MAPPING THE 2010 PAKISTAN FLOODS AND ITS IMPACT ON HUMAN LIFE – A POST-DISASTER ASSESSMENT OF SOCIO-ECONOMIC INDICATORS

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ABSTRACT:

In recent years, in 2010 in particular, several major flood events hit various regions around the world. The Pakistan floods, which affected the country during July to September 2010, were notable as one of the worst natural disasters ever seen in terms of the number of people affected - 20.2 million of whom 1,985 people were killed.
In this paper we present a post-disaster assessment of these 2010 Pakistan floods. Several spatial data sets were used (most of them freely available) to map and analyze the socio-economic impact of the disaster. The datasets compiled for the assessment range from soil moisture data, which help us to analyze root causes for the flood event, to flood extent, population as well as land cover data, which were used to assess the socio-economic impact of the disaster. Information on current and previous soil conditions - as derived through microwave remote sensing - facilitate time series analyses and anomaly assessments for the identification of potentially hazardous situations.
In this paper the availability and application of various socio-economic datasets is discussed and assessed. Additionally, the opportunity to apply soil moisture related data in the context of severe flooding is explored. Focusing on these two elements – indicators on hazard and vulnerability – the integration within a risk assessment will be emphasized.

1. INTRODUCTION

In recent years, in 2010 in particular, several major flood events hit various regions around the world such as the Eastern part of the USA, Central Europe, and Australia. The Pakistan floods, which affected the country over a period of several weeks during the months of July to September 2010, were notable as one of the worst natural disasters ever seen in terms of the number of people affected - 20.2 million of whom 1,985 people were killed (NDMA, 2011). Through this major event, a strong expansion of the flood has been observed along the Indus river, which first caused floods in the mountainous upstream regions, and after a certain delay, went further downstream in the vast floodplain areas of Southern and Central Pakistan. During the flood event itself various maps have been produced on an ad-hoc basis through different institutions involved in the business of providing emergency maps and satellite data to emergency management organizations and agencies involved in relief and recovery efforts in Pakistan.
Within the framework of the GMSM project (Global Monitoring of Soil Moisture for Water Hazards Assessment) a post-disaster assessment of the 2010 Pakistan floods has been carried out. The aim has been to map and analyze the socio-economic impact of the disaster, based on data which is publicly available. In the second place, soil moisture data have been analyzed, in order to identify the hydrological root causes for the flood event. Information on current and previous soil conditions - as derived through microwave remote sensing - facilitate time series analyses and anomaly assessments for the identification of potentially hazardous situations.
The assessment of the socio-economic dimension is transferred into the context of a vulnerability assessment, which in general characterizes the predisposition of a certain area and/or system towards a hazard. Additionally, the opportunity to apply soil moisture related data in the context of severe flooding is explored.
The intention of the paper is not to replace already established post-disaster assessments (such as World Bank, 2010), but to compare the results based on the publicly available data acquired and to take these findings into account.

2. DATA AND METHODS

2.1 Data used

2.1.1 The Soil Water Index (SWI): As earlier mentioned, soil moisture data was used to identify the hydrological root causes for the 2010 Pakistan floods, more precisely, the so-called Soil Water Index (SWI).
The SWI is a measure of the profile soil moisture content, which is estimated from a series of surface soil moisture measurements with an exponential weighting function and an infiltration model. The surface soil moisture (SSM) data are retrieved from the radar backscattering coefficients measured by the 25*25 km resolution ASCAT (Advanced scatterometer) onboard the MetOp satellite using a change detection method (Wagner, 1999). The model was developed at the Institute of Photogrammetry and Remote Sensing (IPF), Vienna University of Technology (TU-Wien). In this model (Naeimi, 2009), long-

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term scatterometer data are used to estimate the incidence angle dependency of the radar backscattering signal σ^0. Knowing the incidence angle dependency, the backscattering coefficients are normalized to a reference incidence angle (40°). Finally, relative soil moisture data ranging between 0% and 100% are derived by scaling the normalized backscattering coefficients σ^0 (40) between the lowest/highest σ^0 (40) values corresponding to the driest/wettest soil conditions.

Within the SWI a simple two-layer water balance is assumed as the infiltration process. The first layer is considered as the top-soil layer and the second layer underneath represents profile soil layer, where the moisture content is estimated. Furthermore it is assumed that the reservoir in the second layer has no other contact to the outside world than via the infiltration from surface layer. Thus the water content in the profile soil layer is fully explained by the past measurements of the SSM. Additionally the time series of SSM data is exponentially weighted, so that more recent surface soil measurements have a stronger impact on the SWI than earlier ones.

In short, the SWI is based on the assumption that the moisture contained within a soil profile is mainly derived from precipitation via the process of infiltration, which is connected to a certain temporal lag. The SWI product represents the soil moisture content in the first 1 meter of the soil in relative units ranging between wilting level (0%) and field capacity (100%). The spatial resolution of the SWI data is 25 km, sampled at a grid spacing of 12.5 km. The temporal resolution of the SWI used in this study has a 5 days interval with a characteristic time length of T=20 days, meaning that SSM measurements of the past 20 days are recognized in each SWI value.

Knowing that the main cause for the floods were heavy rainfalls especially in last days of July 2010 and that the SWI T-20 recognizes the infiltration of water over the past 20 days, SWI data for three days (Figure 1) was chosen for the time series, one before (July 25) and two after the occurrence of the unprecedented rainfalls (August 5 and 15). In order to have an adequate spatial reference frame for the SWI data the Indus basin was used.

In addition to the SWI time series also corresponding SWI anomaly data was used to show where the soil moisture deviated from the long term normal.

2.1.2 Flood mask: The flood mask used in the post-assessment section of this study is composed of a series of polygons derived from MODIS (Moderate Resolution Imaging Spectroradiometer) satellite data. These polygons, which show the water extent on specific days, were taken from various organizations, namely from the International Centre for Integrated Mountain Development (ICIMOD), the Dartmouth Flood Observatory (DFO) and UNOSAT. All of them were freely available online (see references). The resulting flood mask, representing the maximum water extent during the flood event, is incomplete in so far as it has several time gaps – days for which no polygons are available. For details on these time gaps see the timeline in Figure 1, which gives an overview of the availability of flood water extent polygons for the period covered (in blue). It shows that the mask of the maximum flood water extent used in this post-disaster assessment is quite robust from 10 August to 30 August, but before and after this time period it has some time gaps, where no polygon data was available for the composition of the maximum flood extent mask.

To assess the socio-economic impact of the 2010 Pakistan floods population and land cover data were used namely the LandScan Population database 2008 and GlobCover 2004-06.

2.1.3 LandScan Population Database 2008: Produced by the Oak Ridge National Laboratory, the LandScan database is based on spatial data and image analysis techniques and a multi-variable dasymetric modeling approach to disaggregate census counts within administrative boundaries. Populations are thus reallocated from the original census input data to a global 30 arc-seconds grid (this spatial resolution corresponds to about 1 km at the equator). Because of cell-size varying by geographic latitude in LandScan population data cell values stand for integer population counts, rather than for population density. In addition to transportation networks and populated places the LandScan modeling approach includes likelihood coefficients based on parameters such as elevation, slope, nighttime lights and land cover for apportioning census counts to each grid cell, while less effort is spent on using the highest-possible resolution population input information. Compared to other available global population data such as GPW and GRUMP (Balk, 2006), the LandScan dataset has a categorically different focus as it aims at measuring ambient population (averaged over 24 hours) instead of attempting to represent nighttime resident population (Dobson, 2000; Bhaduri, 2002). Furthermore, it is important to bear in mind that the application domain of the LandScan data should be considered in a medium regional level, with the rather coarse 1 km spatial resolution of the data set not suitable to adequately support local-scale analyses.

2.1.4 GlobCover 2004-06: Like the LandScan Population data the GlobCover data is also a global product freely available for any non-commercial use.

The GlobCover Land Cover map used for the impact assessment stands for the period December 2004 - June 2006 and is derived by an automatic and regionally-tuned classification of the ENVISAT Medium Resolution Imaging Spectrometer Instrument (MERIS) time series. It has a spatial resolution of 300 meter and uses 22 land cover classes, which are defined according the UN Landcover Classification System (LCCS) (Arino, 2007).

2.2 Approach and Methodology

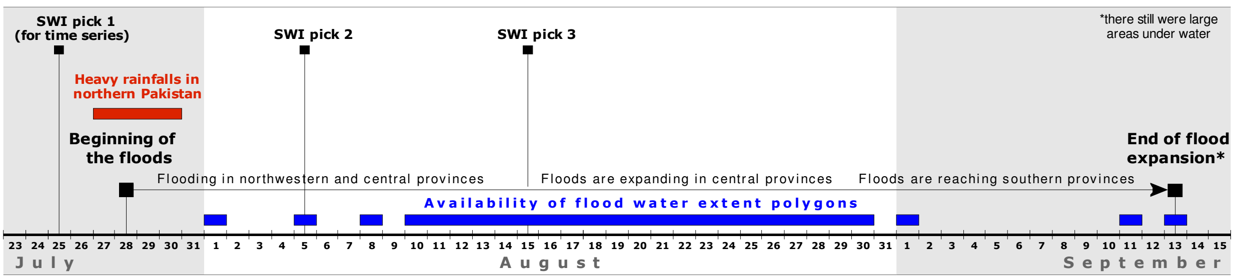

Figure 1. Timeline of the flood event, data availability and the SWI time series

While several major floods occurred in recent years, we are witnessing climate change and global warming, which is underpinned by the fact that 2010 was one of the hottest years and the last 10 years one of the hottest decades on record. Of course, we cannot legitimately ascribe a particular disaster to climate change, because there have always been major floods. But what climate scientists have been predicting is that such natural disasters will become more frequent and more intense (Parry, 2007). That seems exactly what happened in the case of the recent Pakistan floods.

For example, according to the Pakistan Meteorological Department, with 402 mm of rain in Peshawar (northwest Pakistan) in July 2010 fell almost 10 times the amount of precipitation of an average July (46 mm). The annual average of precipitation there is 347 mm. Thus, in July 2010 it rained in Peshawar more in just one month than usually in an entire year. Furthermore, this means that in summer 2010 the previous all-time July record (213 mm) was almost doubled.

In addition to the sheer amount of rain, also the short time period of its occurrence is remarkable. Of the 402 mm July-precipitation, 274 mm fell in just one day (July 29). This 274 mm in 24 hours mean that in Peshawar it rained in just one single day almost the amount of the previous record in a month (280 mm in August 1976). This remarkable figures may suggest that climate change is on-going, altering the monsoon patterns in Pakistan in a way that past averages/records won't hold anymore. With the change in precipitation patterns (as consequence of climate change) together with a rising global population, which is adapted to past patterns of rainfall, flood events will probably become more frequent and more intense and therefore more devastating in terms of their impact on human life.

Meanwhile in Geoinformatics, due to the growing number of sensors above and at the earth's surface as well as ubiquitous connectivity, there is a trend towards greater availability of more current geographic data.

In this changing environment – probably more frequent and more devastating natural disasters and an easier availability of more and more current spatial data – Geoinformation Systems can help to make major progress in disaster management. Therefore our approach was to use publicly available data for the post-disaster assessment.

As mentioned in the introduction, one aim of his paper is to identify the hydrological root causes of the 2010 Pakistan floods through the change of soil moisture, more precisely, the change of the Soil Water Index (SWI). This was done by a time series of SWI, showing the changes of soil moisture content in that period. Furthermore, a corresponding SWI-anomaly time series was used to point out where and in how far the SWI deviated from normal in summer 2010.

The second goal of this study was to map and analyze the socio-economic impact of the 2010 Pakistan floods based on publicly available data. This was done by a simple overlay analysis of the socio-economic datasets with a flood mask covering the maximum water extent. Therefore, first a flood mask of the maximum water extent was made out of a series of available flood water extent polygons derived from MODIS satellite data (see Figure 1), in order to get one aggregated mask of the maximum flood water extent for the period. Then this flood mask was used to determine which areas were affected/not affected by the flood event. Finally results were visualized in various thematic maps in order to get a precise overview of the 2010 Pakistan floods.

3. RESULTS AND DISCUSSION

3.1 Hydrological Root Cause of the Flood

In general, the SWI-time series (Figure 2) shows that while in the lower parts of the Indus river basin, especially in the southwest, the SWI didn't change significantly and stayed at a very low level, in the upper part we see a very strong increase of SWI to the near 100 percent levels. In particular, the development of a broad band of very high SWI values, which extends from southeast to northwest in the upper part of the Indus basin, is remarkable.

Just focused on the development of this broad band of high SWI values during the time period, it shows that in particular between July 25 and August 5 the SWI started to expand, especially in the north-northwest of the broad band. This increasing rate of change seems to suggest that in this period heavy precipitation took place in these areas. But this could be part of a regular monsoon season and therefore a normal development in the region. Monsoon season means that every summer the Indian subcontinent heats up and draws in winds and moisture from the sea. These storms then head northwards from May onwards and bring lots of rain in the coming months. These patterns of rainfall are welcomed, because they are vital for agriculture. Thus the SWI pattern we see in Figure 2 could be a normal development in a monsoon season.

But when we take a look at the corresponding SWI anomaly data in the second part of Figure 2, which shows the deviation of the SWI from normal, we clearly see that this was not a normal, but an unusually heavy monsoon season in summer 2010. The anomaly data shows that in most parts of the north the SWI is higher than normal. In particular in the north-

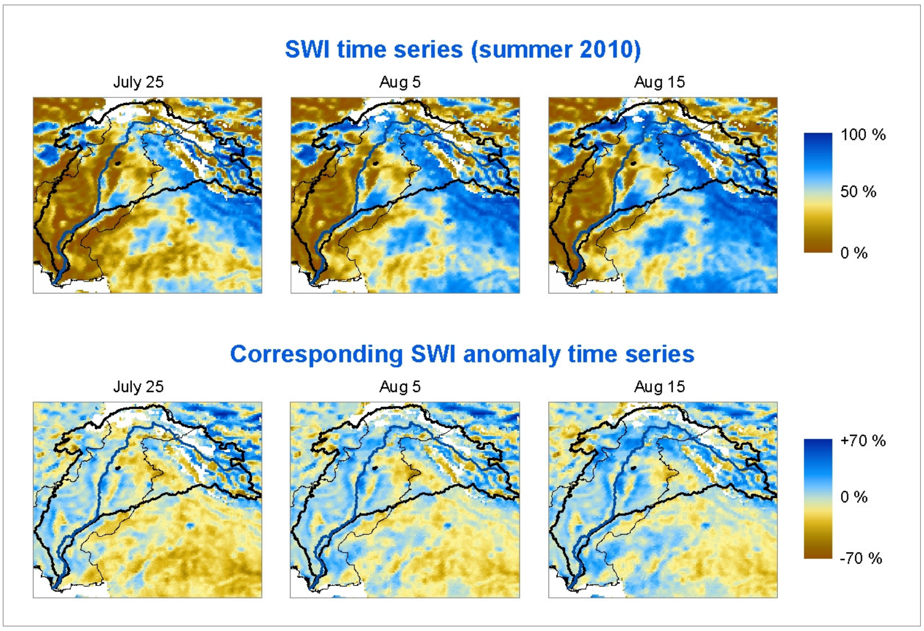

Figure 2. SWI time series and SWI anomaly within the Indus river basin

western part of the basin there is a strong positive deviation from the average SWI values in the sense that there were a lot higher values in summer 2010.

In short, the SWI time series combined with the corresponding SWI anomaly data (Figure 2) seems to provide a good picture of the root causes of the 2010 flood event in Pakistan. It shows that the reason for the extreme dimension of the 2010 Pakistan floods was an unusual monsoon season of extraordinary heavy rainfalls in the north, in particular in northwest of Pakistan (as illustrated with precipitation data from Peshawar).

So, while there seems to exist a close relationship between an increasing SWI and precipitation events, for the interpretation of the SWI it is important to note that an increasing SWI doesn't necessarily mean that precipitation is taking place. This is because the SWI T-20 aggregates surface values of the past 20 days via an infiltration process with an exponential weighting function where recent events get a stronger weight than earlier ones. Thus, while the precipitation could have already stopped, the SWI would still be increasing, because of the further integration of high surface moisture values, resulting from a past rainfall event. Therefore, not an increasing SWI itself, but rather the rate of change is important. On the one hand should this rate of change accelerate there seems to occur increasing rainfall. On the other hand if it decreases, the rainfall amount will either decrease or stop at all.

Moreover, it is important to mention that soil moisture is not necessarily linked to the intensity of rainfall only. We also have to take many other processes like surface run off and evapotranspiration into account in order to draw conclusions/estimates about the amount of rainfall, which took place in a particular area.

Although the SWI represents more a relative than an absolute indicator of precipitation amounts and even this conclusion has to be treated cautiously (i.e. evapotranspiration and surface runoff has to be considered), it has two major advantages over conventional precipitation data. First, it is seamlessly available at a spatial resolution of the input data (25*25 km). While precipitation is measured only at particular points (stations), one of the consequences of precipitation, namely an increase of SSM, can be measured continuously at a medium spatial resolution on a global scale.

A second important advantage of SWI is the fast availability of the data. With the SSM now established as an operational service, the data is available for the user only 130 minutes after reception. The SWI is then easily, and swiftly, derived from this operational product.

If these two advantages, the continuous medium resolution and the fast availability, could make the SWI part of an effective early warning system for floods (and drought) is still an open question and therefore requires further investigation.

3.2 Socio-Economic Indicators

Figure 3 shows a map with the population distribution of Pakistan based on LandScan data 2008. In addition to that the population data is overlaid with the Indus river, its main tributaries and the flood mask, showing the maximum extent of the water during the floods in summer 2010. The map gives a good overview of the 2010 Pakistan floods, because it illustrates exactly which areas/cities were affected by the floods. In addition to the mapping of the disaster, a post-assessment based on the flood mask and the population data was done. The

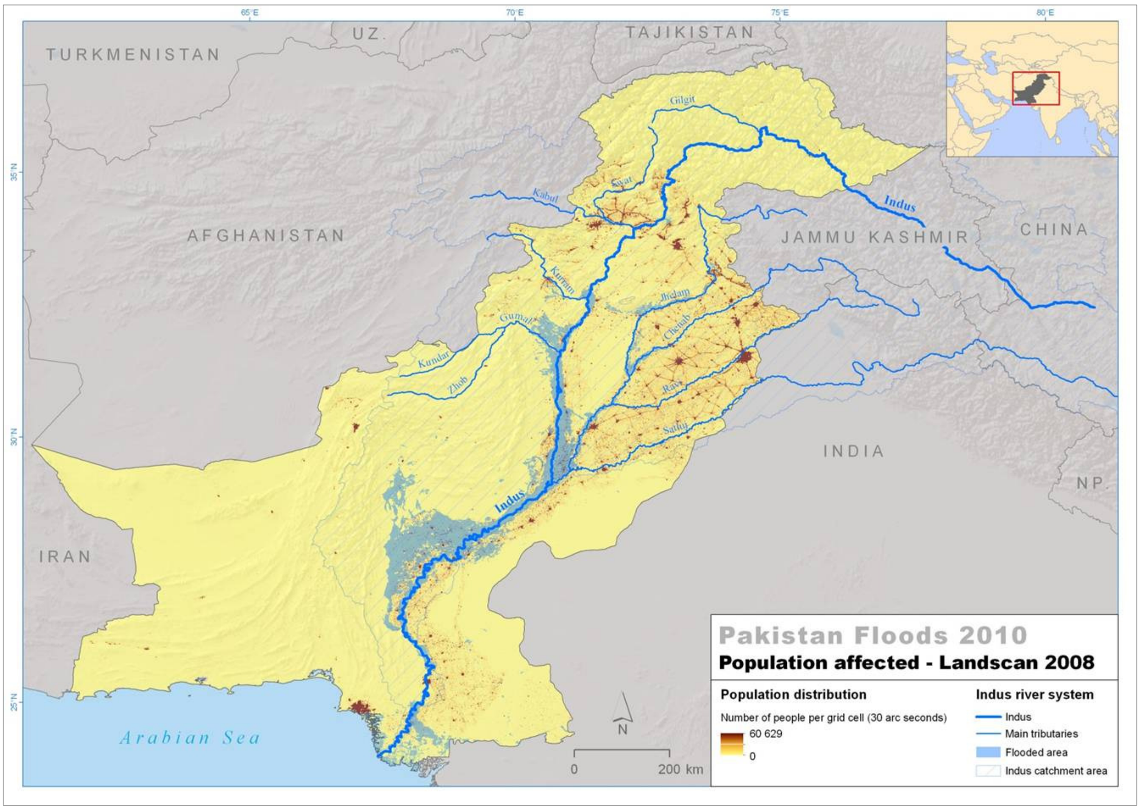

Figure 3. Map of the population affected by the 2010 Pakistan Floods

Note: This product was made utilizing the LandScan 2008™ High Resolution global Population Data Set copyrighted by UT-Battelle, LLC, operator of Oak Ridge National Laboratory under Contract No. DE-AC05-00OR22725 with the United States Department of Energy. The United States Government has certain rights in this Data Set. Neither UT-BATTELLE, LLC NOR THE UNITED STATES DEPARTMENT OF ENERGY, NOR ANY OF THEIR EMPLOYEES, MAKES ANY WARRANTY, EXPRESS OR IMPLIED, OR ASSUMES ANY LEGAL LIABILITY OR RESPONSIBILITY FOR THE ACCURACY, COMPLETENESS, OR USEFULNESS OF THE DATA SET.

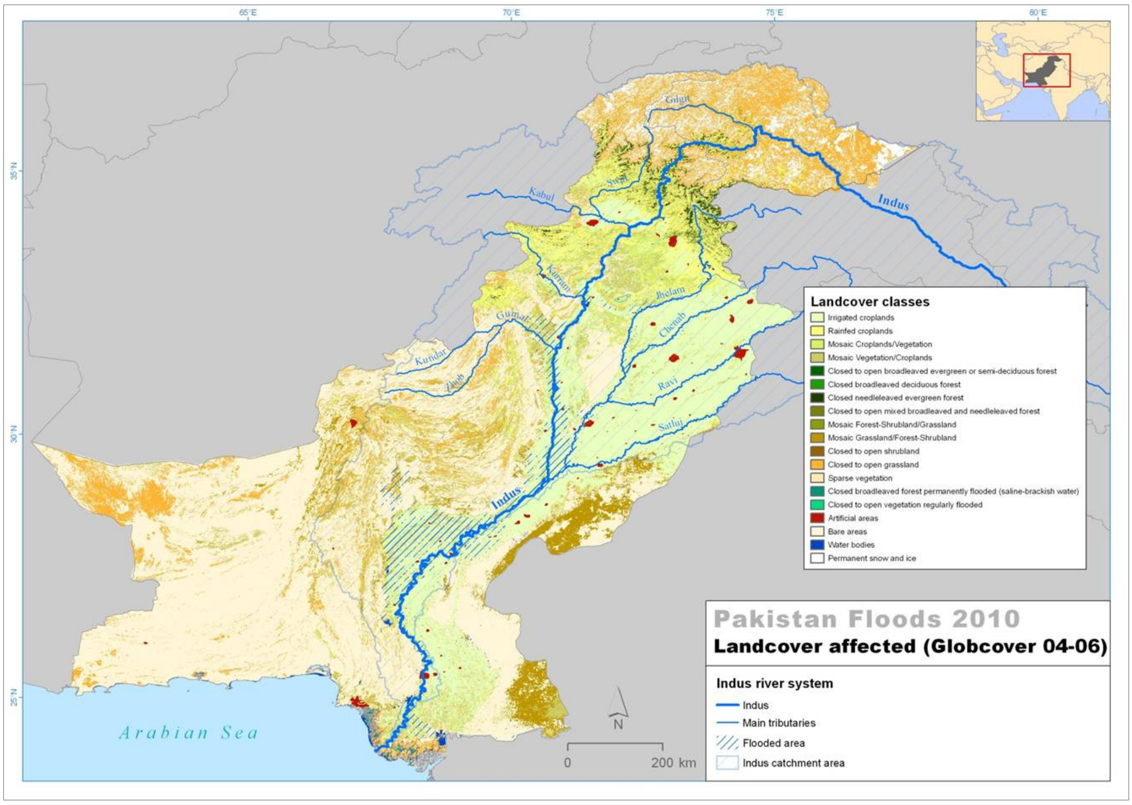

Figure 4. Map of the land cover affected by the 2010 Pakistan Floods
(© ESA GlobCover Project, led by MEDIAS-France)

result of this analysis was that about 13.4 million people were affected by the disaster. Compared to official figures from various organizations, like Pakistans' National Disaster Management Authority (NDMA), which estimates that 20.2 million people were affected, the corresponding estimates of this study are significantly lower. This divergence of the floods impact may have several reasons.

One source of underestimation could be found in the nature of the data used in this assessment. In particular the flood mask used has several large time gaps (see Figure 1 for details) and is therefore probably one of the main reasons for the underestimation of the disaster impact on the investigated socio-economic dimensions. Another minor source for underestimation of the number of people is the population data, which stems from 2008, two years before the disaster.

Another important reason why the figures of this post disaster assessment are lower than official figures in terms of people affected may be found in the vagueness of the definition of the term "affected". "Affected" is a very elastic term and could therefore mean a lot of different things. "People affected" according to this study means that only flooded cells of population count. The definition used here is quite strict, which provides another source for divergence.

For the interpretation of the figure "population affected" in this study it is also important to remember that the LandScan population data used estimates ambient population (averaged over 24 hours), instead of attempting to represent night time population. As stated in the introduction, the intention of the paper is not to replace established post-disaster assessments (such as the World Bank, 2010).

As a second mapping theme in this post-disaster impact assessment land cover data (GlobCover 2004-06) was selected. Figure 4 illustrates this in a map of the land cover in Pakistan overlaid with the Indus river system and a mask of the flooded areas. The map gives a good overview of the land cover / land use in Pakistan in general and shows which land cover classes were mainly affected by the flood event.

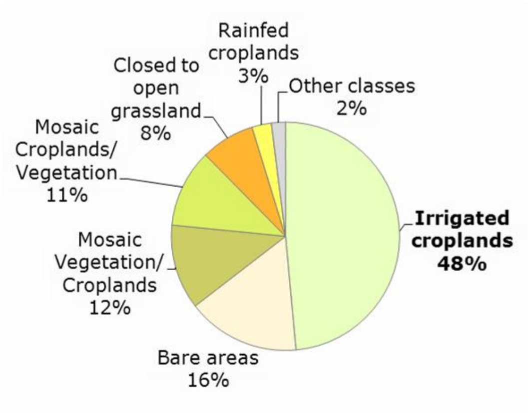

Figure 5. Distribution of the land cover classes affected

The pie chart in Figure 5 accounts for the distribution of the land cover classes affected by the disaster. It shows that of the 54,000 km², which were flooded according to the flood mask, almost half were irrigated croplands, about 20 percent were a mosaic of croplands and vegetation, 16 per cent were bare areas and about 10 percent were closed to open grassland. The remaining land cover classes covered about 5 percent of the flooded area.

Again, it has to be mentioned that because of the time gaps in the flood mask used, this figure potentially underestimates the flood impact as well. Nonetheless Figure 5 illustrates that

mainly the irrigated croplands were flooded, which means that the high crop failures occurred in the region.
Finally let us translate this study into a risk assessment context. To put it simply a risk is a combination of the potential consequences of a hazardous event (vulnerability) and the associated likelihood of its occurrence (hazard). In the case of this paper the (natural) hazard is the flood and the vulnerability, which can also be defined as predisposition of a certain area and/or system towards a hazard, is represented by the population living near the Indus River as well as agricultural fields. As an indicator for the occurrence of the hazard in our case SWI and SWI anomaly data were used.
Due to climate change and a concomitant change in rain patterns, the probability of hazard occurrence increases. At the same time also the number of people, living near the Indus is expected to rise, which means that vulnerability increases as well. Thus, as both hazard occurrence and vulnerability rise, we can expect that the risk of devastating flood disasters will increase accordingly.

4. CONCLUSIONS

The study showed that the SWI can be used to identify the root causes of the 2010 Pakistan floods. Although it is more of a relative than of an absolute rainfall indicator, the SWI time series in combination with corresponding SWI anomaly data illustrated the unusual precipitation pattern in the investigated region well. If the SSM - now established as an operational service - could be used as an element of an early warning system for floods cannot be ascertained as yet. A definitive answer to this question requires further investigation of the Monsoon pattern as well as the response characteristics of the river basin.
The assessment section of this study showed that, although there are lots of public data available for post-disaster assessment, the decisive point for the accuracy of the results lies in the understanding of the data quality as well as the methodological approach used in the assessment. Furthermore, we saw that clear definitions for the impact assessment are also needed for a better interpretation of the results.
Finally, when we transferred this study into a vulnerability/risk framework, we claim that due to the increasing hazard occurrence (climate change) and rising vulnerability (increasing population density near the Indus) it is likely that the risk of devastating flood disasters in Pakistan may increase in the future. Under these changing circumstances a comprehensive risk assessment/management framework is needed more than ever.

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