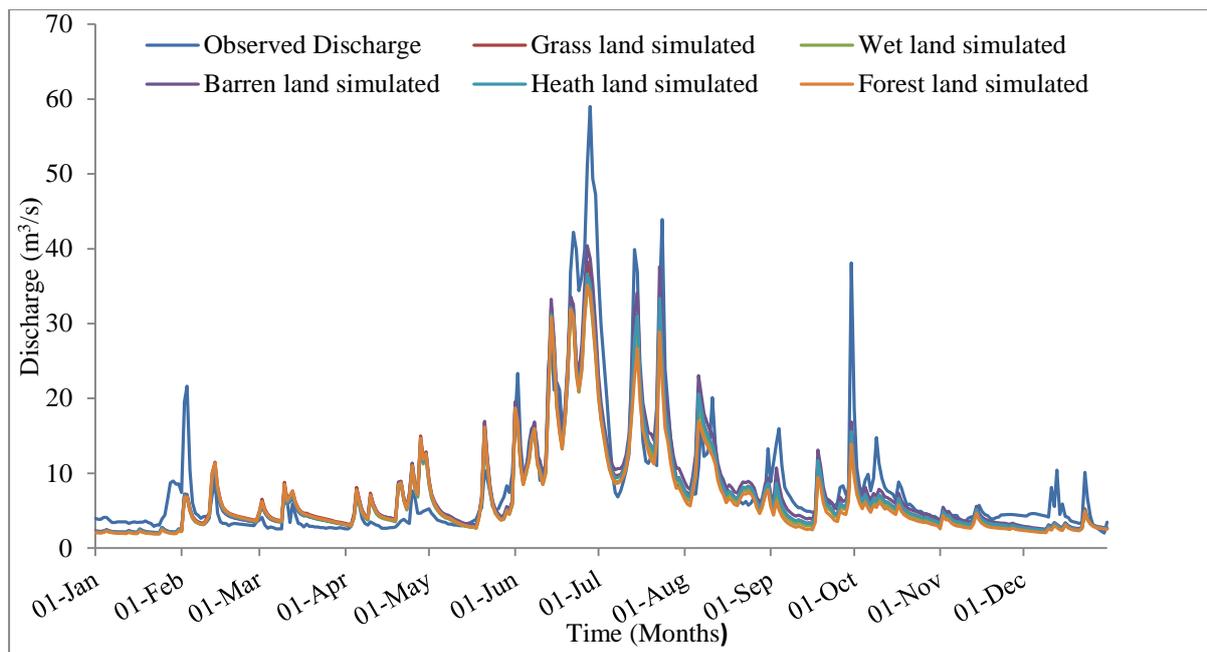
Figure 12. Observed discharge and simulated discharge of different land covers of Hjaltadalur valley, Hjaltadalsá River in 1986

The general trend in Figure 12 above indicated that there seems to be a rather small difference in the simulated discharges from the different land cover types. The detailed and magnified Figure 13 for the month of July also shows that the simulated discharges had almost no difference among different land covers; however, the highest discharge was observed for the barren land and the lowest for the forest land covers for the high discharge and low discharge. The observed discharge had higher values than the simulated discharges for the time with a high discharge and the lowest value for the time with a low discharge. The simulated

discharges had almost no significant differences among them and they had a similar trend and pattern.
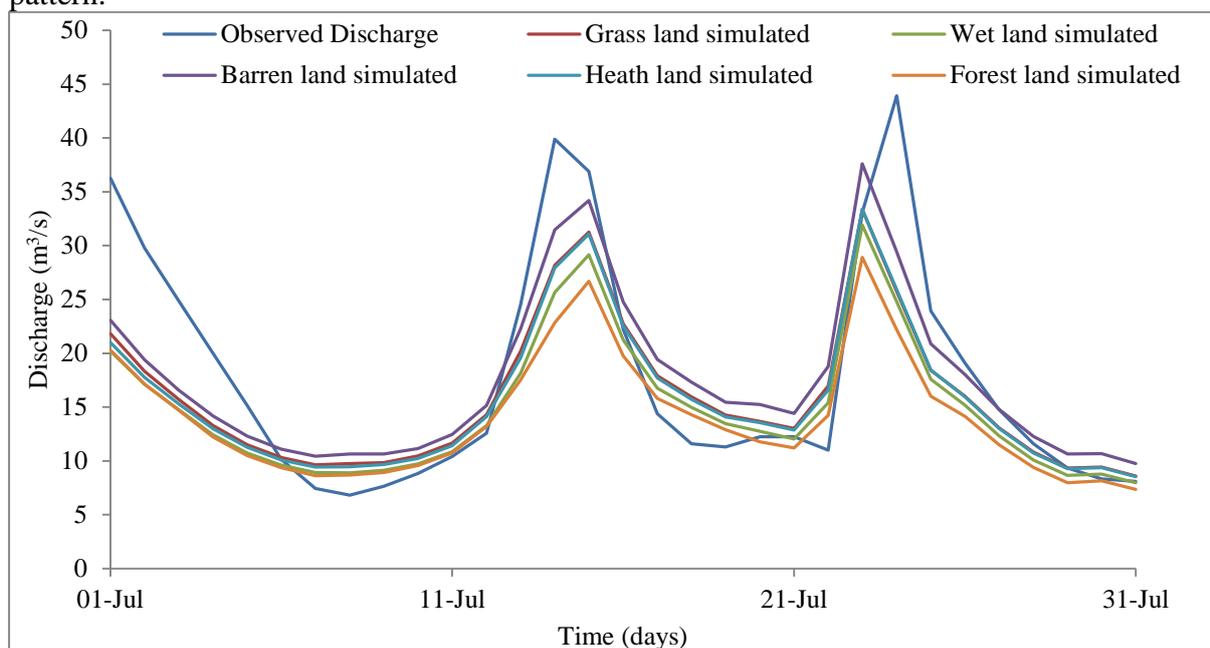
Figure 13. Observed discharge and simulated discharge of different land covers of Hjaltadalur valley, Hjaltadalsá River for the month of July, 1986.

5. DISCUSSION

5.1 Sensitivity analysis of the catchment discharge

As indicated in Figure 12 above, the WaSiM model simulated the catchment discharge well. The simulated discharge for fictional different land covers showed a similar trend to the observed discharge for the actual land cover throughout the year. However, relatively high discharges were observed for the summer season. The simulated discharges had almost no difference among and within seasons with land cover change. In fact, the highest discharge was observed for the barren land cover and the lowest discharge was recorded for forest land covers for the summer and spring seasons. In nature the land cover (soil) and vegetation are interactive. Changes in vegetation can cause changes in the soil and vice versa. As the land cover increases the organic matter of the soil and water holding capacity of the soil improved. Arnalds et al. (1997), Easton et al. (2010), Elfert and Bormann (2010) and Siriwardena et al. (2006) also reported that the discharge was affected by land cover change. As described in Tables 1 and 2 in sub-section 3.7, the thickness of the water layer on leaves (IntercepCap), albedo, root depth and soil surface resistance (rs_evaporation) in the model have the highest value for forest land cover and the lowest value for barren land with no difference in value by season. In contradistinction to this, leaf surface resistance (Rsc) had the highest value for barren land and the lowest for forest land cover. The barren land had the lowest value throughout the year with no difference by season and the forest land cover had the highest value. The values were different by season, with the highest value for autumn and the lowest for summer. The leaf area index (LAI), roughness length (Z0) and vegetation cover fraction had large values for the barren land and small values for the forest and grass land covers. The values were different by season with the highest value for summer and lowest for winter.

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The vegetated lands were assumed to have a rougher surface than the barren land. The rough surface delays/reduces the speed of runoff and the water tends to infiltrate down into the soil rather than going off in the form of runoff. In addition, the vegetated land has a higher carbon content than the barren lands. In fact, the soils with high organic carbon have better water holding capacity. Interception of precipitation by canopy cover is one form of water loss as it hinders the rain from reaching the ground. In the hydrological cycle part of the precipitation is intercepted by the canopy cover of the leaves and evaporation from the land. The vegetated and forest land covers have various shapes of leaves that could intercept a considerable amount of water by the canopy and through evaporation. As a result vegetated lands can trap some considerable amount of water that affects the discharge. However, the difference in discharge by land covers was not high when it was compared over the whole year. The reason for this could have been due to low rainfall intensity. The rain that reached to the surface was not converted to runoff in the short time it occurs in Iceland compared to high intensity tropical rainfall. The andosols soils in Iceland also have high water holding capacity that can trap the water that reaches to the ground in the form of rain. Brady and Weil (1998) and Brooks et al. (2013) also supported the above-mentioned reasons for the small differences in the amount of discharge by land cover. Acknowledging the long term interaction between vegetation and soil type it would be worthwhile to simulate their joint effects. In considering a further research in simulating the effects of different land covers it would be quite interesting to change the soil parameters also towards the soils characteristic of the vegetation type.

For the winter and spring seasons there was little difference in discharge with land cover change. The reason for this could be because the snowfall in the winter time covers all land covers and the infiltration to the ground before melting the snow might be small. As a result the discharge for all land covers was observed to be similar without differentiating between land covers. During the winter and spring seasons the overall discharge was small when it was compared to the summer and autumn. This could have been because most of the precipitation that fell during the winter and spring seasons was in the form of snow. In fact, the precipitation was stored in the form of snow in all land covers. After developing layers of ice on the ground, infiltration was the same for all land covers, even though there was rain at the end of the spring season.

6. CONCLUSION

In this study, sensitivity analysis of land cover change on catchment discharge was conducted. The analysis was performed under fictional five land covers including simulated grass land, wet land, barren land, heath land and forest land on the Hjaltadalur watershed in north Iceland. ArcGIS is very important to process catchment and land cover as inputs for the WaSiM model. Consequently, GIS skill is crucial for hydrological modelling. The simulated discharge under different land covers was compared with the observed discharge. The WaSiM model simulated the catchment discharge well. Generally, the simulated discharges for different land covers and observed discharges had almost no difference and all had a similar trend. However, the highest discharge was observed for barren land cover and the lowest for forest land cover for the summer and spring seasons due to the input parameters which changed with respect to the land cover. From the above results, it can be concluded that land cover change had little impact on the simulated catchment discharge of the Hjaltadalsá River even though slight differences were observed among the land covers. Acknowledging the long term interaction between vegetation and soil type it would be worthwhile to simulate

their joint effects. For further research in this field it would be worthwhile to simulate the joint effect of land cover and soil type change together.

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